Project No. LDA-1401

Worcester Polytechnic Institute:

Renovation of and Addition to Kaven Hall

Major Qualifying Project

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Abstract

The purpose of this Major Qualifying Project was to provide additional spaces to Worcester Polytechnic Institute's Kaven Hall in order to meet the current and future needs of the faculty, staff, and students. Alternative options were compared and evaluated to determine the most feasible and appropriate option. The new space was then designed and egress renovations were integrated into the existing building according to appropriate design standards. Overall, the project was designed in adherence to LEED design specifications and *Massachusetts State Building Code* requirements. A seismic analysis specific to masonry construction was also included to investigate the performance of the existing building and to verify the earthquake resistance of the proposed facility. Lastly, the project included a cost analysis and schedule that determined the management that was required to complete the renovation and addition to Kaven Hall.

Executive Summary

The enrollment of undergraduate and graduate students at Worcester Polytechnic Institute continues to rise every year. Scheduling classes to accommodate all the different academic departments at WPI has become difficult with the current amount of space available. The space for classes is becoming limited, which has led to numerous classes being held at inconvenient times and in locations farther away from faculty offices. The expansion of the campus is necessary in order to ensure that the Institute can continue to provide a high quality education. Kaven Hall currently supports the faculty, staff and other resources for the Civil and Environmental Engineering Department, Architectural Engineering Program, and much of the Environmental Engineering Program. Most of the classes associated with these departments are held in Kaven Hall; however, classes requiring larger rooms have had to be moved to other buildings on campus. In addition, other departments offer courses that require the use of computer laboratories in Kaven Hall due to the availability of the needed software. This leads to spaces in Kaven Hall being unavailable for large portions of the day for other students associated with the Civil, Environmental and Architectural departments. In addition, there currently is not enough office space for all faculty members in the Department. Some professors are sharing office space or have smaller offices, which in turn limits the space they have for holding meetings and performing daily work. Therefore, it has been determined that Kaven Hall lacks the space needed to sufficiently support its undergraduate and graduate programs.

The goal of this project was to propose and develop a renovation plan for the existing Kaven Hall building. Redesigning the current space and/or adding new space to meet the needs expressed by the WPI community could accomplish this task. The following objectives were established as a means to achieve the project's overall mission:

- Evaluate multiple design options for the additional space to find the most satisfactory design.
- Create a floor plan for the renovation and additional space that satisfies building code requirements criteria for LEED Certification.
- Develop structural designs associated with the renovation and additional space in accordance with the provisions of *ASCE 7*, *American Institute of Steel*

Construction, American with Disabilities Act, Massachusetts State Building Code, and OSHA.

- Perform a seismic analysis for the existing masonry construction and new structural systems to ensure the lateral stability of the new facility.
- Prepare a project schedule and cost estimate to determine the feasibility of the renovation and new construction.

Each of these objectives was performed in the sequential order listed above in order to successfully complete the project.

The first objective was to determine the type of additional space that would provide the most satisfactory use for the space needs in Kaven Hall. Three options were explored: an additional floor, a renovated attic, and an additional wing. These designs were evaluated through a weighted rubric with the following criteria: provided square footage, ability to maintain building occupancy during construction, design potential/flexibility, and flow of space. This system ensured that a single design would be chosen without bias or misinterpretation of any kind.

Once an option for best gaining the needed space was chosen, the addition of a new wing, an analysis of applicable building codes was completed. The *International Building Code* and the *Massachusetts State Building Code* (*MSBC)* were reviewed for various safety requirements such as hallway and stairway widths, exit routes, plumbing fixtures and elevator design. Due to the building being expanded with the construction of a new addition, its occupant load increased, and therefore it was important to ensure that all requirements for means of egress were satisfied. In practice, compliance with the applicable codes and standards is key input to the approvals process associated with obtaining building and occupancy permits.

To continue WPI's mission for a greener campus, the building was also designed with the intent of receiving LEED Certification. A checklist that outlines criteria that must be met to earn a specific level of certification under the category of 'New Construction and Major Renovations' was evaluated to determine which aspects were possible during the construction and operation phases for this facility. By evaluating the list of criteria and the specific points system for this category before the planning process began, design and material alternatives that contributed to the delivery of a LEED certified building were emphasized. The checklist was evaluated in order to achieve the highest certification possible.

ASCE 7 was used in the seismic analysis of the new facility, including the existing building and the new additional space. The analysis was performed for the following two separate cases:

- *Case 1: The existing building and the addition are seismically isolated.* This required the addition and the existing building to be analyzed separately.
- *Case 2: The existing building leans on the new addition for seismic resistance.* This required the seismic forces from the existing building to be combined with those from the addition and analyzed as one unit.

Case 1 required the design of a structural steel frame for the additional wing. *ASCE 7* was used to determine the lateral seismic forces and gravity loads acting at each level of the addition. A *RISA 2D* model was created to determine the W-Shapes appropriate for the frames' columns and girders. The existing building was analyzed separately by calculating the distribution of the lateral seismic forces to the masonry piers within each wall of the building. For Case 2, the new wing and the existing building must act as one structure. This required the design of additional structural steel frames that were placed within the footprint of the existing building to sustain the seismic forces due to the entire building weight. Both cases were then compared to unit stress and deflection requirements set forth in *ASCE 7*. Lastly, a comparison in terms of cost and materials was conducted to choose the most satisfactory approach.

The renovation of the current Kaven Hall building required structural designs for the stairways and the elevator. The *MSBC*, *ADA*, the *American Society of Mechanical Engineers (ASME)*, the *Metal Stairs Manual*, and the information provided through the Otis Elevator website were used to develop a design that met code requirements while also causing the least amount of disturbance to the original structural integrity of the building. This was an important factor in determining the cost impact that the implementation of these new designs would have on the final project cost.

A project schedule was developed using a Construction Duration Estimating System (CODES) guideline and *Primavera P6* software. Creating an accurate schedule was important in order to maximize the amount of time Kaven Hall would remain operational. For the renovation, it was important to ensure that any disruptive construction would be completed during school vacations or outside of normal class hours. Careful planning would be necessary to schedule non-disruptive activities during times when students and staff members occupied the building as long as there were no safety risks. For the addition, more work could be completed during the typical workday because the area would be closed off to students and staff. By having a set schedule and required activities, phased and repetitive construction was used as much as possible to ensure that the project stayed on track. It was also important to adhere to the City of Worcester zoning requirements as well as continue to be considerate of the family dwellings and the commercial and religious facilities located in close proximity of Kaven Hall. By running a scheduling simulation in the *Primavera P6* software system, it was determined that the project would take an estimated 42 weeks (10.5 months) to complete. Also, if the construction were to begin at the end of March/early April, all the activities could be completed in approximately 10.5 months and would be able to occur during the appropriate times of the year to avoid predictable weather delays and setbacks that are often problematic in the New England region.

A project's cost is essential to determining the feasibility of the project. An outline specification was developed as the first step in the cost estimating process. Square footage and linear footage costs from *RS Means* as well as lump sum estimates were used to determine the cost for each of the activities/group of activities of the construction phase. Percentage values for general conditions percentages, architects fees, and the location factor were then incorporated into the analysis to determine the total building cost and associated cost per square foot. Table 1 contains a summary of the project cost.

Table 1: Summary of Kaven Hall Project Costs

Kaven Hall Project Costs	
Building Area - Renovation and Addition (SF)	38,000
Adjusted SF Cost	$ 154.27
Building Area * Adjusted SF Cost	$5.86M
General Conditions (25%)	$1.47M
Subtotal - Construction	$7.33M
Architects Fee (5%)	$.37M
Subtotal - Design and Construction	$7.69M
Location Modifier	1.10
Local Replacement Cost	$8.46M
Total Building Sq. Ft. Cost	$ 222.72

From the project's results and conclusions, the following recommendations were made. These recommendations aim to provide Kaven Hall with the necessary space needs based on the research, calculations, and analyses conducted in association with this MQP.

- *Obtain recent structural and architectural drawings of Kaven Hall.*
- *Kaven Hall should be expanded with an additional wing.*
- *Use the proposed floor plans and designs in order to achieve LEED Certification.*
- *The additional wing should be built as a separate structure with seismic separation joints between the new construction and the existing building.*
- *Use the proposed project schedule to maximize the amount of time Kaven Hall can maintain occupancy.*

Authorship

The tasks associated with this project were divided between the group members, Brianna Maljanian and Samantha Meyerhoff, based on each member's strengths and interests. They both contributed equally to the research, writing, and execution of this project. The following is a summary of each team member's principal contributions to the project:

Brianna Maljanian was responsible for the design of the structural steel frames using *RISA 2D* software, and all seismic analyses associated with this project. This included an analysis of the existing masonry piers, and an analysis of the new structure as one building and as two separate structures. She also took the lead in researching and analyzing the different design codes such as the *MSBC, ASCE 7, ASME,* and the *IBC* that were used in both her and Samantha's individual sections. To complement the research and calculations that she performed, she also contributed to the sections related to these topics in the Background, Methodology, and Results chapters of the report.

Samantha Meyerhoff was responsible for the design of the stair and elevator systems, and the research of the LEED design aspect of the project. She also contributed to the architectural section of the MQP by developing a Revit model of the proposed floor plan and exterior elevation views of the proposed building. Furthermore, she created an outline specification that was the principle component that she used in developing the project schedule and cost estimate portion of the report. To supplement this work, she also wrote the Background, Methodology, and Results sections of the report that corresponded to these topics.

The two group members worked together to write the other sections of the Introduction, Background, Methodology and Results chapters. They both contributed to all edits and revisions to the MQP report.

Name	Signature	Date
Brianna Maljanian	Brianna Maljanian	2/24/14
Samantha Meyerhoff	Samantha L. Meyerhoff	2/24/14

Capstone Design

The engineering design problems that this MQP addressed included creating a new layout for the existing Kaven Hall, while also designing an additional space to the building. For the renovation of the existing building and the design of the new space, current architectural and structural layouts were utilized to aid in the design creation of a new set of plans. These new building designs included LEED requirements for certification to make the proposed facility more sustainable, while also complying with the standards set forth by the ADA, the *Massachusetts State Building Code,* and the *International Building Code*. Multiple designs were considered for the addition to ensure the most efficient use of the new space. Lastly, the analyses of both cost and scheduling were necessary in order for project deadlines to be met. The constraints addressed in this report include: economic, environmental, sustainability, constructability, ethical, health and safety, social, and political.

Economic: Finances involved in construction are very important for choosing the most satisfactory design. The costs for structural members such as concrete and steel were investigated when considering the structural design options. Data from the *RS Means* was used to estimate the cost of construction, outlining the cost of each activity including elements such as structural materials, various systems in the building (plumbing, mechanical, electrical, etc.) finishings and labor. Using this information, the total cost of the project was determined and used as a tool to evaluate the economic feasibility of the proposed solution.

Environmental: Construction activities can exert negative impacts on the environment. In an effort to counteract these impacts, the site was evaluated, and any activity that could be potentially harmful was reconsidered. In addition, renovation work can have negative environmental effects, such as dust, waste, noise, and disruptive vibrations. Steps that were considered as options to help mitigate these effects included scheduling the noisiest activities during morning or evening hours when classes are not in session, daytime when the Institute is on holiday, and the community will not be disturbed, frequent sweeping and watering of areas prone to dust, using erosion and sedimentation control, and restoring vegetation to construction area upon the completion of site work (RWDI Inc.). The goal of this evaluation was to reduce the amount of environmental impacts the project will have.

Sustainability: In February 2007, the WPI Board of Trustees made an executive decision that required all new buildings on campus to meet a certain level of LEED certification. One of the most recent buildings to be constructed on the WPI campus, the Sport and Recreation Center, was completed in 2012 and was the third building constructed by the Institute to receive USGBC LEED Certification (Worcester Polytechnic Institute, 2013a). Figure 1 below shows a picture of the Gold Certification emblem that adorns the front entranceway of the building. In the WPI community's efforts towards building a greener campus, the construction and designs of the proposed renovations and addition for Kaven Hall should also be LEED certified. The requirements for LEED certification for new buildings and major renovations were addressed in this report.

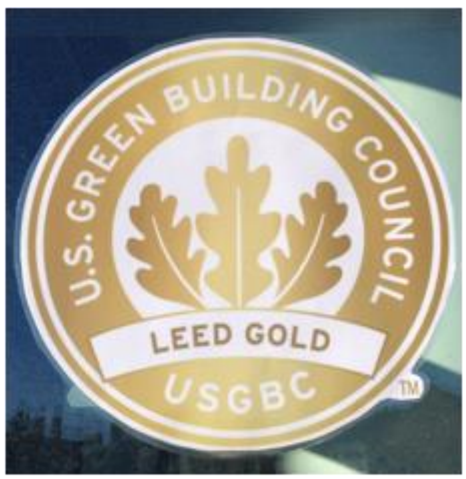

Figure 1: USGBC Gold Certification for the WPI Sports and Recreation Center

Constructability: For the design of the renovations for the existing building integrated with the addition to Kaven Hall, multiple configurations and structural schemes were considered. Structural solutions involving standard and widely available elements and large amounts of repetition often are more effective in terms of cost and construction duration compared to elaborate designs with unusual member sizes. These options were investigated and evaluated in order to choose the most satisfactory design for the addition based on the space needs, ease of constructability, and budget/schedule constraints.

Ethical: All aspects of the project were completed in compliance with the Civil Engineering Code of Ethics (*ASCE*, 2014). For the structural design and seismic analyses, the most recent design standards from ASCE were utilized, as well as the newest version of the *ICC Building Code* and *Massachusetts State Building Code Amendments*. These resources ensured that the project was completed in the safest manner.

Health and Safety: It was essential that the design of the proposed renovations and addition met proper safety standards. The architectural layout of the building was designed to meet egress requirements such as stairway and hallway widths. Resources provided by the ADA were also studied in order to meet the requirements for the addition of an elevator that provides access to all floors of the building (United States Access Board, 2010). Additionally, occupancy requirements for the classrooms were considered. This was important to ensure that building and fire codes were met and that the entire occupancy for each room can be safely evacuated in the case of an emergency. Lastly, the structural and seismic analyses specific to masonry construction were developed using design loads provided by the *Massachusetts State Building Code* and *ASCE 7* in order to ensure that the principal members were able to withstand all required forces and verify that the building was safe under all conditions.

Social: In order to address the social aspect of this project, the effects that the renovations to Kaven Hall will have on the rest of campus as well as the constraints on the final design and construction imposed by the City of Worcester were considered. For instance, depending on the length of construction, faculty office space and classrooms may need to be relocated. The schedule was organized in such a way as to minimize the amount of time that the building would be inaccessible. This was especially important given the lack of additional available spaces on campus and the inconvenience that would be caused as a result of classroom and office relocations. Also, the transportation of materials and equipment to the site was seen as a potential adverse impact on traffic conditions on the areas closest to Kaven Hall. The contemplation of these possible social constraints were essential in making sure that the campus was not negatively affected by the project.

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1.0 Introduction

As the enrollment of undergraduate and graduate students at Worcester Polytechnic Institute continues to rise, the renovation and expansion of the campus is critical in order to ensure that the quality of education is not being sacrificed due to space limitations. According to Chuck Kornik, the Administrator of Academic Programs at WPI, it has become difficult to schedule and accommodate all the different classes with the current classroom space on the WPI campus. This, in turn, has led to classes being held at inconvenient times and in locations farther away from faculty offices.

Faculty, staff, and other resources to support the Civil and Environmental Engineering Department, Architectural Engineering Program, and much of the Environmental Engineering program are currently located in Kaven Hall. Although most classes associated with these majors take place in Kaven Hall, larger classes have been moved to other buildings on campus because of occupancy requirements. On the other hand, laboratory sections associated with other departments that require computer labs and specific software are being moved into Kaven Hall, which often leads to lab spaces being booked for large portions of the day, making them unavailable for other students to use for homework and project work.

The objective of this project was to propose and develop a renovation plan for the existing Kaven Hall building, redesigning the current space and adding new space to meet the needs expressed by WPI faculty, staff, and students. To accomplish this task, the space needs required for WPI's campus to have sufficient space for current and future student enrollments were first determined. Using past studies in addition to current research, three options were investigated to provide the additional space, including the renovation of the existing attic, the addition of another floor within the current footprint, and the construction of an entirely new wing. A decision was made in regards to which of the three options would be further analyzed and developed based on a predetermined set of criteria. The space needs versus the space available was a critical factor in this determination process as was the consideration of the anticipated needs of future generations. Figure 2 shown below shows the current location of Kaven Hall on the WPI campus and the area that is being evaluated as a potential space for the construction of an addition.

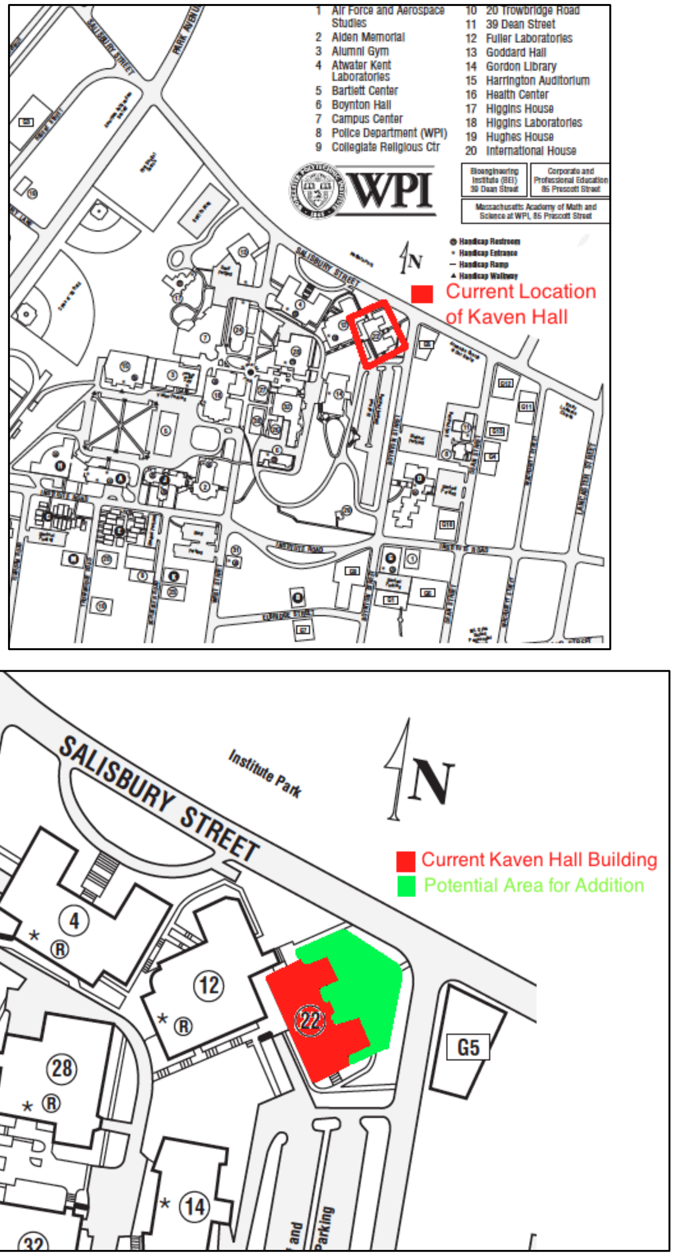


Figure 2: Current Location of Kaven Hall on WPI Campus (above) and Current Building with Potential Area for New Construction (below)

(Worcester Polytechnic Institute, 2013b)

Upon determining the main objectives to be addressed in this Major Qualifying Project (MQP), a further breakdown of major facets related to accomplishing these goals was considered. The time constraints of the project limited the scope to what was considered to be the most vital. This MQP focused on the renovation and the design of additional space to Kaven Hall. As part of determining the feasibility of the project, seismic analyses specific to masonry construction of the existing building and the proposed facility as a whole were conducted. The choice of which design to pursue was based on the educational space needs for WPI, the impact that construction would have on the department, the flexibility of construction, and the flow of the additional space. Recommendations from the CEE Department were also considered. The reasoning as to why this addition and renovation are necessary are elaborated on in Chapter 3 of this report.

The design aspects were proposed with the goal of meeting all code requirements such as the *Massachusetts State Building Code* and the zoning requirements for the City of Worcester. ADA regulations and the guidelines established by the United States Access Board were also essential considerations for the design in order to ensure that the building was easily accessible. Due to the MQP's time constraints, the investigation of egress requirements was limited to the redesign of the stairways to meet current building code requirements and the design of an elevator system to adhere to *ASME* requirements (*ASME*, 2010). It was also necessary for the structural design to satisfy *ASCE 7 (ASCE*, 2010), *AISC* (*Steel Construction Manual, 2011),* and *ACI* (*ACI*, 2011) requirements, as these standards have been adopted within the *Massachusetts State Building Code* and are regulatory documents.

Achieving LEED certification for the addition as well as the renovation was also essential, as WPI continues to move towards more green building initiatives on campus. LEED certification can range from certified buildings to platinum certified buildings based on a credit rating system. The various possible credits need to be evaluated before construction begins in order to help determine certain design aspects and the projected level of certification that the building will ultimately achieve. These requirements not only affect the type of design chosen, but also the possible room layouts, the types of materials selected, and the cost analysis of the project.

In addition to the design of the renovation and addition, project management was an essential aspect for a project of this magnitude. A project schedule was determined once the design was finalized. This involved the use of the scheduling software, Primavera. Constraints such as time limits were investigated in order for the schedule to meet the needs of the owner. These types of constraints also had an impact on the design decisions made such as limiting the amount of changes to the existing structural integrity of the building. With the project schedule, a cost estimate was also calculated. Data from *RS Means* and other unit cost values were used to arrive at a construction cost estimate. Financial constraints were considered while creating the cost estimate. Several constraints were considered due to their possibility of impacting the final cost and budget, including the availability of materials, the type of financing used, interest rates, and the cost and availability of specific subcontractors/companies. Schedule and cost estimates were prepared in an effort to assist the owner in making an educated decision regarding the practicability of the project.

Before any work could begin with the development of this project, background research and pertinent information were gathered and analyzed in order to create an appropriate scope and plan. Background information included previous research conducted on Kaven Hall[1], zoning and layout requirements, design standards, and project management resources. The Methodology chapter focused on the step-by-step processes that were used to obtain information regarding the specific needs of faculty and staff, the evaluation of alternative design options, egress renovations and additions, LEED related considerations, seismic evaluation of masonry walls, and the overall cost and schedule analyses of the project. Each of the chapters following the methodology presents a more detailed description and the associated results of each of the aforementioned main topics. After all calculations and analyses were completed, a conclusion of the overall results of the project was presented as well as appropriate recommendations associated with further research and developments of Kaven Hall.

[1] Current architectural drawings could not be shown in full in this report due to the WPI Facility Department's confidentiality agreement.

2.0 Background

Regardless of the magnitude and scope of a particular project, every construction project comes with its own unique set of challenges and complexities. This is due to the numerous factors that must seamlessly work and flow together to ensure an overall success at completion. This chapter is dedicated to understanding the relationship that these factors have to one another, the critical aspects that impacted both the development of the most satisfactory design of the three design proposals, and the subsequent recommendations for the final construction project. During the planning phase, a thorough understanding of the current layouts and required space was necessary in order to establish ideas for functional layouts. The design that was developed then needed to adhere to both the *Massachusetts State Building Code* and *City of Worcester Zoning Ordinances* before construction can commence. Proposed renovations regarding egress in the existing building were evaluated and were required to meet building codes while the structural design of the new space needed to consider the effect of gravity and lateral loads on principal members. Overall, it was necessary for the renovation and additional space to earn a specific set of credits outlined in the LEED Specification for New Construction and Major Renovations in order to receive the certification necessary to help WPI continue with its green building initiative. With a comprehensive understanding of the effect that these elements have on the construction of this project, the most satisfactory design was possible. Once the design was finalized, a cost estimate and schedule was formulated. Combining these architectural and structural designs with the different project management aspects overall led to a successful project.

2.1 Layouts

The original and more recent architectural layouts of Kaven Hall were necessary inputs to considering renovations and additional space. The original architectural drawings obtained were done by Appleton and Associates in 1957. The content of the drawings differs greatly from what is currently in Kaven Hall due to the drawings' age and the renovations that have been introduced. The original drawings of the basement, first floor, second floor and attic were referenced in this report. More recent architectural layouts were done in 1993 by W. Barry and were also used as a reference in this report; they were recreated for use in subsequent sections.

However, due to the WPI Facility Department's confidentiality agreement, the drawings were not included in this report.

The original layout and design of Kaven Hall was driven by the need for the Institute to have a more modern facility to include civil engineering labs as well as computer-aided material and design areas. It was also necessary to house the faculty and staff associated with the Civil Engineering Department as well as to accommodate some new classrooms and learning spaces for students. Table 2 below displays a comparison the current square footage and new square footage of each type of space in Kaven Hall by floor.

Table 2: Square Footage of Current and New Spaces in Kaven Hall

Floor	Type of Space	Current Square Footage	New Square Footage
Floor 1	Classrooms	2239	4998
	Computer Laboratories	0	0
	Offices	1404	2108
Floor 2	Classrooms	676	0
	Computer Laboratories	2239	2772
	Offices	1872	2540

More than fifty years later, the needs of the WPI faculty, staff, and students have changed and more space and different uses of the available spaces are required. These changes to current layouts are necessary to meet code requirements as well as the current educational needs of the Institute. For example, larger classrooms are needed to accommodate the growing number of undergraduate students as well as additional computer labs are necessary with the growing emphasis being put on computer design and software applications in the classroom.

2.2 Zoning

Zoning ordinances are a set of codes and regulations established by a city in an effort to, "improv[e] the living conditions of residents in existing dwellings, and assur[e] safety and quality in new construction" (City of Worcester, 2013a). These regulations include but are not limited to the types of structures that can be constructed in certain areas, the height of these buildings, and the minimum distances (or setbacks) from roadways and property lines. *The City of Worcester Zoning Ordinance* provides charts and text outlining specific regulations while also providing a map showing the five separate districts into which the city has been divided: airport, business, institutional, manufacturing, and residential. As can be seen in Figure 3 below, the existing Kaven Hall building, as well as the currently open area that could be used for a potential addition, all lie within the institutional district (IN-S).

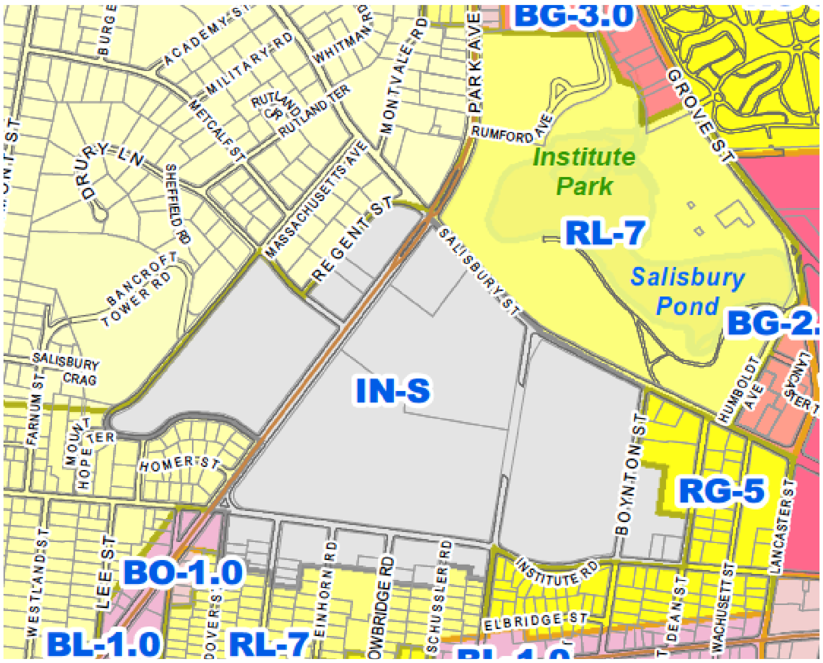


Figure 3: City of Worcester Zoning Map of Current Kaven Hall Location (City of Worcester, 2013b)

From the table that outlines the general permitted uses (Table 3), Kaven Hall would be classified as Institutional, Educational (IN-S) by the Zoning Ordinances because it adheres to the description of "Schools (K-12, college, University, or technical institute) non-profit" (City of Worcester, 2013c, p. 33).

Table 3: Permitted Uses by Zoning Districts (Taken from City of Worcester, 2013c, p. 33)

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
GENERAL USE - Continued

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
16. Place of worship	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
17. Radio/TV Transmission Tower	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	N	N	N	N
18. Recreational/service facility (non-profit)	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	Y	Y	N
19. Religious or educational use (EXEMPT)(See Art. XVII; M.G.L.c.40A, s.3)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
20. Schools (K-12, college, University, technical institute) non-profit	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
21. Schools (vocational, professional, other) profit	N	N	N	N	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	SP
22. Shooting Ranges – Indoor/Outdoor (see note 11)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	SP	N	N	N	N

Table 4.2 of the *City of Worcester Zoning Ordinance* summarizes some of the regulations that must be met when constructing within this particular district. A segment of this table is shown below in Table 4 (City of Worcester, 2013c, p. 44). As can be seen, there are no set height, area, and frontage requirements; however, minimum front, side, and rear yard setbacks have been established, which will influence any extensions to the footprint of Kaven Hall.

Table 4: Permitted Dimensions by District (Taken from City of Worcester, 2013c, p. 44)

PERMITTED DIMENSIONS BY DISTRICT
TABLE 4.2 – Continued

DISTRICT	USE	LOT		YARD SETBACKS			HEIGHT		FLOOR TO AREA RATIO (Maximum)
		AREA (Minimum SF)	FRONTAGE (Minimum linear ft.)	FRONT	SIDE[1]	REAR	Maximum in stories[2]	Maximum in ft.	
				Minimum depth (linear ft.)					
IP-0.33	All	75,000	200	25	25	25	NA	50	0.33 to 1
ML-0.5				25		25		50	0.5 to 1
ML-1.0	All	NA	NA	10	NA	15	NA		1 to 1
ML-2.0						25		NA	2 to 1
MG-0.5				25		25		50	0.5 to 1
MG-1.0	All	NA	NA	15	NA	15	NA	NA	1 to 1
MG-2.0									2 to 1
IN-S									
IN-H	All	NA	NA	15	10	10	NA	NA	NA
A-1									

1 Not applicable to that portion of a semi-detached or attached single-family dwelling, where permitted, that shares a party wall or a double wall on or along a common side lot line with an adjacent unit

2 These designations indicate a height in stories plus an attic, as herein defined. The designation 2+ indicates a maximum of 2 habitable stories with a non-habitable attic and garage underneath, if provided. The story containing the garage is not considered habitable if the garage area occupies 50% or more of the entire story.

2.3 Massachusetts State Building Code and ICC

When designing a building, it is essential to follow specific regulations set by the state in which it is being built. Each state has its own building codes which dictate the minimum construction requirements. The primary purpose for the establishment of building codes was to, "specify the minimum requirements to adequately safeguard the health, safety, and welfare of building occupants" (Federal Emergency Management Agency [FEMA], 2013). The building code essentially becomes the jurisdiction or "law" on a construction project and must be adhered to by all parties involved, including architects, engineers, contractors, laborers, and safety inspectors. In many instances, individual states adopt the *International Building Code* (IBC) that is developed by the International Code Council (ICC) as the basis for their building code requirements. In an effort to stay up to date and current with evolving design and construction practices, the ICC makes an effort to publish new editions of the *International Building Codes* every three years. Individual states then often establish an addendum or additional section to note the exceptions or additions to the *IBC* that coincide with the laws and regulations specific to that state and area.

The eighth edition of the *Massachusetts State Building Code (MSBC)* was used as the building code of record for this project. The *MSBC* adopted the *International Building Code* (2012) and made certain revisions for what is considered best for construction in the State. The scope of this project required using the following chapters of these codes

- Chapter 6: Types of Construction
- Chapter 7: Fire and Smoke Protection Features
- Chapter 8: Interior Finishes
- Chapter 9: Fire Protection Systems
- Chapter 10: Means of Egress
- Chapter 15: Roof Assemblies and Rooftop Structures
- Chapter 16: Structural Design
- Chapter 18: Soils and Foundations
- Chapter 19: Concrete
- Chapter 22: Steel

Local building codes contain the minimum design loads that are specific for the area's conditions such as snow, wind and earthquake loads. The *MSBC* also offers information about the accessibility for buildings and deflection requirements. An entire chapter focused on the various means of egress provided the information necessary for the design of hallways and stairways in accordance with the codes and regulations. It was necessary to follow the local building code to produce a sufficient design that also met safety requirements.

2.4 Design Standards

Design of the proposed renovations and addition to Kaven Hall relied on building design codes and standards. The *Massachusetts State Building Code (MSBC)* has adopted many other building standards including those published by the American Society of Civil Engineering Standards (*ASCE 7*), the American Society of Mechanical Engineering Standards (*ASME 17.1*), the American Concrete Institute Standards (*ACI 318*), and the American Institute of Steel Construction (AISC) Specification. Each of these building standards played an important role in the structural design portion of the project.

ASCE 7 provides the minimum design loads for buildings. In addition to live loads that reflect building usage, the design loads include the seismic, wind and other lateral loading necessary for ensuring the structural integrity of the building. *ACI 318* standards provided the limit states and other requirements for the design of concrete. Similar to the ACI 318, the 14th edition of the *AISC Steel Construction Manual* provided the requirements for steel design. As a design aid, the *Manual* provides the limit state capacities for stress conditions such as axial compression and flexural based on the shape and cross sectional area of the different standard section sizes.

In addition to the structural standards, mechanical standards were consulted for certain aspects of the project. The American Society of Mechanical Engineers (*ASME*) *A17.1* provides the basis for elevator design. The most recent version of *A17.1* addresses the safety requirements for the most up-to-date elevator equipment being used, as well as a maintenance control program. Elevator design also must conform to the National Fire Protection Association standards, including proper sprinkler and alarm systems (*NFPA 13*, 2013). ADA codes also provide the elevator area requirements based on the building's occupancy. Three critical considerations that were analyzed were the minimum dimensions of the elevator cab for accessibility, automatic safety features that must be installed and working properly at all times, and the height of the call buttons. Comprehensive design of an elevator involves other considerations that are evaluated on a case-by-case basis, in which it is often in the best interest of the owner and project team to consult a qualified technician who can assure that all building and elevator codes are being met (OTIS, 2013). The following sub-sections will further discuss the application of the standards applicable to this project.

2.4.1 Seismic Concerns for Masonry Construction

The seismic analysis of Kaven Hall was essential because of the impact that the proposed architectural and structural redesigns have on the existing and new masonry walls. If an additional wing is built, for example, and it is merged with the existing building as a single structure, it would need to be designed to withstand seismic forces that consider the total base shear due to the existing building and the addition. The desired seismic behavior is such that Kaven Hall and the additional space can withstand the design seismic forces associated with the Worcester area. The seismic concerns for masonry construction were found in the *Masonry Standard Joint Committee (MSJC) Code* (MSJC, 2011). When designing masonry walls and their anchored connections, it is vital to understand the distribution of the seismic base shear on each level of the building. This distribution is dependent on the fraction of each floor weight relative to the building in its entirety. In addition, any windows and doors in the walls do not assist in withstanding the seismic forces, and therefore, each adjoining wall section (termed pier) must sustain these forces (Derecho, 1974). An additional concern was the anchorage of the masonry walls. *MSJC Code* requires that the masonry walls be anchored to the roof and all floor diaphragms, and foundation anchorage to provide lateral support (MSJC, 2011). The distributed forces are also dependent on the seismic zone of the building's location. Therefore, the seismic zone also plays an important role in the seismic analysis of masonry construction. The zones are given numerical values such that the lower the value, the lower the seismic hazard. A map of the Central and Eastern United States and its seismic zones is shown in Figure 4.

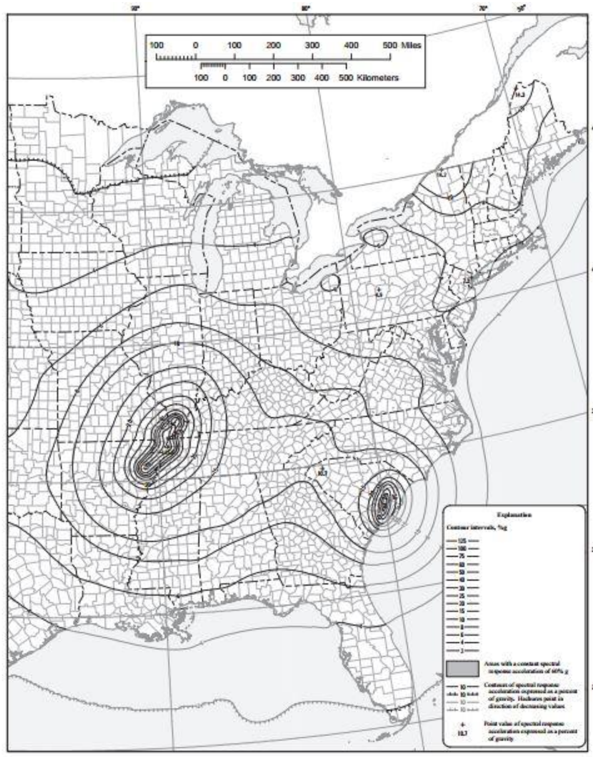


Figure 4: Mapped Risk Coefficient at 1.0 s for the Central and Eastern United States (*ASCE 7*)

2.4.2 Egress Requirements for Designs

The redesign of the renovation and the new design of the additional space were impacted by the egress requirements set forth by *ADA*, the *MSBC*, and the Occupational Safety and Health Administration (OSHA). "Means of egress," is defined by the IBC as, "a continuous and unobstructed path of vertical and horizontal egress travel from any occupied portion of a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit, and (3) the exit discharge." The specific egress requirements addressed in this project included corridor width, stairway width, travel paths, and the accessibility of escape routes as outlined in *ADA 4.3* (United States Access Board, 2010). Additional requirements related to accessibility that OSHA has specified in Standard *1910.36* include the number of exit routes from an area based on occupancy, the use of fire resistant materials between exits and other areas of the facility, the required capacity/size/height of the exit route, and the types of hinged doorways that are permitted. Egress and accessibility requirements are essential in ensuring that the constructed facility is a safe environment for its occupants. One of the main philosophies behind the creation of these provisions was to ensure that all building occupants, with or without mobility impairments, would be able to safely and successfully utilize different means of egress to gain access to or exit from all areas of a building.

2.4.3 Comparison of Different Elevator Systems

In accordance with the aforementioned provisions for egress design and accessibility, the incorporation of an elevator system in the new design of Kaven Hall was necessary. There are numerous types of elevators that are each beneficial in particular types of buildings. According to the Otis Elevator Company, (2013), the main types of hydraulic elevators and some of the respective prominent features are shown below in Table 5.

Table 5: Comparison of Different Hydraulic Elevator Systems

Type of Elevator System	Machine Room	Below Ground Elevator Pit	Speed (ft./min)	Capacity (lbs.)	Max Stops
Holeless Hydraulic (HydroFit)	Not Required	Not Required	100, 125	2100-5000	4
Roped Hydraulic	Required	Not Required	100, 125, 150	2000-3500	5
Holed Hydraulic	Required	Required	50 to 175	2100-4000	5 to 6
Roped Holeless Hydraulic	Required	Not Required	50 to 175	2100-4000	5

Normally, the type of elevator can be chosen based on the number of floors that the cab will service in the building. There are also specialty elevators that are used in hospitals while others are designed to carry freight and other heavy loads. In this particular design, a typical low-rise elevator will be adequate to service the four floors in Kaven Hall. A typical low-rise elevator is hydraulic powered.

Another groundbreaking advancement in elevator system design has been the creation of machine room-less technology. This type of technology is available for buildings with anywhere between 2 and 30 floors and can be mounted in the hoistway, thereby eliminating the need for a machine room. Machine rooms often took up a significant amount of space and required additional HVAC and lighting in areas that were not often utilized. New belts that are made from flat polyurethane-coated steel are more durable and flexible take the place of the previous heavier, woven steel cables, which ultimately make this smaller sheave/machine room-less system possible (Otis, 2013).

2.5 Leadership in Energy and Environmental Design (LEED)

The United States Green Building Council (USGBC) has developed the LEED program in an effort to "change the built environment" through the adoption of green building requirements. The LEED program has put forth a rating system that categorizes every type of building or project into a specific group that is based on a unique prerequisite and credit system that determines the level of certification that the facility can receive. The main categories that these credits are broken down into are Sustainable Site, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process, and Regional Priority (U.S. Green Building Council, 2013c).

Within each of the seven categories, scoring points are associated with different phases of the project including design decisions, construction, and performance after building occupancy. Although some criteria aren't considered until later in the project's life cycle, it is still important for all the potential credits to be outlined at the beginning of the project so a plan can be put in place from the outset to assure that the certification goals are recognized and met. Out of a possible total of 110 points, a project's LEED certification level is designated as follows:

- Certified: 40-49 points
- Silver: 50-59 points
- Gold: 60-79 points
- Platinum: 80+ points

U.S. Green Building Council. (2013a)

In addition to this information, the USGBC website provides the clearly defined steps that are necessary for registering a project for LEED certification. The five steps that are outlined are: Choosing a rating system, registering and payment, submitting the certification application, the review process, and the final certification decision. The amount of information and documents available and additional contact and support options make the USGBC a very user-friendly website that provides owners, designers, and contractors with all the information necessary to plan and construct a successful LEED certified facility.

2.6 Cost Analysis

The cost of a project is essential to a successful project. It is what ensures that construction projects are bid and completed within an agreed cost framework and in the most economical manner while also meeting quality requirements. This section will discuss the design work and the data used to prepare the cost estimate.

2.6.1 Completing the Design Work

The renovation and addition of new space to Kaven Hall consisted of numerous types of design work, all of which had different impacts on the final cost analysis. One of the main differences was the complexity involved with the renovation work verses the new construction. According to the article, *Renovation vs. New Construction: Choosing the Right Path,* Catherine Cruickshank discusses the main steps involved in the undertaking of such a renovation and construction project. First and foremost, it was important to know the different people who were involved and who were considered stakeholders for the project. They are the ones who had the most say in issues concerning the budget. Potential issues as well as challenges specific to the project were also outlined in an effort to plan for the conceivable associated costs.

A design evaluation was necessary in order to understand the impact that certain changes and additions would have on the project's budget. Main factors that were considered for both renovation and new construction of Kaven Hall are outlined in Table 6 below.

Table 6: Factors to Consider for Renovation and New Construction (Cruickshank, 2013)

Renovation	New Construction
• Structural Integrity • Architectural Merit • Thermal Benefits • Hazardous Material • Location • HVAC Systems • Community Connection	Sustainable Features New Technology Better Use of Space Easier Prioritization Efficient Layout Maintenance Savings

In this project, both renovation and new construction were defined, which required merging designs from both areas. By taking all of these considerations into account, an informed decision was made regarding the design changes that occurred in the renovation as well as the new designs that are associated with the construction of the additional space. A final design evaluation helped to provide a more comprehensive understanding of the costs associated with each activity and the impact that each had on the final cost proposal of the project.

2.6.2 Cost Data and Its Application to Cost Estimating

There are numerous types of data sources available that are pivotal tools in the process of procuring estimates for construction packages. This data is often obtained in one or both of the following ways:

- Owner or contractor has collected data over the years from past projects that they use as a baseline when estimating new costs (historical information)
- Electronic database or software program (current resources)

Historical information can often times be helpful with the pricing of specific line items in a bid package. This is especially useful information to contractors who work on numerous projects in the same location. By knowing the local labor rates and specific materials available, a more accurate estimate can be established. Other historical information available online including inflation rates and location factor multipliers help alleviate some of the uncertainty that is involved in predicting future costs.

Additional information that is needed in order to create a competitively priced bid package is unit, square footage, and systems/assemblies costs. Unit costs assign a dollar amount to a specific item. By doing a simple calculation of unit cost times the number of items needed, an accurate cost estimate for that line item can be produced. This information is most often obtained from the *RS Means Building Construction Cost* database (RS Means, 2013). *RS Means* is an estimation database that provides cost information specifically developed and organized for construction. The information includes labor costs, material costs and equipment costs. The values are determined based on the U.S. averages and are adjusted depending on the location within the country, the size of the project, the time of year, and the quality of work. Also, based on research from local subcontractors, additional unit costs could be estimated. Sources including *Building News International*, the *General Construction Cost Review Guide (GCCRG)*, and publications issued by the American Society of Professional Estimators also provide comprehensive cost estimations for various aspects of construction projects. These resources are important, as they are able to provide detailed information and more complete descriptions of particular estimates and the processes behind how the quantities were developed.

Square Footage estimates are also important to developing a project estimate, and the *RS Means Square Foot Costs* (RS Means, 2011) provides a breakdown of typical square footage costs for over 100 different types of buildings including but not limited to school, hospitals, fire stations, and movie theaters. This source also includes over 6,000 assemblies costs which helps to create accurate cost estimates based on component specifications. This information is updated on a yearly basis and is available in both hard copy and electronic versions.

These are only some of the types of data that must be considered when putting together a complete cost estimate. The more information that a contractor has available to them, and the accuracy of said information, will have a pivotal impact on the reliability of the estimate and how competitive they will be against their competitors. With all of the various software currently available, numerous databases can be electronically stored and used with bid and estimating software to help alleviate some otherwise tedious calculations Programs such as ProContractorMX (Construction Accounting Software, 2014), Estimation (Estimating for MEP: Estimation, 2014), Bid4Build (Bid4Build Enterprise Estimating System, 2014), Hard Dollar (Construction Estimating Software, 2014), and BID2WIN (B2W Software, 2014) are all powerful forms of estimating technology that many companies are utilizing to increase their competitive edge in the construction industry.

2.7 Schedule

As construction projects continue to grow in complexity and design, scheduling methods have been becoming increasingly more sophisticated. The preparation of a project schedule requires a brainstorm of the activities to be completed, a logical order of these activities, followed by an estimate of the time required for each activity. Understanding the importance of the timing of major activities is also essential to developing an effective project schedule. *Primavera* scheduling software has most recently released the P6 Professional Project Management version of their software that has the ability to organize up to 100,000 activities, track progress, and compare alternative options; it is an efficient visual tool used for monitoring time and performance (Oracle, 2014). This software was utilized to create a network of activities (CPM diagram) with corresponding durations and adjusted floats. This enables the management team to track progress and have an accurate means of tracking work-in-place versus time while also providing the owner with accurate deadlines for major milestones and the project as a whole.

When assembling a construction schedule using P6 or other type of scheduling software, there are numerous additional factors that can impact the project's duration and need to be considered before an accurate duration estimate can be produced. Material procurement rates and productivity rates are two areas that need to be carefully calculated when putting together a schedule. Large equipment, machinery, and materials that need to be processed in large plants often have lengthy lead-times and need to be ordered well in advance of when they are actually required on the job site. If advance ordering is not taken care of, delays in many other areas will often occur resulting in both time and budget increases. Often times, contractors will have an understanding of which items have longer lead-times than others, but verification from the company or facility producing the product is essential in making sure all information in the schedule is as accurate as possible.

Productivity rates are also important to consider for predicting activity durations. Factors that play a role in this are man-hours per day, amount of man-power on site on a given day, the learning curve of the workers, and the amount of repetitive construction. Numerous studies have been conducted to help scheduling and estimating personnel quantify productivity rates in their budgets and schedules. Some of these sources include *ASCE,* Chris Hendrickson's textbook, *Project Management for Construction,* Construction Industry Institute, and the *Journal of construction Engineering and Management.* The Army Corp of Engineers also published an article titled, *A Prototype Construction Duration Estimating System (CODES) for Mid-Rise Building Construction* that provides information related to the major activities associated with construction activities and the typical durations associated with these activities (Construction Engineering, 1991). Using this article in conjunction with *RS Means* resources will provide a reasonable level of accurateness when developing the project schedule and time-scale.

Other factors that should be considered in scheduling, although the estimates may not be as accurate as other areas, include:

- Change in Project Scope
- Work Delays as a result of safety/accident on job site
- Change Orders

- Weather

While these are often unforeseen conditions that cannot be estimated with accuracy, allowing for a certain amount of float on critical activities is often times helpful to avoid cost and time delays. For example, if working on a project in the Northeastern part of the country, it should be assumed that outside work in the winter and early spring has a significant probability of being delayed based on the high possibility of snow, rain, and other types of inclement weather conditions.

The scheduling challenges that had the greatest impact on this project were related to staging construction around the academic year and determining the possibility of keeping sections of the Kaven Hall building open and in operation. In order for the building to be used in the fall, the construction project would have to be at a certain phase of completion by the end of the summer. Also, minimal construction and renovations can be done within the building once school is back in session. Due to the current space needs for WPI, all of the civil and environmental engineering courses could not be easily relocated to other academic buildings. There is also not enough office space on campus to temporarily relocate the faculty and staff. Therefore, the project schedule needed to be created such that the building was at least partially available for faculty, staff, and students.

3.0 Methodology

The goal of this MQP was to develop a new design for Kaven Hall that effectively contributes to meeting the current and future space needs of WPI. There was a set list of tasks and sub activities that must be completed in order to accomplish this objective and associated goals. These tasks and the work completed were broken down into areas of emphasis with some activities happening simultaneously and others requiring a sequential timeline. These major topics are outlined in Table 7.

Table 7: Methodology Tasks, Activities, and Resources

Tasks/Topics	Activities	Plan for Completing Tasks/Resources	
Determine space needs and propose a redesign layout for Kaven Hall	Redesign layout for Kaven Hall renovation and the new addition	Obtain current architectural and structural drawings (Meet with William Spratt)	WPI Facilities documents
	Current space Needs	Interview with Charles Kornik, WPI scheduling documents	Bar graphs and charts related to current sceduling and classroom usage
	Research old MQPs (Previous attic plans)	Research--Gordon Library	
	Design a new architectural layout	Use current architectural and structural drawings as a basis to layout a new floor plan that meets all the required space needs	
	Occupancy loads for sizes of rooms	Obtain information from Charles Kornik and the Mass Building Code	
Architectural and Structural Layouts and their Evaluation	Evaluation of space needs options	Develop list of necessary additions and their associated square footage	Develop scoring rubric to determine most satisfactory space addition
	Design alternative architectural designs	Design options for use how new space will be used based on space needs	Use information from interviews and current architectural and structural drawings
	Design alternative structural designs	For new space, determine the best-fit design based on constructability, cost, etc…	ASCE 7, MSBC, ICC
	Code Review	Research codes to ensure that all areas of design and construction are in compliance	ASCE 7, MSBC, ICC, OSHA, ADA, ASME, LEED
Renovation improvements within existing Kaven Hall	Egress--Stair Requirements	Mass. Building Codes, ADA, OSHA	
	Egress- Installation of an Elevator	Using architectural and structural layouts to determine area of building to install system	ASME 17.1
	LEED requirements	LEED website, checklists outlining credit system for New Construction and Major Renovations	
Design to meet LEED requirements	Evaluate checklist system BEFORE any deisgn takes place	LEED	
	Choose a set of certain criteria to address in report (materials, site improvements, curtain wall, etc…)	LEED, RS Means	
	Determine the ROI for the selected components	LEED, RS Means, Research	

Structural Design	Gravity Loads	ASCE 7	
	Lateral Loads	ASCE 7	
	Typical Bays	LRFD, ASCE, MSBC	
	Stair Design	Design stairways in existing Kaven Hall as wel as the new space addition	Metal Stairs Manual, ADA, OSHA, ICC
	Elevator Design	Design elevator cab and hoistway for new elevator system	ASME, ICC, Otis Elevator Company
Seismic Anaysis	Effect of forces on principal members of the **system**	ASCE 7	
	Lateral Loads	ASCE 7	http://www.eng.auburn.edu/users/staylor/seismic_loads_calcs.PDF
Scheduling	Estbalish tasks/milestones/durations	Research, Primavera	
	Create project schedule	Primavera	
Cost Analsyis	Materials	RS Means	
	Labor	RS Means	
	Lump sum of various systems	RS Means	
	Total cost/lazy s-curve	Additional Research	
Writing MQP Proposal	Abstract, Introduction, Scope of Work, Capstone Design, Background, Methodology, Deliverables, Schedule, Conclusions, References	Divide research tasks and writing sections Each person then edits the other sections and adds any additional information that they have researched A final read through with complete fomatting will be done before the final submittal	
Final Report	Further development of proposal sections in addition to sections: results, analysis, calculations, appedices, etc…	Each person will be involved with every section of the report, with one person taking the lead and doing the reseach necessary to obtain the necessary equations and relevant information Each person will be responsible for checking the calculations and editing the writing of all sections A schedule of activities has been created to stay on track and finish the MQP final report by the scheduled deadline (end of C term 2014)	

3.1 Space Needs

A critical first step was an assessment of the current and projected future space needs for Kaven Hall. Data and information obtained from interviews were reviewed and analyzed in order to establish a set of proposed space options. Evaluation criteria were then established in an effort to help identify the option that provided the most satisfactory use of the renovated and new space.

3.1.1 Gather and Analyze Data on Space

Gathering relevant data was the first step in understanding the necessary and desired space needs for Kaven Hall. Meetings and interviews with the Director of Facilities Operations, William Spratt and the Administrator of Academic Programs, Charles Kornik, created a better understanding of the current and future space needs of this particular academic building. Architectural drawings were also obtained from Spratt, which were able to assist in further locating structural walls and partitions that governed the renovations that could be done. For example, many of the classrooms, such as the computer lab in room KH 202 on the second floor, have been made smaller and have partition walls running through them. This information was useful in helping determine the locations of critical elements in the building. The architectural drawings also assisted in calculating the minimum space needs for Kaven Hall using dimension of similar rooms currently in the building. As an example, if the square footage of an existing 25-person classroom is known, this same square footage can be used to aid in the layout and design of additional spaces that meet 25-person occupancy requirements. Additional research of previous MQP reports also aided in the understanding of the current available space and the alterations that could be made to the structure.

3.1.2 Propose and Evaluate Options for Additional Space

After obtaining all the preliminary information from interviews and previous research reports, an evaluation of the additional space options was conducted.

The three proposed options that were considered as possible solutions to address space needs are:

- The refurbishment of the current attic space
- The addition of a 3rd floor within the current footprint of the building
- The design and addition of a new wing

Each of these options underwent an evaluation using a predetermined set of criteria in an effort to determine which proposal would be developed in greater detail based on which option was the most suitable for this project. According to Au (2000), “It is important to evaluate facilities rationally with regard to both the economic feasibility of individual projects and the relative net benefit of alternative…projects.” Each of the options for this project was evaluated for the following four criteria:

- The amount of additional space that will be provided (square footage)
- The circulation and flow of the space
- The ability to maintain building occupancy during construction
- Flexibility of the space in terms of design potential and layouts

A standard system of evaluation was created in order to determine in an objective manner which of the proposed space options was the most suitable for this specific project. After the criteria were developed, they were categorized into a hierarchy system in which certain factors carried more weight than others in the decision process. A visual representation of this weighting system can be seen below in Figure 5.

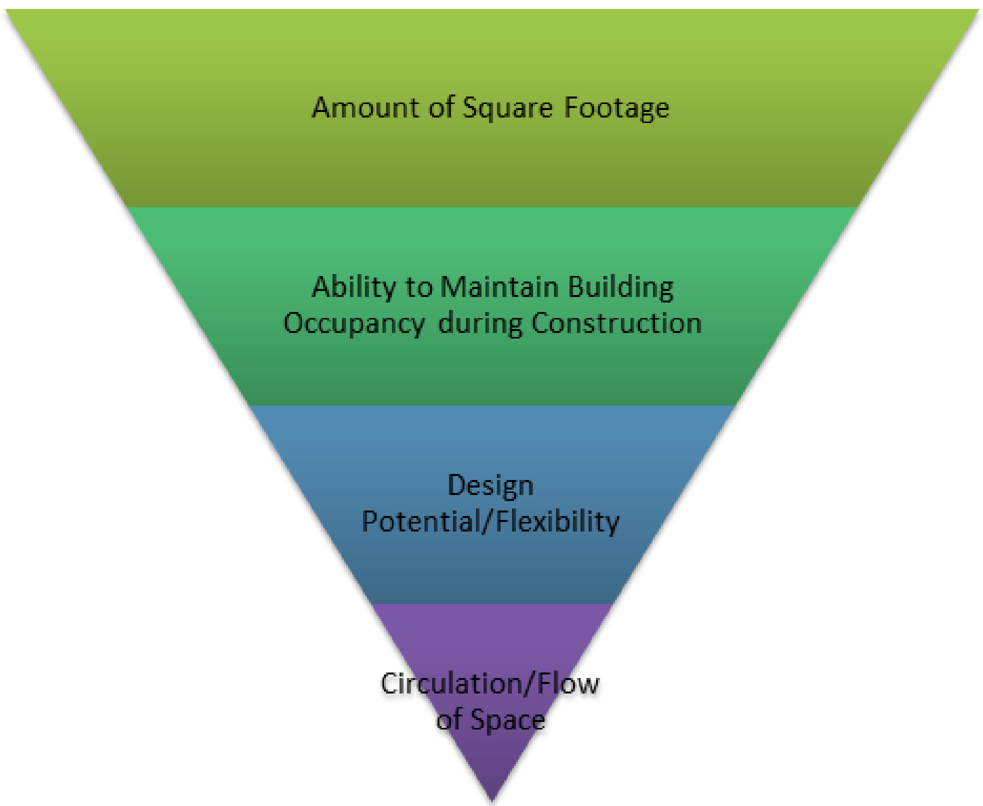


Figure 5: Evaluation Factors for Proposed Space Options

The amount of square footage was considered to be the most essential of the four criteria in order to ensure that the design option offers enough space to meet the minimum space needs requirement. Since the campus is open year round and needs to be used by faculty and students, a design that could maintain building occupancy during construction would be the most beneficial, and was therefore the second most emphasized factor. A design space that had the most potential for different special layouts was also beneficial to allow for flexibility of the future uses; however, it is not essential for the project to be completed. Last, the ability to merge the new space and the current space with good flow and circulation was the least important of the four criteria because, similar to the previous criterion, it is not essential but it provides a more pleasing architectural design layout, both functionally and aesthetically.

Each option was rated with respect to each criterion based on a specific set of guidelines or scoring rubric defined for each category. Then, based on the hierarchy system, the rating for each criterion was multiplied by a weighting factor that was established based on the level of importance assigned to each criterion in the final decision making process. The total score for a given option was given by the simple sum of the weighted ratings values. A table summarizing this scoring technique is shown below in Table 8. The purpose of using these evaluation techniques was to avoid any possible bias and ensure that each option was being evaluated in the same manner. Upon the completion of this evaluation, an option was chosen that best met the needs of Kaven Hall based on the summation of the final scores.

Table 8: Evaluation of Proposed Space Options Scoring Tool

		0	1	2	3	Weighting Factor
Amount of Sq. Footage	Attic	Does not meet space needs	Close to meeting space needs	Provides acceptable space needs	Exceeds space needs	4
	3rd Floor					
	New Wing					
Ability to Maintain Building Occupancy during Construction	Attic	No occupancy throughout entire construction	No occupancy for more than half of construction	No occupancy throughout summer months	Almost full occupancy throughout entire construction	3
	3rd Floor					
	New Wing					
Design Potential/ Flexibility	Attic	No design flexibility	Numerous constraints to design flexibility	Few limitations to design flexibility	Full design flexibility of space	2
	3rd Floor					
	New Wing					
Circulation/ Flow of Space	Attic	No flow of space	Limited flow of space	Acceptable flow of space	Excellent flow of space	1
	3rd Floor					
	New Wing					

3.2 Alternative Architectural/Structural Layouts and their Evaluation

Current structural drawings of Kaven Hall provided the basis for proposing the new architectural layouts. By knowing the location of existing columns and structural walls, the redesign of specific areas was facilitated. Building code and occupancy requirements were also necessary considerations in the layout of lecture halls and classrooms to ensure that specific class sizes could be accommodated. An architectural layout was then defined for both the new addition and a portion of the existing building, and a Revit model of the entire facility was created in an effort to provide a visual of the final product.

Upon completion of the space needs evaluation for Kaven Hall, the proposed idea that was selected needed to undergo another evaluation. This second evaluation dealt with alternative structural schemes that were to be considered the best-fit options for the specific space that was being designed. *ASCE 7* was utilized to structurally design the new space area by taking into consideration gravity and lateral loads in order to design a typical steel frame system. Alternative column and girder sizes were tested during the design phase in order to produce the most satisfactory system. This was not only were evaluated based on constructability and design, but also on the cost impact that they would each have on the final budget. It was important to find a balance between the cost and design to meet all the needs of WPI.

3.3 Egress Renovation Improvements

As part of the renovation of Kaven Hall, an analysis of the *MSBC, IBC,* and *ADA* were necessary in order to conduct a thorough update to the means of egress. This included updates to the current stairways, hallways, and incorporating an elevator system to provide easier accessibility to all areas of the building. Current architectural and structural drawings of Kaven Hall aided in determining the location of the new elevator system and coinciding mechanical shaft. It was essential to ensure that all updates complied with the *2012 International Building Code*. Since the *Massachusetts State Building Code* is in compliance with the *IBC*, the *IBC* was evaluated first, and the addendums in the *MSBC* were consulted as a second evaluation. Critical considerations that were analyzed in further depth were those related to accessibility and safety requirements, as these were thought to be of the utmost importance.

3.3.1 Stairway Evaluation and Design

The design and construction of the stairwells in the existing Kaven Hall building as well as the addition was necessary in order to comply with *ADA* and *MSBC* regulations. With no set process in place to design these stairwells, a strategy was devised to help accomplish the design goals of this system. Keys ideas that were addressed included:

- Determination of Design Loads that adhered to requirements of the *Metal Stair Manual* (*Metal Stairs Manual*, 1992) and *IBC* (*ICC*, 2012)
- Using current dimensions of landings taken from architectural drawings and personal measurements

- Calculate length of stringers, angle between stringers, and tributary widths of each section being evaluated
- Using factored loads, area formulas, and resultant forces to calculate maximum moments of sections
  - Compare calculated moments to maximum allowable moments found in Table 3-2 of *AISC*
- Designed typical floor beam (*AISC* Table 3-2) and typical column (*AISC* Table 4-22)

The process by which the design of these stairwells was completed can be seen in Figure 6 below. A complete description of the stairway design as well as the corresponding calculations can be referenced in Section 7.1 and Appendix B respectively.

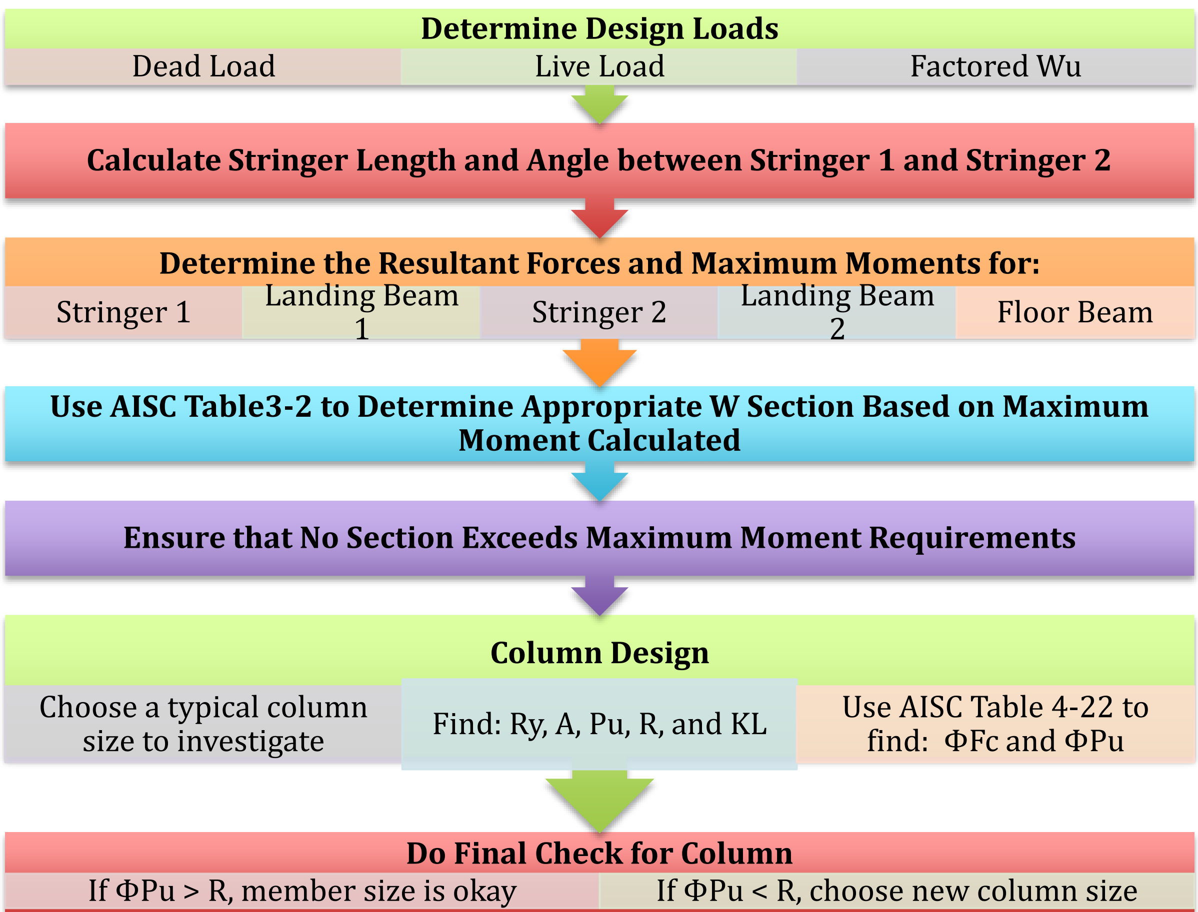


Figure 6: Flowchart for Design of Stairwells

3.3.2 Elevator and Shaft Design

The design of an elevator and hoistway system was also necessary in order for Kaven Hall to be in compliance with the various codes concerning handicap accessibility and means of egress. Therefore, based on the decision to limit impact to the structural systems within the existing building, the elevator system was designed in the current location of the stairway that leads from the second floor to the attic. The elevator system was designed using concrete masonry units (CMU) with a steel safety beam. The safety beam was required because the four 14-ft. tall sections exceed limitations set forth by *ACI*-530. The key ideas for defining the design process are outline below.

- Determine Design Loads that adhere to requirements of the *IBC*
- Research different types of elevator systems and designs by *Otis Elevator Company* and make a selection based on the needs of Kaven Hall
    - Obtain dimensions for cab interior, hoistway, and the elevator capacity
- Determine appropriate size of CMU for shaft –*ICC* requirements for Masonry Structures, Section R606.2.1
- Use dimensions and areas to determine number of CMU blocks needed
- Design Safety Beam for impact loads *(IBC* 1607.9.1 and *ASME* A17.1) -- Must withstand twice the elevator capacity due to dynamic loads
- Ensure that maximum possible loading for any section of masonry wall did not exceed the compressive strength of 1500 psi (*ICC* 2012, Section 2105.2.2.1.2)

A flowchart outlining the design process can be seen in Figure 7 below while additional design details and calculations can be found in Section 7.2 and Appendix C respectively.

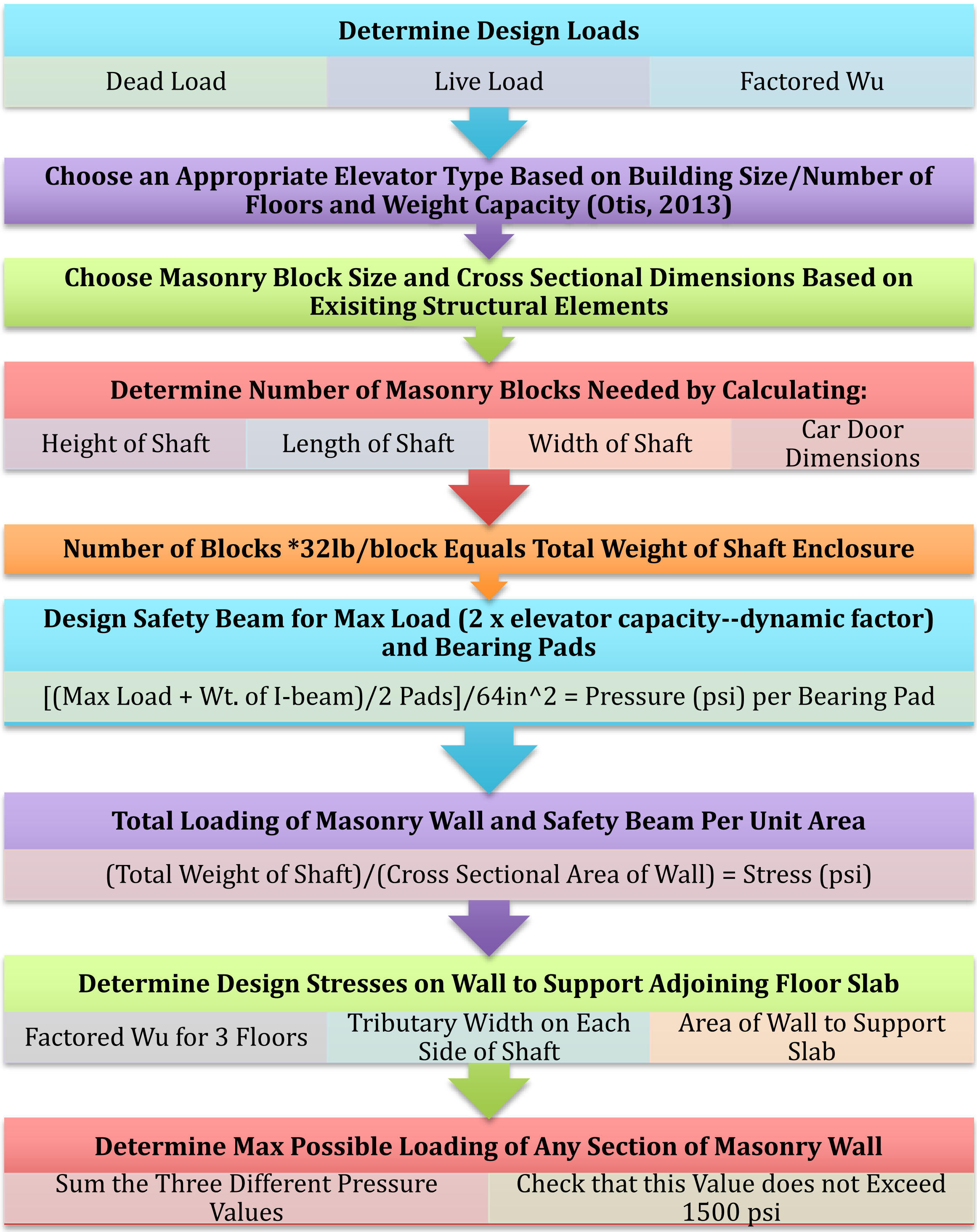


Figure 7: Flowchart for Elevator Cab and Shaft Design

3.4 Leadership in Energy and Environmental Design (LEED) Considerations

In an effort to comply with WPI's recently adopted mission of building a more environmentally friendly and "green" campus, decisions were directed at obtaining LEED certification. A checklist that outlines criteria that must be met to earn a specific level of certification under the category of 'New Construction and Major Renovations' was evaluated to determine which aspects were considered for this facility (U.S. Green Building Council, 2013c*)*. By evaluating the list of criteria and the specific points system for this group before the planning process began, design and material alternatives that contributed to the delivery of a LEED certified building were emphasized. Some critical areas of impact include:

- Material Selection
- System(s) Performance
- Amount of Construction Waste
- Use of Energy-Efficient Technology
- Air Quality

It was also important to consider alternative options for certain line items, especially those with higher costs. This is because products and systems associated with "green building" often times require the owners to incur a higher initial cost with the idea that cost savings will occur later in the life cycle of the project/facility. This idea of evaluating alternative options is known as value engineering. If the rating system were not examined critically before the design process, time delays and additional costs would be incurred in order to accommodate alterations and changes later in the construction phase.

3.5 Seismic Evaluation and Analysis of Exterior Masonry Walls

The completion of a seismic evaluation of the existing building was essential to determining the building's structural vulnerability. This section discusses the processes for the design of the steel frame for the additional wing, and the seismic analysis of the exterior masonry walls of the existing building.

3.5.1 Seismic Design and Analysis of Steel Frame

In order to perform a seismic analysis of the existing Kaven Hall and the additional space, the weight of the superstructure had to be determined. Therefore, for the additional space, a structural design of the steel frame was completed. A two-dimensional analysis was done in RISA2D in order to determine the forces, moments and deflections in the members and joints of the frames due to the dead and live loads acting on it. Some values for distributed dead loads were estimated in order to further the frame design process. Using values from the analysis, the Story Stiffness Method assisted in choosing the most adequate column and girder sizes for the stability of the steel frame. The structural design of the frame allowed a weight in pounds per square foot to be calculated for the addition, which was then combined with the weight of the existing building to establish the total weight for entire facility.

3.5.2 Seismic Analysis of Masonry Walls

Upon the completion of the structural and architectural design of the existing Kaven Hall and the additional space, a seismic analysis was performed. Two cases were considered for the seismic analysis.

- *Case 1: The existing building and the addition are seismically isolated.* This required the steel frame for the new addition and the masonry construction for the existing building to be analyzed separately.
- *Case 2: The existing building leans on the new addition for seismic resistance.* This required the seismic forces from the existing building to be combined with those from the addition and analyzed as one unit.

The Case 1 and Case 2 analyses were done in accordance with *ASCE 7* standards and took into account gravity and lateral loads to determine the forces on the principal members of the structure. This was a critical evaluation in order to assess the feasibility in completing a construction project with these specific design parameters.

3.7 Scheduling and Cost Estimation

Information obtained through the *RS Means* databases and projects of a similar nature were used to develop a design and construction schedule as well as a corresponding cost estimate. The project's activities were brainstormed within the project group based on the scope of the work. Further information obtained through interviews with knowledgeable WPI facility employees and research regarding code compliance and common construction practices helped to define the scope and activities that were associated with this MQP project. Grouping similar activities based on assembly codes resulted in approximately 25 separate construction activities. The costs associated with these activities were then determined using *RS Means Square Footage, RS Means Assembly Costs,* and lump sum estimates. This information was then combined into an outline specification that showed how the cost of each line item (activity) was determined. The full outline specification can be referenced in Appendix D.

Cost is always a factor that owners and designers must consider when planning a project as there is often a maximum allowed budget that cannot be exceeded in order for the project to continue past the design phase. A cost analysis of the entire project from beginning to completion was performed as part of the project management portion of this proposal. The activities included in the outline specification related to the structural design, egress renovations, interior improvements and finishes, and all sustainability considerations that were developed to meet LEED requirements. For any values that could not be determined using *RS Means* references, unit costs were estimated based on lump sums for similar projects researched. Upon determination of the building's cost per square foot, additional fees associated with general conditions, architect work, and location of site were included in an effort to produce the most accurate estimate possible. Overall, the cost estimate of the entire project should provide the owner with the information necessary to be able to make an informed decision about whether to move forward with the project.

Upon completion of the outline specification, the activities were put in a logical order to create the project schedule, highlighting the major activities and milestones of the project. The CODES guideline was used as a baseline to estimate the durations of the activities listed in the outline specification and any lag times that were appropriate (Construction Engineering, 1991). *RS Means* was then used as a supplement to estimate the durations of activities that were not included in the CODES breakdown but were a part of the Kaven Hall project. *Primavera P6* software was then used to create a visual representation of the logical sequence of activities and the critical path of the project's construction phase.

The schedule was important in understanding, which activities rely on the completion of others and whether some could overlap and take the form of a fast-tracked schedule. The schedule was also important for helping the owner make decisions regarding the best time for construction to take place. With WPI being an active campus, the current occupants of the building would need to be relocated for a set duration of the construction phase. An interview with a member of the facilities staff at WPI was conducted to discuss alternative construction options and the possibility of staged construction. This had a significant impact on the schedule of the project and whether the current building could remain open for any portions of the project's duration (i.e. summer construction versus academic year construction options).

An accurate timeline helped with the owner's decision making process as well as ensuring that equipment and materials were delivered and available on-site when they are needed to avoid delays once construction has started. This, in effect, has an impact on the cost analysis if the original schedule begins to deviate in any type of way. *Primavera* (P6) software was used to create a network diagram and the lazy s curve which ultimately helped to coordinate all activities and cash flow throughout the different phases of the project's delivery.

An evaluation from a structural system standpoint also provides the owner with valuable information regarding alternative options. With cost as a main objective, it is important to consider multiple structural options in the hopes that one meets the performance needs of the facility and the budget of the owner. Depending on the level of flexibility in the budget, a more in-depth and complex design may be feasible but for this project, the aim is to provide a design that meets the needs of the owner by the most effective cost means necessary.

In an effort to provide the owner with the most cost effective design, a series of cost evaluations were developed that take into account the various design options that were available. By providing a cost breakdown for separate structural design systems discussed in Section 3.2, owners and project management personnel could more clearly understand how the money is being divided amongst the different areas of the project. This assisted in making a final judgment decision about which design proposal would be selected for construction. Also, by providing a detailed breakdown of the costs in the early phases of design and construction, expenditures could be tracked and compared to help the project stay on course and within the proposed budget.

4.0 Space Planning and Design

To select the most satisfactory design option, the minimum amount of additional space required must be determined. Through interviews and scored evaluation, a design option was chosen. The following sections will discuss this process.

4.1 Additional Space Needs

In order to evaluate the three design options, it was necessary to have an understanding of the amount of additional space that is needed. Based on an interview with WPI's Administrator of Academic Programs, Chuck Kornik, the minimum space requirements include an additional lecture hall, computer lab, and several new faculty offices. The dimensions of similar rooms currently in Kaven Hall were used to calculate the area of the spaces needed. Using these values, a sum of the minimum square footage needed is shown in Table 9. Since this total of 3880 ft^2 is the minimum required area, other demands from faculty and students regarding space needs were also considered.

Table 9: Minimum Additional Space Needs

Room Need	Capacity	Similar Room Currently in Kaven Hall	Quantity Recommended	Square Feet/Unit	Total Square Feet
Lecture Hall	70	Kaven 116	1	1472	1472
Computer Lab	26	Kaven 202	1	1472	1472
Offices	1	Offices on First Floor	6	156	936
Total			**-**	**-**	**3880**

4.2 Evaluation of Options

As mentioned in Section 3.1.2, three design options were created. The first option was the refurbishment of the current attic space. The second option was to add a third floor within the current footprint of the building. The third option was to add an additional wing to the east side of the existing building towards Institute Park. Each option was considered equally based on the design criteria set forth in Section 3.1.2.

The square footage for the three options increased in the order of the attic, the new floor, and the new wing. The attic provided the least amount of usable space with only about 3,280 ft^2. The new floor provides almost three times that space with approximately 9,558 ft^2. Last, with the new wing being able to be two stories tall, an area of 5,096ft^2 of usable space per floor made the total for this option around 10,192ft^2. The additional square footage for each design option is displayed below in Table 10.

Table 10: Square Footage for Three Design Options

Design Option	Amount of Square Footage
Attic	3,280
New Floor	9,558
New Wing	10,192 (5096 per floor)

For the addition of a new floor, the area was calculated based on the current area of the first/second floor. Since the attic has an angled ceiling, *MSBC* 780 CMR 1208.2 states that a minimum of 7.5 ft. of headroom is required in all areas considered usable space. Therefore, the area provided by the attic is much less than that of an entire new floor. The area of the new wing was calculated assuming that the building would end 15 ft. from the road in order to be in compliance with the City of Worcester Zoning Ordinances. For the square footage requirement, the attic did not provide enough for the space need, and therefore received a score of a zero, whereas the other two design options provided more than enough space and got the highest score.

The other three criteria are qualitative, and therefore were scored based on the descriptions in Table 5 in an effort to avoid any bias by the individuals performing the evaluation. Because a new wing would mostly be isolated from the rest of the building and would not require the building to be shut down, it received the highest score. For a new floor or an attic, it would be more difficult for the building to be open if construction was going on above the occupants, and therefore both received a lower score than the new wing. The attic design received a lower score for the design potential and flexibility criteria because of the angled ceiling and the limited space; however, the new wing and the new floor received the highest score because both are large open spaces that would be easier to design. An entire new floor would have the most satisfactory flow of space because it can be designed independently of the current building design, whereas an addition would need to be merged with the current building layout. The attic still received the lowest score for this criterion because of the lower ceiling height. The points for each design option were totaled, and the design option with the highest score was chosen. The evaluation and resulting scores for each of the three options are displayed in Table 11.

Table 11: Evaluation of Options Results

Design Option	**Criteria**	**Score**	**Multiplying Factor**	**Total**
ATTIC	Sq. Ft.	0	4	0
	Schedule	2	3	6
	Flexibility	1	2	2
	Flow	1	1	1
	Total			**9**
NEW FLOOR	Sq. Ft.	3	4	12
	Schedule	2	3	6
	Flexibility	3	2	6
	Flow	3	1	3
	Total			**27**
NEW WING	Sq. Ft.	3	4	12
	Schedule	3	3	9
	Flexibility	3	2	6
	Flow	2	1	2
	Total			**29**

From the above table, the addition of a new wing had the highest score, and therefore was the chosen design option. From this, the architectural designs of the new wing and the renovations to the existing building were developed, and they are discussed in Chapter 5.

5.0 Architectural Design

The most up-to-date architectural layouts were obtained from the WPI Library Archives and Facilities Departments, and these drawings were used as the basis to help develop an accurate layout of Kaven Hall's current floor plans. By comparing these different layouts, the location of important structural components such as walls, columns, and stairways were identified. It was also critical to research current building code and design standards to ensure that the renovation and new addition were meeting regulatory requirements and industry specifications. The *International Building Code (IBC)* provided a majority of the information pertaining to occupancy load requirements, hallways and stairway widths, and fire protection standards. Also, codes such as those developed by the *ADA, MSBC, and ASME 17.1* were used to aid in the design of the different egress systems for both the renovation of the existing building and the construction of the new wing. By combining the information regarding the location of structural components and a comprehensive understanding of the current building and design codes, the redesign and integration of the current space with the layout of the new wing was possible. This chapter discusses the factors that played a role in the design of the functional and structural layouts.

5.1 Architectural Layout

One of the main considerations that was taken into account with the design of the renovation was the current structural components. In order to cause the least amount of disturbance to the existing structure, it was important to design the new layout using the current location of structural walls and columns. This still allowed for major design changes with the removal and addition of partition walls and hallways. One of the driving forces in creating a new layout was to make more satisfactory use of the current space so that the needs of both the students and faculty/staff were met. It was also important to design these new spaces with the understanding that the building must be able to support the growth in facilities and faculty that WPI is expecting within the coming years.

A breakdown of the location of the offices, lounges, classrooms, computer labs, and bathrooms for both the renovated space and the new addition can be found in Table 12 below.

Table 12: Spaces in the Renovation and New Wing

	Renovation		New Wing	
1st Floor	Space	~ Sq. Ft.	Space	~ Sq.Ft.
	2 Lecture Halls (70 person)	2944	Restrooms	390
			Student Lounge	2220
			Offices (5)	838
	3 Classrooms (25 persons)	2054	MQP Suites (3)	563
	Offices (6)	1270		
	Elevator	69		
	Storage Closet	176		
	Janitor Closet	70		
2nd Floor	Space	~ Sq. Ft.	Space	~ Sq.Ft.
	Larger Restrooms	438	Offices (8)	1260
			Storage/Janitor Room	105
	3 Computer Labs (26 persons)	2772	Area overlooking student lounge and Institute Park	2220
	Drafting Studio	1050		
	TA Office	1056		
	Copy Room	305		
	Offices (8)	1280		
	Elevator	69		

With the amount of new space that was gained with the addition of the new wing, the sizes of faculty and staff offices, the TA Lounge, and the current bathrooms could be expanded. Another driving force for the designs of the new layout was accommodating the new spaces that Chuck Kornik stressed as the most important current and future needs of the campus. These space needs are outlined in Table 6 in Section 4.1 of this report. Lastly, with enough square footage still available in the floor plan, the design of additional spaces such as new bathrooms, a larger student lounge, and MQP suites could be integrated into the building.

The overall layout of the building was designed with the idea in mind to create open and usable spaces that meet the needs of all occupants of the building. Therefore, previously narrow and winding hallways were also opened up, and an elevator was incorporated to provide access to all levels of the building. Keeping the objective in mind of causing the least amount of disturbance to the original structural design, the elevator shaft will be constructed where the stairway to the attic is currently located. Numerous sketches were done in an effort to create a layout that provided the most satisfactory use of the space based on the criterion developed in Section 4.1. The final sketch was then input into *Revit 2014* software to provide a visual design aid that includes floor layouts and typical furniture for the additional wing, and a final 3D realistic view of the building. Due to the confidentiality agreement signed upon obtaining the original Kaven building layouts, limited information can be shown in these Revit models (Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, and Figure 13).

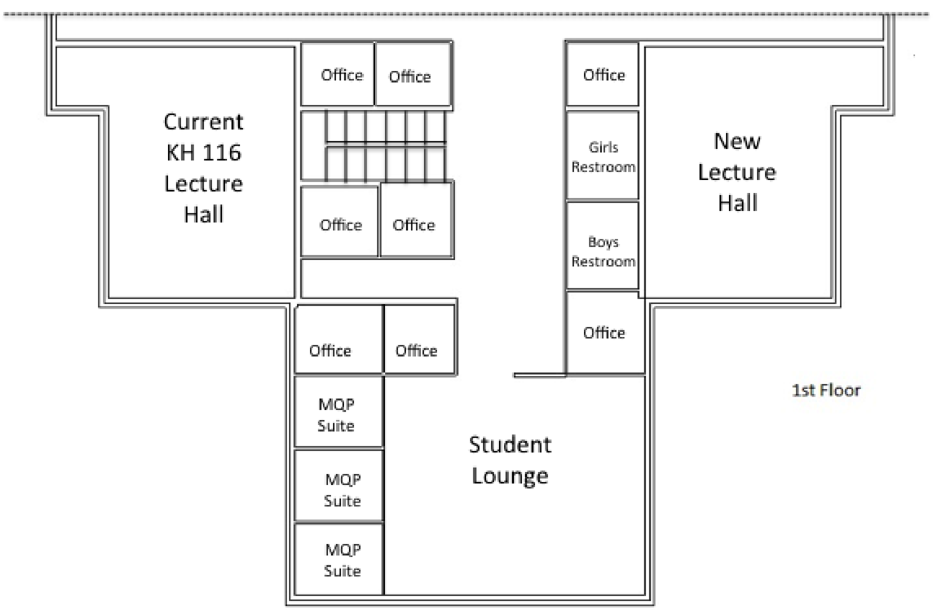


Figure 8: Proposed Layout of Kaven Hall First Floor

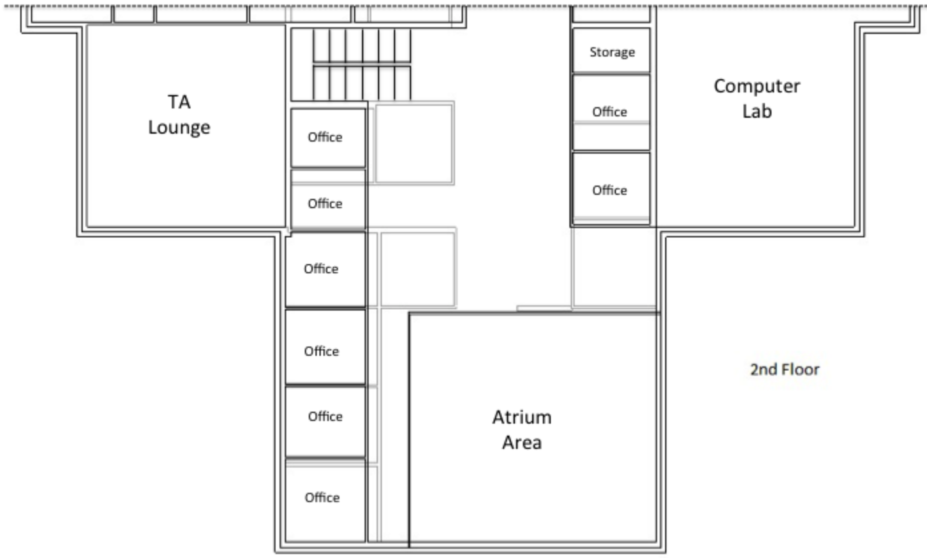


Figure 9: Proposed Layout of Kaven Hall Second Floor

Figure 10: Revit Model of Student Lounge

Figure 11: Revit Model Overlooking Atrium

Figure 12: Revit Model of MQP Suites

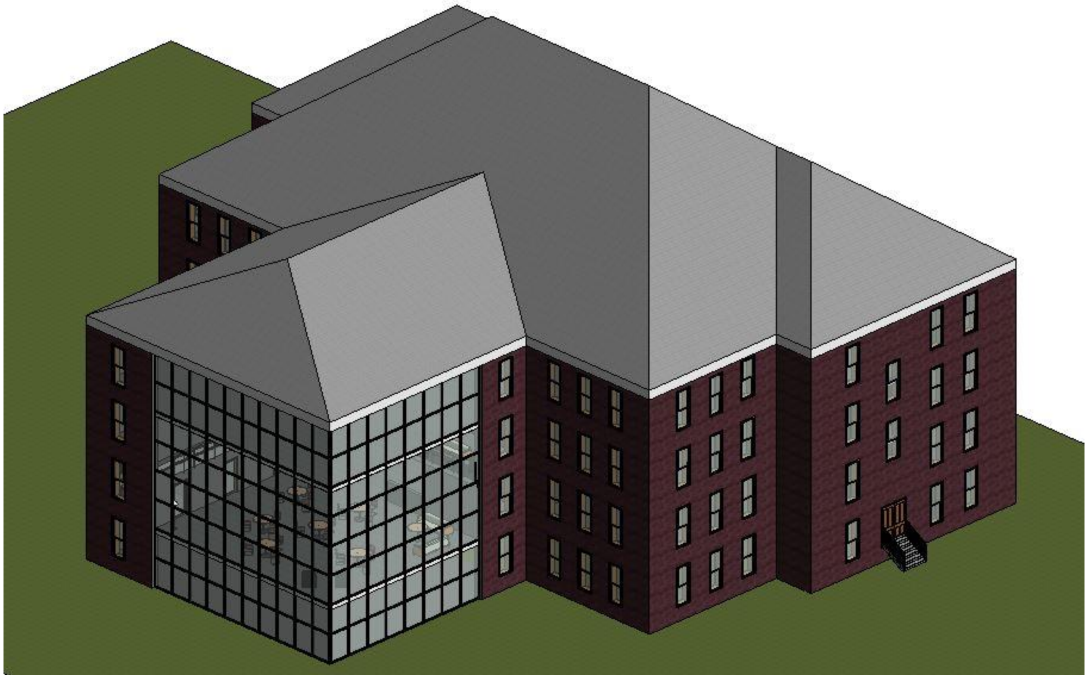


Figure 13: Revit Model of Kaven Hall Proposed Renovation and Addition

5.2 Code Review

When completing a building design, it is essential to confirm that the building is in compliance with the applicable codes and standards in order to proceed with the approvals process associated with obtaining building and occupancy permits. *The Massachusetts State Building Code (MSBC)* is an adoption of the *2009 International Building Code (IBC 2009). The MSBC* lays out minimum the requirements for how a building should be constructed, what materials can be used, and various dimension requirements. The building must also be designed in accordance with the *Americans with Disabilities Act* (*ADA*). Although Kaven Hall currently is a “grandfathered” building, renovations in excess of $100,000 or alterations of 30% of more of the structure require the building to be in compliance with the most up-to-date set of standards, including those outlined by the *ADA* (Massachusetts Architectural Access Board, 2013). The following section discusses the different aspects of the building codes that are applicable to this MQP.

5.2.1 Building Overview

Kaven Hall is a three-story academic building principally housing the Civil, Architectural, and Environmental Engineering students, faculty, and staff at Worcester Polytechnic Institute. The building contains classrooms, offices, and computer laboratories.

According to *IBC, 2012*, Section 304.1, this type of building classifies as a Business Group B Occupancy. In addition, the Occupancy Category is Category II, which is used for education facilities including college facilities with occupancy less than 500 (*IBC, 2012*, Table 1604.5).

5.2.2 Occupant Load

Occupant loads for the first and second floor were calculated for this building. The occupancies for the renovated and additional classrooms, computer laboratories and lecture halls were determined based on the existing similar areas. These existing areas include the large lecture hall, the smaller classrooms, as well as the computer laboratories on the second floor. The occupancies of the lecture hall is 70, and the small classrooms and computer labs are 25. All other areas were calculated based on the general area requirements set forth in Table 1004.1.2 of the *IBC* for Business Areas, which is 100 square feet per occupant (IBC, 2012, Table 1004.1.2). A breakdown of the areas for the first and second floor is shown in Table 13.

Table 13: Breakdown of Total Floor Occupancy

Floor	Space Type	Square Footage	Total Square Footage	Occupancy	Total Floor Occupancy
First	Classrooms	4998	14628	215	299.5
	Offices	2108		13	
	MQP Suites	562.5		12	
	Other Spaces	6959.5		59.5	
Second	Classrooms	2772	14628	78	166.66
	TA Offices	1056		20	
	Drafting Studio	1050		10	
	Offices	2540		16	
	Other Spaces	7210		42.66	
Total			**29256**		**466.16**

In Table 13, “Classrooms” include the small classrooms, lecture halls, and computer laboratories. The category “Other Spaces” includes all hallways, wall partitions, rest rooms, and storage closets.

5.2.3 Means of Egress

Corridors, stairways and doors must comply with width requirements in order to accommodate the number of occupants on each floor. Chapter 10 of the *IBC* includes information regarding these egress requirements. Table 14 below summarizes the requirements for Kaven Hall based on their corresponding code references.

Table 14: Egress Requirements

Egress Requirement	**Width**	**Code Reference**	**Notes**
Corridors	44 inches minimum	IBC 2012 Table 1018.2	
Stairways	8 feet	IBC 2012 Section 1005.3.1	Using occupancy of first floor
Doors	32 inches	IBC 2012 Section 1008.1.1	Swinging doors - 48 inches maximum

The *ADA* has also established a set of guidelines regarding these minimum requirements. After comparing the two sets of values, it was determined that the minimum requirements outlined in the *IBC* governed in all cases. For example, the *ADA* requires a minimum hallway width of 36 inches while the *IBC* requires 44 inches minimum (United States Access Board, 2013). All of the existing hallways, stairways and doors in Kaven Hall are in compliance with these standards, and any renovated or additional hallways created will follow.

The *IBC 2012* has also set forth requirements for the exit locations in buildings. Section 1014 covers all exit requirements broken down by Occupancy Group. Primarily, the common path of egress travel is measured based on the maximum distance required to get to an enclosed exit where more than one direction of escape routes is possible. Second, the exit access travel distance is determined based on the distance from the most remote point within a story to an exit, or the absolute maximum distance needed to travel to an exit. The required values of these two distances for Kaven Hall, and their corresponding *IBC* references are displayed in Table 15.

Table 15: Exit Requirements

Exit Requirement	**Without Sprinkler System**	**With Sprinkler System**	**IBC Table Reference**
Common Path of Egress Travel	75 feet	100 feet	1014.3
Exit Access Travel Distance	200 feet	300 feet	1016.2

Based on the architectural layout chosen for the Kaven Hall Renovation and Addition, the common path of egress travel cannot meet the maximum 75-feet requirement necessary for no sprinklers as is shown below Figure 14: Longest Path of Egress Travel from New Wing. In this figure, the longest 'Common Path of Egress Travel' for the new addition is illustrated with a dashed line. The dimensions shown are 37' 9-1/4" and 59' 8-7/8" respectively which totals 97'-6". Therefore, sprinkler systems must be installed in the building in order to meet the code requirements for exit routes and ensure the safety of building occupants. Although there is a cost associated with the addition of the sprinkler system, alternative design options with revised or additional exit locations did not make as satisfactory use of the space as the proposed layout. This was the main reasoning behind the decision to continue forth with an investment in sprinklers as opposed to revising the design and architectural layout.

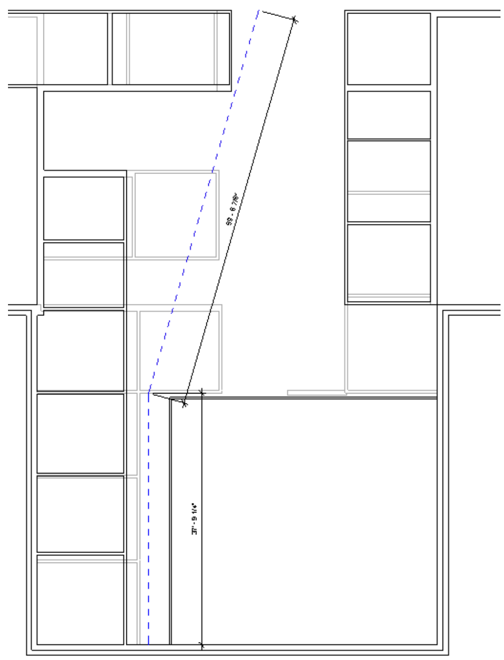


Figure 14: Longest Path of Egress Travel from New Wing

Another consideration regarding means of egress is ceiling height. Any area that is considered a general means of egress such as a hallway must have a ceiling height of no less than seven feet (*780 CMR 1003.2)*. Otherwise, ceiling heights for offices, meeting spaces, and other occupiable spaces have a required minimum of six feet (*780 CMR* 2108.2). With all ceiling heights being 14 feet, both of these requirements were easily met.

Once the *IBC* was reviewed, *780 CMR: Massachusetts Amendments to the IBC* were checked for significant differences. After analyzing the addendums to Chapter 10: Means of

Egress, it was concluded that there were no significant differences from *IBC 2012*, and therefore had no impact on the project.

An additional standard that *ADA* has established regarding egress relates to accessible routes and rooms. According to Section 4.5 of *ADA*, all rooms and accessible routes including all floors, walks, ramps, stairs, and curb ramps must be designed with surfaces that are stable, firm, and slip-resistant.

5.2.4 Stairway Requirements

Both the *IBC* and *ADA* have developed regulations and minimum requirements for stairway design. These references were used to determine the governing values in each situation in an effort to develop a design in compliance with both codes.

As shown in Table 1607.1 in the *IBC*, a live load of 100psf can be assumed in all situations aside from one and two family dwellings. In the same chapter of the code, section 1607.4 states that a concentrated dead load of 300 pounds on stair treads can be supported. However, this value rarely governs and in this particular design, the *Metal Stair Manual* provided a more realistic value of 50 psf.

Additionally, section 1009.7 from the *IBC* provided requirements pertaining to riser height being within the range of 4 feet-7 feet and tread depth being a minimum of 11 inches. The vertical rise between the landings the floor was also governed by a 12-foot dimension as per the code. Lastly, *OSHA* requires that a check be done to ensure that design calculations of the stairway rise angle fall within the range of 30-50 degrees on the diagonal in order to comply with the codes for fire escape stairwells. Further design specifications required by *OSHA* include the allowance of a 7-foot minimum vertical clearance and non-slip finishes on nosings and treads.

5.2.5 Elevator Requirements

ASME 17.1 and *ADA 4.10* are the safety codes for the design of elevators and escalators. From *ADA 4.10.9*, the minimum dimensions of the elevator for accessibility can be determined. A diagram displaying these dimensions from the *ADA* is shown in Figure 15.

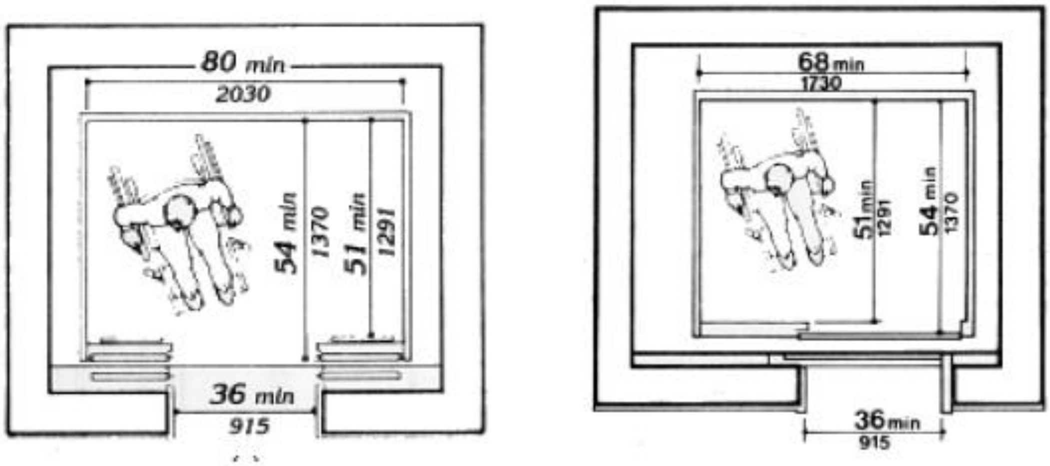


Figure 15: Requirements for the Dimensions of Elevators (Taken from ADA 2010)

There are numerous other requirements that the *ADA* established for elevator design that were investigated as a part of this report. Section 4.10.2 of the manual states that the car must be equipped with a self-leveling feature that can bring the car to floor landings within a tolerance of ½". It is mandatory for this feature to be automatic regardless of the type of elevator being used. Section 4.10 also states that elevator doors should open and close automatically which is considered a safety feature that would require immediate maintenance if it was ever found to be working improperly. One of the last sections that were considered due to the scope of this project was 4.10.3 which required that call buttons in elevator lobbies be located 42" above the floor with a minimum button diameter of ¾". The up/down buttons also must be visible by all potential elevator occupants.

5.2.6 Plumbing Fixture Requirements

The plumbing fixture requirements for a building are based on the building's occupancy category. Table 2902.1 from *IBC 2012* states the minimum plumbing fixture requirements for Occupancy Group B. The standards for each type of plumbing fixture and the corresponding result for Kaven Hall and its additional spaces are displayed below in Table 16. These values for the plumbing requirements will be implemented within the renovations to the existing building and the construction of the new additional wing.

Table 16: Plumbing Fixture Requirements

Plumbing Fixture	**Code Requirement**	**Minimum Number of Fixtures**
Water Closets (combined toilet stalls and urinals)	1 per 25 for the first 50 and 1 per 50 for the remainder	11
Lavatories	1 per 40 for the first 80 and 1 per 80 for the remainder	7
Drinking Fountains	1 per 100	5

6.0 Evaluation of Leadership in Energy and Environmental Design (LEED) Options

Evaluation of LEED criteria for the Renovation and Addition to Kaven Hall began at the outset of the design phase when the functional layouts of the building were being established, and continued through the completion of the construction management portion of the project. The Project Checklist published by the USGBC along with the corresponding LEED document explaining the credit system for 'New Construction and Major Renovations' were used to help develop a spreadsheet that outlined the credits that could be obtained for this specific project. These credits were then summed together to find a total and ultimately determine the level of certification that the building would receive upon the completion of construction.

The *LEED 2009* series was used as the evaluation tool, as it is the most recent publication issued by USGBC for this particular type of project. The credit system is broken down into separate categories, with some categories requiring the fulfillment of prerequisite requirements before any credits can be earned in that section. For example, for the 'sustainable site' section, a prerequisite of 'Construction Activity Pollution Prevention' must be adhered to before any of the additional 26 credits in that category can be considered, as shown in Figure 16 below (the full "LEED 2009 for New Construction Checklist" can be found in Appendix E.

LEED 2009 for New Construction and Major Renovations		
Sustainable Sites	Possible Points:	26
Prereq 1	Construction Activity Pollution Prevention	
Credit 1	Site Selection	1
Credit 2	Development Density and Community Connectivity	5
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation - Public Transporation Access	6
Credit 4.2	Alternative Transportation - Bicycle Storage and Changing Rooms	1
Credit 4.3	Alternative Transportation - Low-Emitting and Fuel-Efficient Vehicles	3
Credit 4.4	Alternative Transportation - Parking Capacity	2
Credit 5.1	Site Development - Protect or Restore Habitat	1
Credit 5.2	Site Development - Maximize Open Space	1
Credit 6.1	Stormwater Design - Quantity Control	1
Credit 6.2	Stormwater Design - Quality Control	1
Credit 7.1	Heat Island Effect - Non-roof	1
Credit 7.2	Heat Island Effect - Roof	1
Credit 8	Light Pollution Reduction	1

Figure 16: Sustainable Site Category for LEED 2009 New Construction and Major Renovations Project Checklist (Taken from U.S. Green Building Council 2013e

The seven separate categories of the checklist included:

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation and Design Process
- Regional Priority

U.S. Green Building Council (2013b)

After analyzing all the potential credits, a list of the specific ones that were applicable to this project was tabulated. Table 17 below summarizes each of the credit categories and the corresponding number of credits that are anticipated for the Kaven Hall project. The full checklist with the total credits can be referenced in Appendix E.

Table 17: Summary of Anticipated LEED Credits Earned on Kaven Hall Project

LEED for New Construction and Major Renovations (v2009) Credit Breakdown		
Credit Category	Anticipated Number of Credits for Kaven Hall Project	Total Available Credits
Sustainable Sites	22	26
Water Efficiency	4	10
Energy and Atmosphere	22	35
Materials and Resources	8	14
Indoor Environmental Quality	12	15
Innovation and Design Process	2	6
Regional Priority	Unknown	4
Total	70	110

The categories that had the largest influence on the number of credits that this project could earn included Sustainable Sites, Energy and Atmosphere, and Indoor Environmental

Quality. An evaluation of a select few credits is shown below in Table 18, which illustrates the level of complexity that was involved in achieving some of the credits (U.S. Green Building Council, 2013d). This information was evaluated early in the design process because numerous activities were scheduled for completion throughout the duration of the project. The final total that the building was designed to receive was 70 credits, which would fall in the range of 60-79 points, making the building Gold Certified. Due to some categories having a range of possible credits associated with them, the number of assumed credits to be earned can change from the beginning of the project to the end. Therefore, because the project is currently in the middle of the Gold Certification range, it is possible that changes in design and use of technology throughout the construction process could lead to the building only achieving a Silver Certification. This is still an acceptable level of LEED Certification for the WPI campus and community, which will make Kaven Hall the fourth building on the WPI campus to achieve LEED certification.

Table 18: Intent/Requirements of Credits for LEED 2009 New Construction and Major Renovations Certification

Category	Credit Title	Intent/Requirements	Possible Credit(s)	Credit(s) Earned
Sustainable Sites	Alternative Transportation — Public Transportation Access	Option 2: Bus Stop Proximity Project is located within ¼-mile (400-m) walking distance (measure from a main building entrance)	6	6
Energy and Atmosphere	Optimize Energy Performance	To achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use	1 to 19	12
Indoor Environmental Quality	Daylight and Views — Views	To provide building occupants a connection to the outdoors through the introduction of daylight and views into the regularly occupied areas of the building	1	1

7.0 Structural Design

Once the architectural design was completed, a structural design of the renovations and new wing was developed. This chapter discusses the design of the renovations in compliance with egress requirements, the steel frame design for the new wing, and a seismic analysis of the building in its entirety.

7.1 Design of Stairway Enclosure and Framing

Currently, Kaven Hall has two stairwells leading from the basement and continuing through the first floor and up to the second floor on opposite ends of the main corridor. These stairs are known as parallel stairs, which means they are, "straight stairs [that] permit a change in direction at an immediate landing (Merritt, 2001)." There is also a third stairwell that is located in a more central location on the second floor that leads to the attic. To meet one of the main objectives of this MQP, new stairwells were designed that spanned from the basement level up to the attic on both ends of Kaven Hall. The previous location of the third stairwell would then be renovated and used an elevator shaft.

Due to the proposed location of the new stairwell leading from the second floor to the third floor being in the same location as the other set of stairs, it was decided to use the same parallel stair design to stay consistent as well as aesthetically pleasing. This is also a cost effective solution due to only one section of stairs needing to be renovated.

Currently, the stairs have a 12 in. tread and a 6 in. rise, and each floor has a landing that is sized at approximately 5 ft. by 10 ft. The landing dimensions needed to be in compliance with *IBC* Section 1009.4 which states that, "the width of landings shall not be less than the width of stairways they serve." The width of the landings was also a critical factor in designing the stairwells to meet fire code requirements. With the new stairwells being designed to serve four floors, an enclosure with a fire resistant rating of not less than 2 hours and 1-1/2 hour self-closing doors that swung open in the direction of egress travel were required. Figure 17 below illustrates these requirements. Based on the architectural layout of Kaven Hall, the current stairway locations provide enough space for the new enclosures to be constructed without sacrificing the structural integrity of the space.

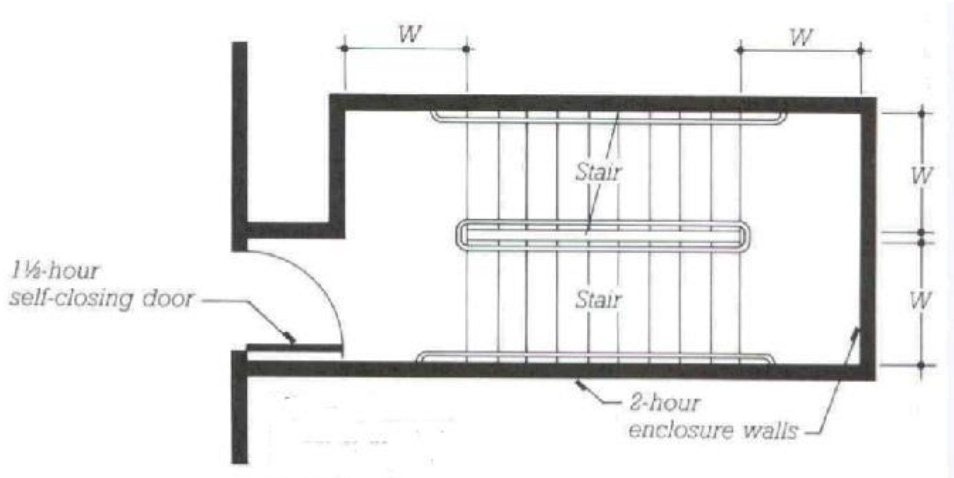
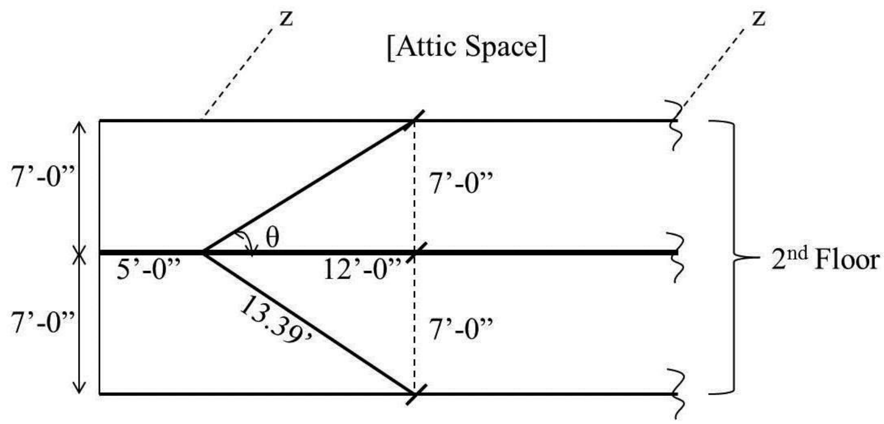


Figure 17: Stairway Enclosure Requirements (Luxenburg, 2009)

To design the stairs, it was necessary to determine the dead loads and live loads that would be acting on the structures. Normally, the dead load would be determined by calculating the self-weight of the slab and the self-weight of the steel pan (assumed values). Due to the exact values of these variables being unknown, the *Metal Stair Manual* provides an assumed value of 50 psf. The design live load was determined from *ASCE 7*, Table 4.1.

- Dead Load = 50 psf (This value is assumed unless exact details of pans, rails, and finishes are known. This is a common assumption in the *Metal Stair Manual*).
- Live Load = 100 psf

The design calculations for these stairs can be found in Appendix B. A graphical representation of the cross section and design layout of the stairs can be seen below in Figure 18. Due to the scope of this MQP, this stair design will be typical for the new stairwell in the addition as well. This type of repetitive design will also be helpful in completing the final cost analysis at the completion of the project.



Member Selection: Stair Design	
Member Type	**Member Size**
Stringer 1	W8x12
Stringer 2	W12x14
Landing Beam 1	W10x12
Landing Beam 2	W8x10
Floor Beam	W8x15
Column	W8x15

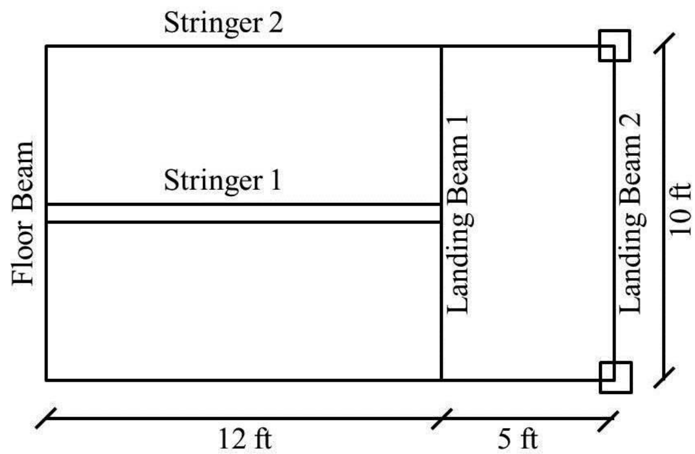


Figure 18: Cross Sectional View and Design Layout of Stairs

7.2 Elevator Design

One of the major additions that were proposed as part of the renovation of Kaven Hall was incorporating an elevator. Due to the extent of the total renovations, this design component is required in order for the building to be in compliance with the *ADA.* As stated in the code, all handicapped/disabled persons must have access to all floors of the building through the use of accessible routes and means of egress. By using the requirements outlined by the *ADA* and *ASME 17.1*, the elevator could be designed to meet all safety standards in addition to meeting the varying needs of the building's occupants. Refer to Section 5.2.5 for elevator dimension and accessibility requirements.

The proposed location of the elevator currently contains the stairwell leading to the attic. On the first floor, this space corresponds to the current location of the copying room and a closet in the basement. This area was chosen, as it was believed to have the least amount of structural impact on the building, which in turn made it a more cost effective option.

Based on the available elevator systems that could adequately service Kaven Hall, a holeless hydraulic elevator was selected. This type of elevator eliminates the risks associated with extending the cylinder and piston of the elevator into bedrock and unstable soil, which can be extremely dangerous and impractical. This is often an option used in areas with a high water table as well for similar concerns (Otis 2013). A typical holeless hydraulic elevator can be seen in Figure 19 below.

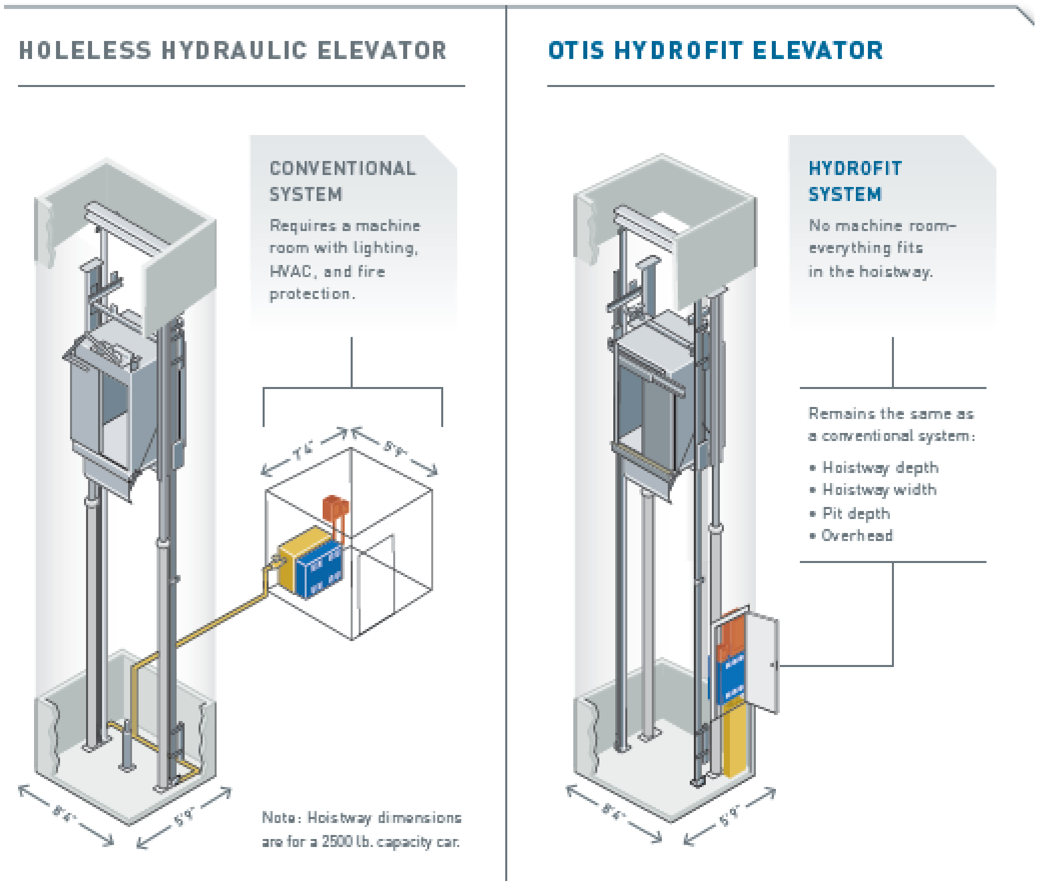


Figure 19: Typical Holeless Hydraulic Elevator and Otis HydroFit Elevator (Taken from Otis, 2013)

While also keeping in mind the LEED specifications that must be met in the renovation of and addition to Kaven Hall, a new type of elevator technology was also evaluated. Otis Elevator Company has recently added holeless hydraulic elevators to their product line of machine-room-less technology. This new elevator, the Otis HydroFit Elevator, remains the same as the conventional holeless hydraulic system in terms of hoistway depth, hoistway height, pit depth, and overhead. The main difference lies in the fact that a machine room equipped with lighting, HVAC, and fire protection is no longer a requirement, which effectively means that there is more usable space available in the building. The new HydroFit Elevators are also equipped with energy efficient designs such as LED lighting, sleep mode for lights and fans, which have led to measurable decreases in total energy consumption as shown in Figure 20 below.

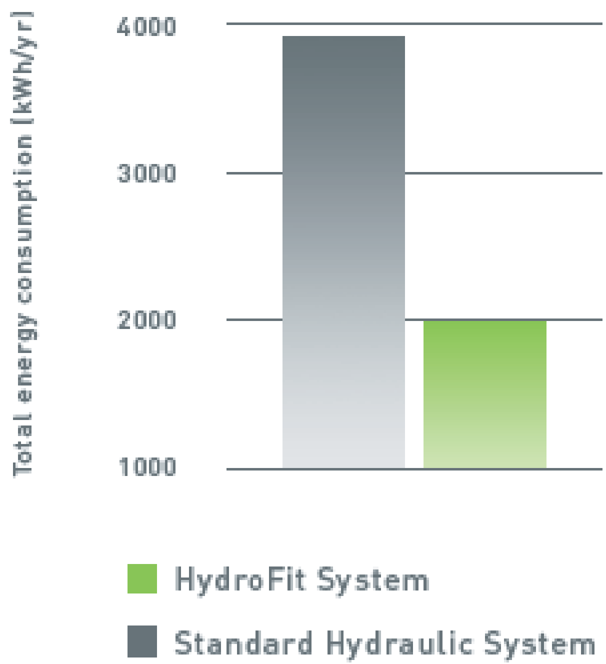


Figure 20: Total Energy Consumption of Standard Hydraulic System Compared to HydroFit System (Taken from Otis, 2013)

This design and model was therefore chosen based on its environmentally-friendly aspects and its compliance with the standard requirements for the elevator design in Kaven Hall, which are: that it must be designed to travel to four floors, which is approximately 48 ft.; make four stops; and have a capacity of 2,500 pounds, which is typical of an elevator at WPI.

The following Table (Table 19) outlines the HydroFit Specifications that are directly related to the design of the elevator system in the Kaven Hall Renovation.

Table 19: HydroFit Specifications and Dimensions

HydroFit Specifications		
Travel Height Maximum	26'-6" (8m)	
Maximum Stops	4	
Speed (ft/s)	100	125
Dimensions	**2500 rated pounds** **Passenger Capacity: 15**	
Interior Width	6'-5 9/16"	
Interior Depth	4'3 9/16"	
Interior Height	7'-9" (Optional 9'-9")	
Car Door Width	3'-6"	
Entrance Height	7'-0" (Optional 8'-0")	
Hoistway Width	8'-4"	
Hoistway Depth	5'-9"	

The first set of values necessary to design the elevator shaft was the specific design loads. These design loads included the weight of the elevator cab and the maximum load capacity of the system. Also, to account for dynamic loads associated with the kinematics of the machinery, the supporting members of the elevator shaft were designed such that the dead and live loads were both doubled in order to provide sufficient support for the impact loads (*ASCE 7* Section 4.7.1). The critical members that needed to be designed included a safety beam and two steel bearing pads. An illustrative sketch of this configuration can be seen below in Figure 21, and the supporting calculations can be referenced in Appendix C. The main purpose of a safety beam is to accommodate the various distributed and dynamic loads throughout elevator installation and operation. The two additional bearing pads were designed at the top of the hoistway to help disperse the load being taken by the safety beam in the case of structural failure.

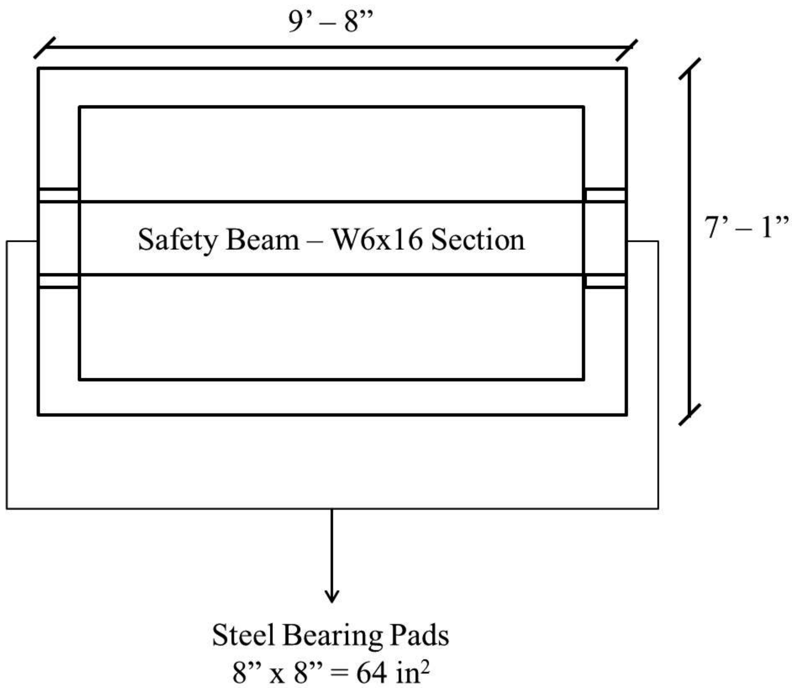


Figure 21: Schematic Drawing of Safety Beam and Steel Bearing Pads for Elevator Design

After these values were determined, the dimensions of the cab and hoistway, which were provided by the Otis Elevator Company specifications brochure, were used to aid in the design of the concrete masonry unit (CMU) shaft. An illustrative sketch of the relevant dimensions involved in the design of this system is shown below in Figure 22 with supporting calculation in Appendix C.

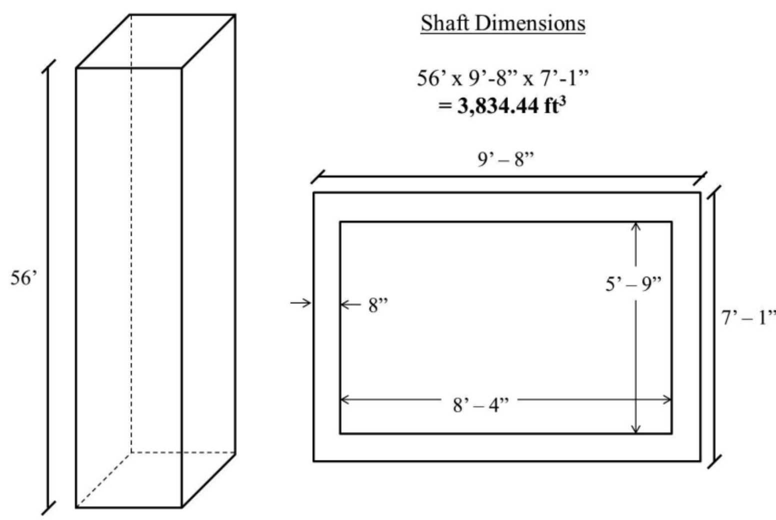


Figure 22: Dimensions for Elevator Shaft/Masonry Enclosure

In adherence with the International Code Council's requirements for Masonry Structures, Section R606.2.1 states that any load bearing wall needs to have a minimum thickness of eight inches (*ICC*, 2007). Therefore, masonry blocks with dimensions of 8"x8"x16" were selected for the design of this particular elevator shaft. With the interior dimensions of the shaft measuring 5'9" by 8'-4", the outer dimensions were then calculated to be 7'-1" by 9'-6" based on the size of the standard CMU blocks. These outside dimensions are the same size as the cuts that needed to be made in the existing concrete slabs. Based on tributary areas and concrete slab thickness, the slab load that needed to be carried by the CMU shaft was also determined. A totaled factored loading of 74 psi was calculated for the design stress in the CMU wall for this elevator system. The complete design calculation of the elevator shaft can be found in Appendix C.

7.3 Steel Frame Design for Additional Space

In order to perform a seismic analysis of the new building, the weight of the additional space must be known. Two different frames were designed: one for the sides of the addition parallel to the East and West sides of the existing building, and one for the two sides of the addition that meet the existing building. The placement of the columns was based on the location of classrooms and offices, as well as what was reasonable spacing in order to limit the depth of construction. The height of the first level was based on the height from ground level to where the current building would need to be met, which was about 11.25 feet. The heights of the second and third levels were chosen to match the ceiling heights of the two existing floors at 14 feet each. A schematic of the location of the new frames relative to the existing Kaven Hall is shown in Figure 23.

Figure 23: Location of New Steel Frames

The E-W frames extend the building outward toward Institute Park, and the existing walls in this direction will remain intact. The N-S frames were placed such that one is within the outermost wall, and the other connects the two E-W frames at the opposite end of the new wing. Since the existing interior wall parallel to the N-S frames has an opening leading to the current lobby, it is assumed that there is sufficient reinforcement to maintain that current opening, and therefore, additional steel are not needed within the footprint of the existing building. Sketches of the two frames designed in *RISA 2D* with their dimensions are shown in Figure 24 below.

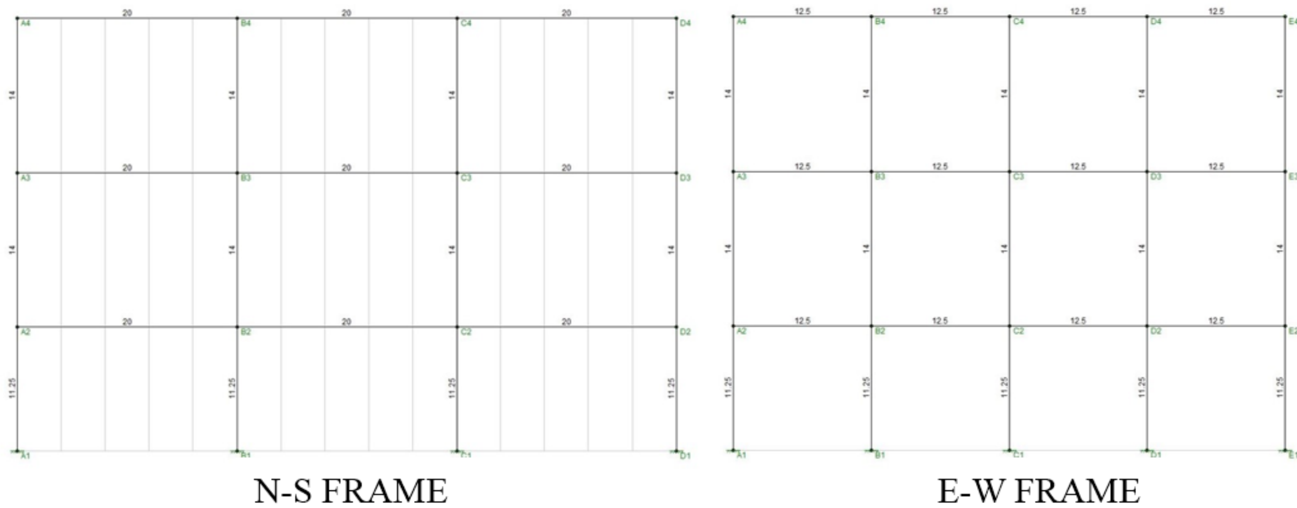


Figure 24: Steel Frame Designs for Additional Space

7.4 Seismic Analysis

Two different cases for seismic design were investigated. The first case considered the seismic behavior of the existing building and the proposed addition acting as separate structures. The second case evaluated the seismic behavior of the combined facility acting as one structure. This section discusses each of these cases and how they compare.

7.4.1 Case 1: Addition as a Separate Building

When the addition is treated seismically as a separate building, it must be able to sustain its associated seismic forces without any contribution from the existing building. In this case, the steel frames designed in Section 7.3 for the new addition for lateral load resistance should be located symmetrically about the center of gravity for the addition.

First, the design loads for the addition were determined. The Dead Load values for insulation, flooring, ceilings, and mechanical and electrical systems were approximated as a total of 10 pounds per square foot (psf). In addition, the dead load of the interior beams and girders was estimated at 10 psf for simplicity of the calculations. The live load was determined based on Kaven Hall's occupancy category, and the snow load was defined by snow load for Worcester given in *780 CMR*. Table 20 below displays all of the gravity loads for design of the additional space.

Table 20: Gravity Loads on Additional Space

Load Type	Load (psf)	Source
Dead Load – Insulation, flooring, and ceilings	5	Estimate
Dead Load - Mechanical/Electrical	5	Estimate
Dead Load – Interior Steel Bays	10	Estimate
Floor Live Load	100	ASCE 7
Snow Load	55	780 CMR
Exterior Masonry for Addition (Wall Area)	65	ASCE 7
Wall Partitions	10	Estimate
Metal Deck	10	ASCE 7
6" Concrete Slab	75	ASCE 7

Using Chapter 11 of *ASCE 7-10*, the seismic lateral loads at each story level of the frames were calculated. The layout geometry of the two frames resulted in equal gravity loads for the two different frames because they support similar tributary areas. First, the base shear was calculated for the frames.

Table 21 displays the values used to calculate the base shear.

Table 21: Base Shear Design Factors

Base Shear Calculation		
Tributary Area	Length x Trib. Width	1500
Importance Factor	I	1
Acceleration Factor	Sds	0.192
Resistance Factor	R (for steel)	3
Total Weight of Addition	W (kips)	330.2
	Base Shear (kips)	**21.1**

Using the base shear, the individual forces at each level were calculated. Each level was computed based on a fraction of the total base shear. The values Fx in Table 3 are the total seismic forces for each level in the N-S or E-W direction. Because there are two frames in each direction, the lateral forces on each level of each frame are actually half of Fx. The magnitudes of these seismic forces are displayed in Table 22. All calculations can be obtained from Appendix F.

Table 22: Seismic Forces on Each Floor

Level	**Story Ht (ft)**	**Wi (k)**	**hi (ft)**	**Wihi**	**Wihi/sumWihi**	**Fx (k)**	**Fx per frame (k)**
Roof	14.00	112.54	39.25	4417.11	0.73	15.40	**7.70**
Floor 2	14.00	45.08	25.25	1138.16	0.19	3.97	**1.98**
Floor 1	11.25	45.07	11.25	507.02	0.08	1.77	**0.88**
Ground	0.00						
Total		202.68		6062.28	1.00	21.13	

For each level of the two frames, factored distributed loads were calculated. Using the LRFD equation 1.2D+0.5L+0.2S+1.0E, the total gravity load for each floor (1.2D+0.5L+0.2S) in pounds per square foot was found. Using the tributary width of the frames, a distributed gravity load in kips per foot for each frame was calculated. Table 23 displays the distributed loads for each level of the front and side frames.

Table 23: Gravity and Lateral Loads on the Addition's Frames

Frame	Tributary Width (ft)	Level Number	Distributed Load (1.2D+0.5L+0.2S) (k/ft)	Seismic Load (k)
Front Frame	25	Floor 1	4.73	0.88
		Floor 2	4.73	1.98
		Roof	3.74	7.70
Side Frames	30	Floor 1	5.67	0.88
		Floor 2	5.67	1.98
		Roof	4.49	7.70

Figure 25 and Figure 26 display the N-S frame and E-W frame, respectively, with their applied forces in the software *RISA 2D* for analysis.

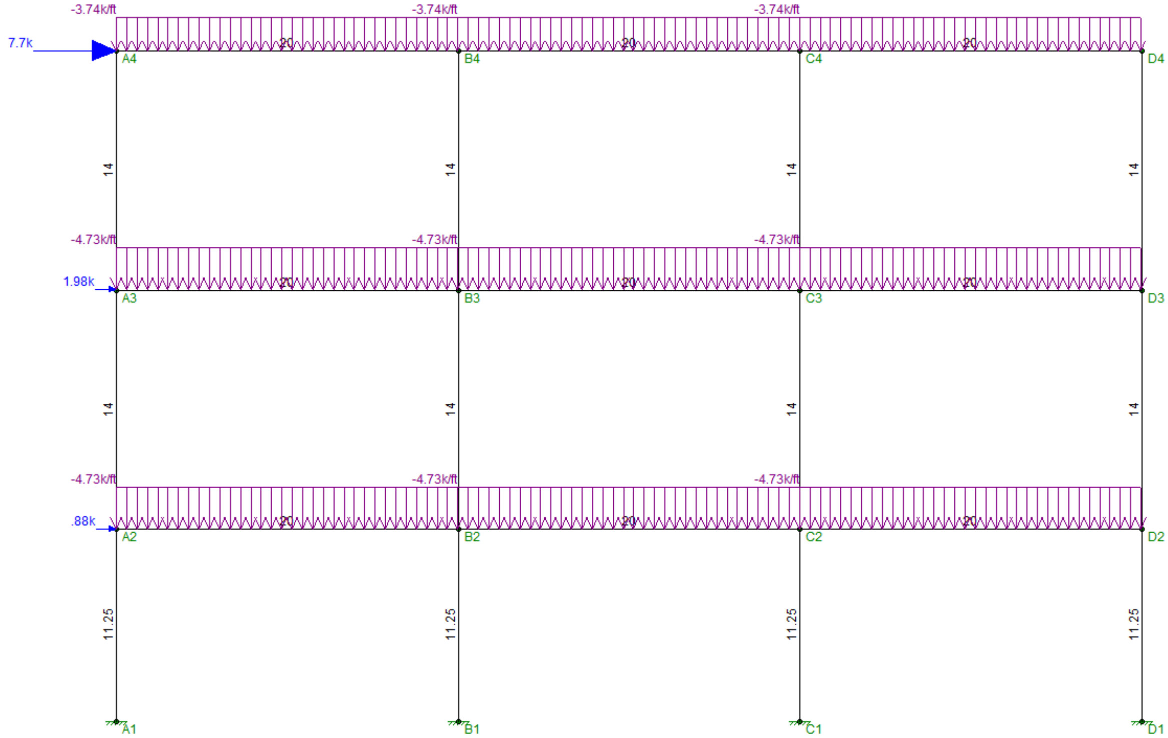


Figure 25: N-S Frame Model with Applied Loads

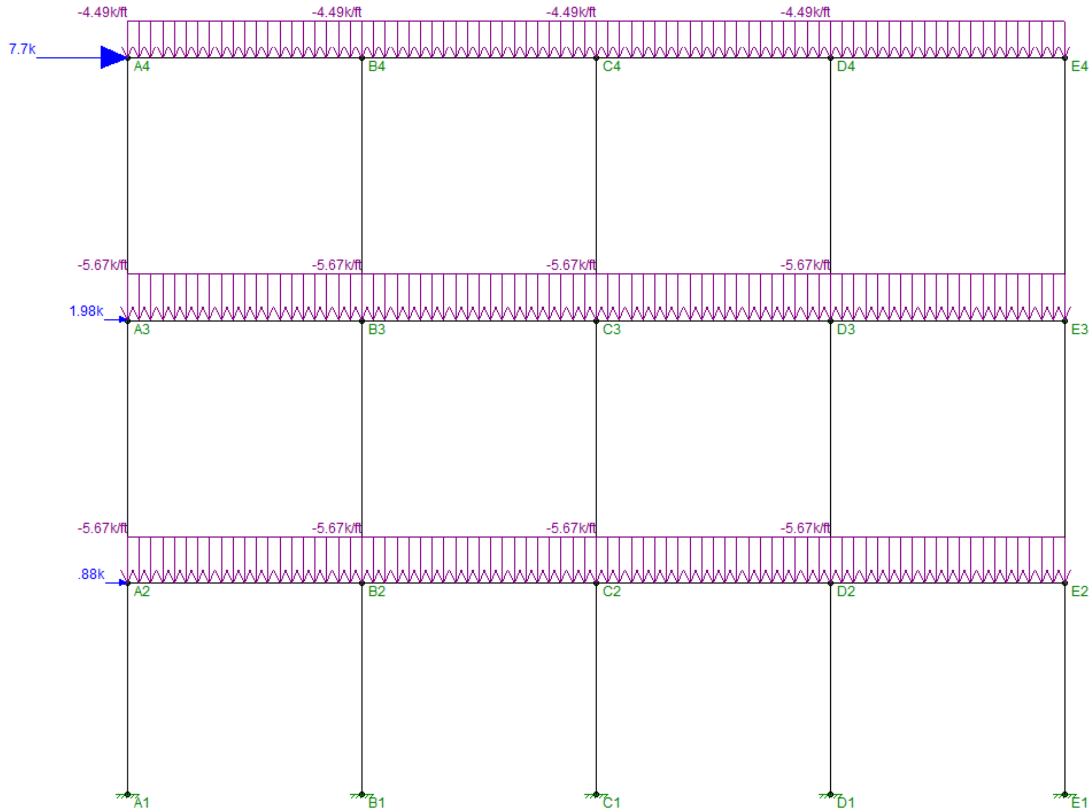


Figure 26: E-W Frame Model with Applied Loads

The Story Stiffness Method for frame stability was used to find acceptable column sizes for combined bending and axial effects. The design process typically involved completing multiple trials to ensure that the governing interaction equation H1-1a or H1-1b from *AISC Specification* was as close as possible to 1.0 without going over; however, the trials were done to make the interaction equation result as close to 0.5 as possible. This lower limit was chosen to reduce seismic drift and maintain physical separation between the seismic responses of the new addition and existing building. The results of multiple trials can be found in Appendix F. The chosen sizes from the structural analysis with the result from the interaction equation are displayed in Table 24.

Table 24: Column and Girder Sizes for Addition Steel Frames

Frame	Column Size	Girder Size	Interaction Equation Result
N-S Frame	W 12X50	W12x45	0.55
E-W Frame	W 12X50	W12x14	0.43

The column sizes for all of the frames were kept the same for consistency and constructability purposes. The investigation of alternatives for the E-W frame was stopped with an interaction value somewhat less than the anticipated target of 0.5 because the girder sizes were starting to become much smaller than the W12x50 column sizes, therefore W12x14 was chosen. The design of the frame was essential to determining the total weight of the additional wing so that the entire building frame could undergo a seismic analysis.

Next, the existing building was analyzed for its seismic capacity. Similar to the calculations in Section 7.3, the weight of the existing masonry building was used to calculate the base shear, and the total lateral loading at each floor was calculated. A Resistance Factor R of 1.5 for ordinary masonry structures was used. Table 25 below displays the values used to calculate the base shear.

Table 25: Base Shear Calculation for Existing Building

Base Shear Calculation		
Total Floor Area	Length x Width (ft^2)	9558
Importance Factor	I	1
Acceleration Factor	Sds	0.192
Resistance Factor	R (for masonry)	1.5
Weight of Building	W (kips)	4860
	Base Shear (kips)	**622**

For a multi-story building, the total load acting at any level is equal to the load applied at the level (Fx) plus the shear forces from all the overlying levels. The lateral story forces and total shear loads are displayed in Table 26.

Table 26: Lateral Force Distribution for Existing Building

Level	**Story Height (ft)**	**Wi from exist (k)**	**hi (ft)**	**Wihi**	**Wihi/sumWihi**	**Fx (k)**	**Shear (k)**
Roof	14	1764.97	39.25	69275.07	0.55	341.79	**341.79**
Floor 2	14	1570.55	25.25	39656.39	0.31	195.66	**537.45**
Floor 1	11.25	1524.25	11.25	17147.85	0.14	84.60	**622.05**
Ground	0						
Total		4859.77		126079.3	1	622.05	

For each wall (North, South, East and West), the distribution of the lateral forces to the piers for the three floors was calculated based on each wall's relative stiffness according to the reference, *Analysis and Design of Small Reinforced Concrete Buildings for Earthquake Forces*, published by PCA. A wall's relative stiffness is its stiffness compared to all other walls providing lateral resistance in the same direction. For example, the relative stiffness of the North wall at the third floor level is a fraction of the summation of the stiffnesses of the third floor North and South walls. The relative stiffness of each wall by floor is shown in Table 27.

Table 27: Relative Stiffness by Wall

Floor	North	South	East	West
Level 3	0.5	0.5	0.166	0.834
Level 2	0.5	0.5	0.166	0.834
Level 1	0.637	0.363	0.167	0.833

Next, in order to find the seismic force in each wall, an analysis by level was done. Using relative stiffnesses and P/delta, the center of rigidity was calculated. The center of rigidity was then compared to the location of the center of mass of the building to get its eccentricity. These values were used to calculate the seismic forces at each level by wall. This process was done for two directions: the N-S direction and the E-W direction. In these cases, the walls that are perpendicular to the direction of the seismic action will just have a torsional effect; however, walls parallel to the seismic action have both a base shear and torsional effect. The base shear values are a fraction of the lateral distribution force calculated earlier. Table 28 displays the force on each wall at each level for seismic actions in the N-S and E-W directions.

Table 28: Force Distribution by Wall and Seismic Action

Wall	**Level**	**V (k)**	
		N-S Seismic Action	**E-W Seismic Action**
North	Level 3	5.77	170.94
	Level 2	9.60	268.79
	Level 1	13.85	396.64
South	Level 3	5.77	170.94
	Level 2	9.60	268.79
	Level 1	7.88	225.61
East	Level 3	56.73	15.20
	Level 2	89.21	17.31
	Level 1	103.83	33.17
West	Level 3	285.06	76.38
	Level 2	448.24	86.97
	Level 1	518.22	165.56

In order to check that this design is in compliance with *ASCE 7*, the seismic deflections at each level were calculated. The allowable story drift, or cumulative deflection, for masonry shear wall structures is limited to a certain percentage of the story height, as explained in Section 7.4.3. Deflection values were checked for where the existing building meets the addition. For the steel frame, values at each level were obtained from the *RISA 2D* analysis software for the E-W frames. For the existing building, values were obtained from the analysis of the piers within the East Wall. The calculation of the deflection values required a deflection amplification factor Cd, which can be found in ASCE 7 Table 12.2-1. The C_d values for the existing building (masonry) and the proposed addition (steel) are 1.25 and 3, respectively. The resulting values for the predicted seismic deflections at these locations are shown in Table 29. The column titled "Allowable" contains the total allowable story drift for each level of the building according to *ASCE 7*.

Table 29: Case 1 Deflections by Level

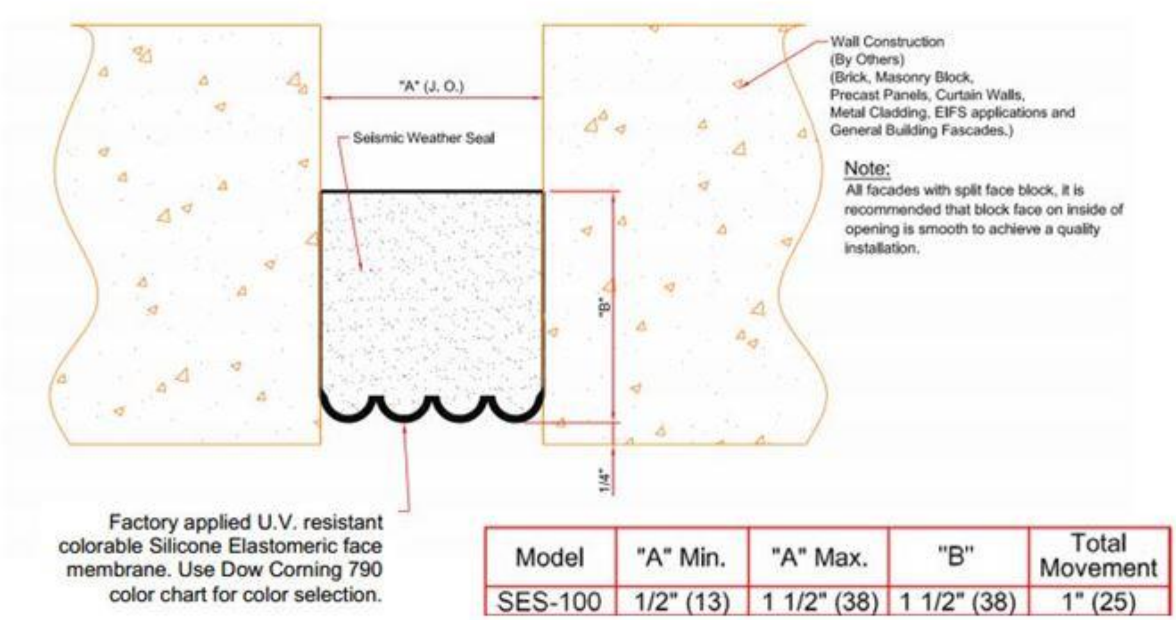
Level	Deflection (in)		
	Existing Building	Addition	**Allowable**
Roof	0.059	0.048	4.710
Level 2	0.116	0.009	3.030
Level 1	0.116	0.006	1.350

In order to prevent the existing building and the addition from striking against each other, the use of seismic separator joints are required. ASCE 7 Equation 12.12-2 establishes the minimum separation between the two adjacent structures. This equation therefore produces the minimum thickness of the separation joints. Table 28 displays the size of the joints required at each level.

Table 30: Required Structural Joint Thicknesses for Seismic Separation

Level	**Required Joint Thickness (in)**
Roof	0.08
Level 2	0.12
Level 1	0.12

NYSTROM Building Products, a company based in Minneapolis, manufactures seismic expansion joints for interior and exterior walls. Of their products, the minimum thickness for expansion joints was ½ of an inch. The product, *SES: Wall-to-Wall Exterior Seismic Compression Seal Expansion Joint System*, is a pre-compressed elastomeric coated expansion joint that can be used thermal movements occur or on applications where seismic movement is anticipated (Nystrom, 2013a, para. 2). For simplicity, this seismic joint model was chosen for the separation at each level. The thickness exceeds the minimum required thickness at all levels. A shop drawing of this product with its dimensions is shown in Figure 27.



Model	"A" Min.	"A" Max.	"B"	Total Movement
SES-100	1/2" (13)	1 1/2" (38)	1 1/2" (38)	1" (25)

Figure 27: SES Expansion Joint Shop Drawing (Nystrom, 2013b)

The nominal shear stress at each level for each wall was also calculated to check with the requirements set forth in Table 2109.2.1 of the *IBC*. These stresses and the allowable stress are shown in Table 31: Nominal Shear Stresses and Allowable Stress.

Table 31: Nominal Shear Stresses and Allowable Stress

Wall	Level	N-S direction			E-W direction			Allowable Stress (psi)
		V (k)	Area (in^2)	Calculated Stress (psi)	V (k)	Area (in^2)	Calculated Stress (psi)	
North	Level 3	5.77	43344.00	**0.13**	170.94	43344.00	**3.94**	10.00
	Level 2	9.60	86688.00	**0.11**	268.79	86688.00	**3.10**	
	Level 1	13.85	84537.00	**0.16**	396.64	84537.00	**4.69**	
South	Level 3	5.77	43344.00	**0.13**	170.94	43344.00	**3.94**	
	Level 2	9.60	86688.00	**0.11**	268.79	86688.00	**3.10**	
	Level 1	7.88	89082.00	**0.09**	225.61	89082.00	**2.53**	
East	Level 3	56.73	18144.00	**3.13**	15.20	18144.00	**0.84**	
	Level 2	89.21	36288.00	**2.46**	17.31	36288.00	**0.48**	
	Level 1	103.83	41814.00	**2.48**	33.17	41814.00	**0.79**	
West	Level 3	285.06	72576.00	**3.93**	76.38	72576.00	**1.05**	
	Level 2	448.24	145152.00	**3.09**	86.97	145152.00	**0.60**	
	Level 1	518.22	135352.63	**3.83**	165.56	135352.63	**1.22**	

7.4.2 Case 2: Addition and Existing Building acting as One Structure

When the existing building and addition act as one structure, steel frames must be provided to control the seismic performance of the combined facility. Therefore, in order to calculate the base shear for the entire building, the total weight used was the weight of the existing building plus the weights from the proposed addition. Table 32: Base Shear Calculation for Combined Existing and Addition below displays the values used to calculate the base shear.

Table 32: Base Shear Calculation for Combined Existing and Addition

Base Shear Calculation			
Factors		N-S Frames	E-W Frames
Trib. Area	Length x Trib. Width (ft^2)	1500	1560
Importance Factor	I	1	1
Acceleration Factor	Sds	0.192	0.192
Resistance Factor	R (for steel)	3	3
Weight on Frame System	W (k)	1717.15	1740.55
Base Shear	**V (k)**	**131.03**	**132.76**

The process from Section 7.4.1 was repeated to calculate the total lateral loads acting at each level. Since there are two frames in each direction, the lateral loading per frame is half of the calculated load. These total loads are displayed in Table 33: Load Distribution by Level for Combined Existing and Addition.

Table 33: Load Distribution by Level for Combined Existing and Addition

	Level	Story Height (ft)	Wi from exist (k)	Total Wi (k)	hi	Wihi	Wihi/sumWihi	Fx (k)	**Fx/frame (k)**
N-S Frames	Roof	14.00	475.69	588.23	39.25	23087.94	0.48	63.40	**31.70**
	Floor 2	14.00	643.88	688.96	25.25	17396.13	0.36	47.77	**23.89**
	Floor 1	11.25	597.58	642.65	11.25	7229.83	0.15	19.85	**9.93**
E-W Frames	Roof	14.00	485.29	597.83	39.25	23464.74	0.49	64.44	**32.22**
	Floor 2	14.00	650.78	695.86	25.25	17570.35	0.37	48.25	**24.13**
	Floor 1	11.25	604.48	649.55	11.25	7307.46	0.15	20.07	**10.03**

When the existing building and addition are treated as one building, the building's floor area and gravity loads increased, and therefore, the lateral force at each level increased. This extra weight caused the need for steel frames to be added within the existing building for both the N-S direction and E-W direction. Two sets are needed for resistance of seismic forces from either direction. For both directions, the steel frames were placed symmetrically about the center of mass of the total building. The center of mass on the building's footprint is displayed in Figure 28.

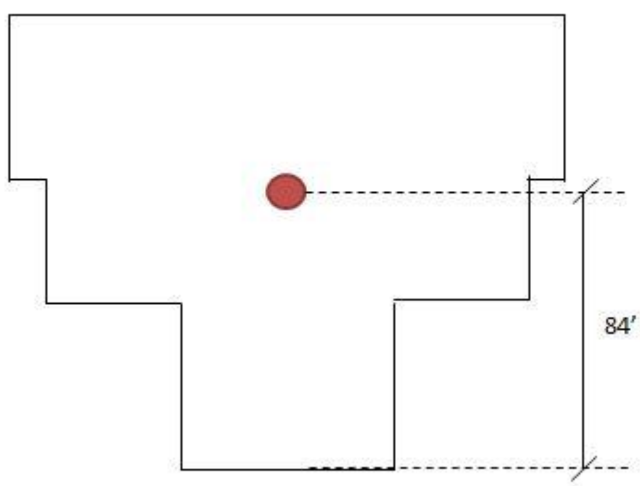


Figure 28: Center of Mass of Kaven Hall

The added frames were also strategically placed in the building such that they were not disruptive to the spatial layout or the interior aesthetics. Figure 29 shows the locations of these frames on a sketch of the floor plans.

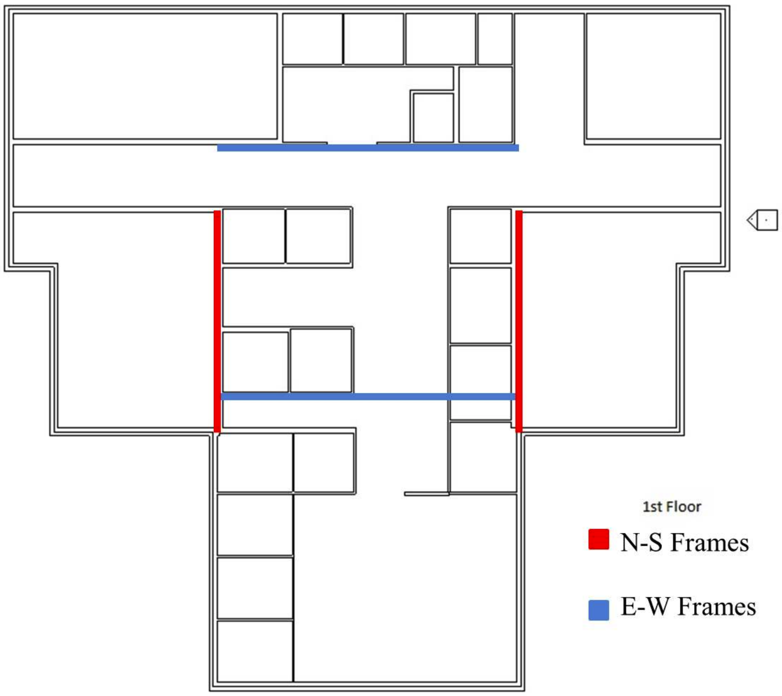


Figure 29: Case 2 Additional Frame Locations

For the N-S direction, the frames were placed as a continuation of the side frames of the additional wing in order to reinforce the walls. These are centered symmetrically about the x-component of the center of mass of the building. For the E-W direction, the y-component of the center of mass is located about 84 feet from the front of the addition. Two frames were placed symmetrically about this point; one could be hidden in the partition walls of the main office, and the other could be hidden in the partition walls of the offices and men's bathroom in the renovated space. These locations were selected to not obstruct any views in lecture halls or have columns in the middle of hallways. The frame designs were kept the same as the front and side frames of the addition shown in Section 7.4.1. This helped to ensure that for the E-W frames, there were openings between the columns large enough for doors and hallways.

The total weights on each floor and the seismic forces at each level were calculated using the tributary areas for each set of frames, similar to the calculations for the steel frames for the additional wing. These values are shown in Table 34 below.

Table 34: Axial and Lateral Forces on Case 2 Additional Frames

	Level	Axial (k/ft)	Lateral (k)
N-S FRAMES	Roof	15.86	31.70
	Level 2	21.46	23.89
	Level 1	19.92	9.93
E-W FRAMES	Roof	18.30	32.22
	Level 2	24.76	24.13
	Level 1	22.98	10.03

RISA 2D models were created as in Section 7.3 and analyses were completed. Figure 30 and Figure 31 display the models for the N-S frames and E-W frames, respectively.

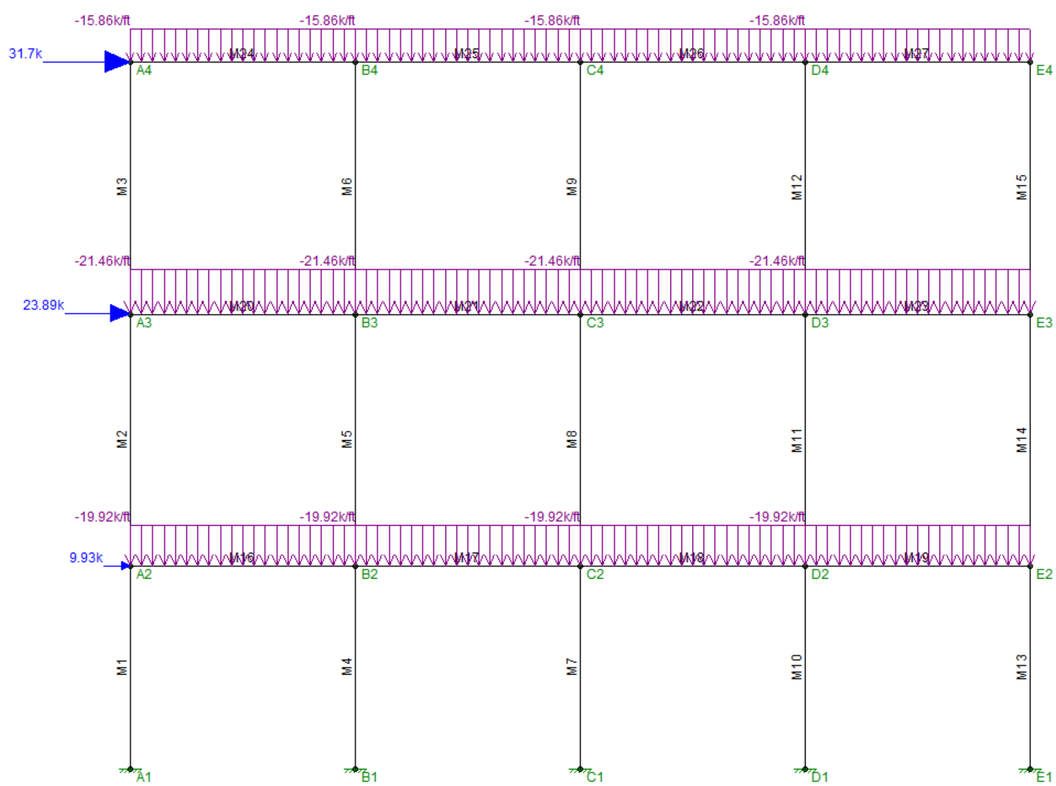


Figure 30: RISA 2D Model of N-S Additional Frames

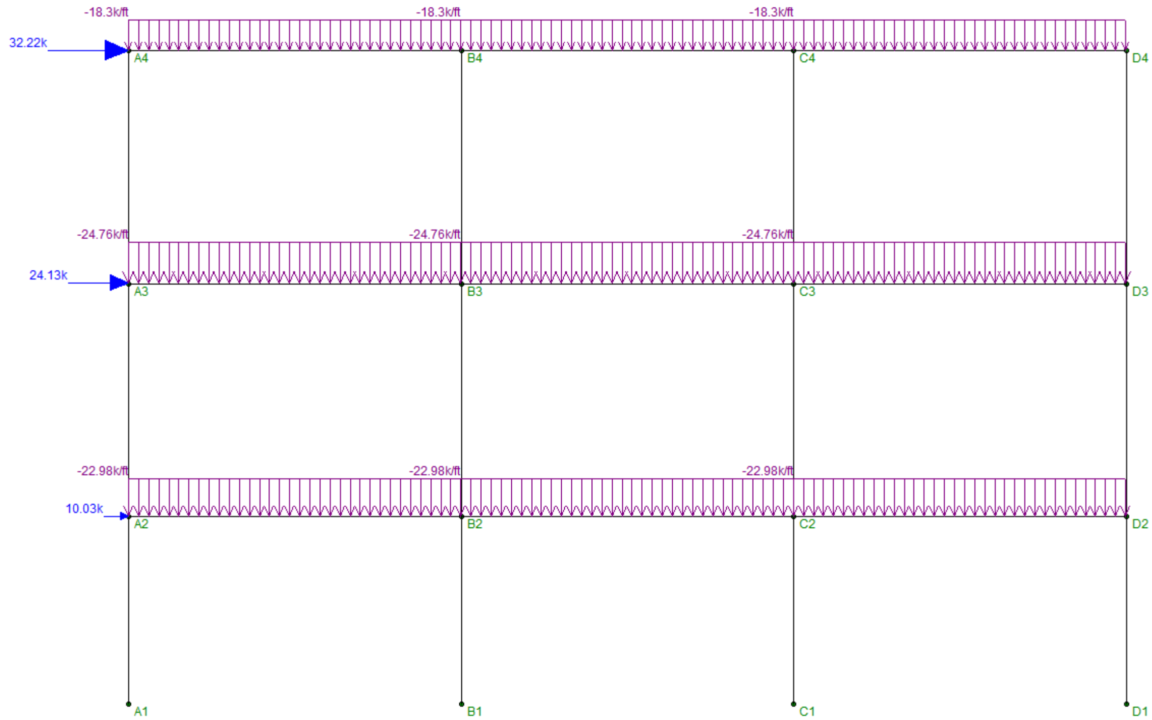


Figure 31: RISA 2D Model of E-W Additional Frames

The Story Stiffness Method for frame stability was used to determine acceptable column sizes for combined bending and axial effects. It is important to note that the trials for the column and girder sizes were governed by the deflection requirements set forth in *ASCE 7* as opposed to the interaction equation. The deflection results and the code requirements are compared below in Section 7.4.3. The chosen sizes from the structural analysis with the result from the interaction equation are displayed in Table 35.

Table 35: Column and Girder Sizes Chosen for Case 2 Additional Frames

Frame	Column Size	Girder Size	Interaction Equation Result
N-S Frames	W14X132	W14X48	0.46
E-W Frames	W14X132	W14X68	0.90

The deflections at each level were then calculated. For the two steel frames, values at each level were attained from the *RISA 2D* analysis software. The deflections at these locations are shown in Table 36.

Table 36: Case 2 Deflections by Level

Level	Deflection (in)		
	NS Frames	EW Frames	**Allowable**
Roof	3.030	4.350	4.710
Level 2	2.214	2.904	3.030
Level 1	0.717	0.933	1.350

7.4.3 Discussion of Results

While both cases seem plausible, it is important to confirm that the results from the analyses comply with all code requirements. The deflections for each floor for both cases were compared to the limiting values given in *ASCE 7*, which states that the allowable story drift, or cumulative deflection, for Occupancy Category II masonry shear wall structures is 1% of the story height. The results from Case 1 and 2 with the predicted and allowable deflections for each floor are shown in Table 37.

Table 37: Comparison of Case 1 and 2 Cumulative Deflection Results to Allowable

	Deflection (in)				
Level	Case 1		Case 2		**Allowable**
	Existing	Addition	NS Frames	EW Frames	
Roof	0.059	0.048	3.030	4.350	4.710
Level 2	0.116	0.009	2.214	2.904	3.030
Level 1	0.116	0.006	0.717	0.933	1.350

Both cases are compliant with the allowable deflections set forth in *ASCE 7*; therefore, both cases can be considered for the structural design of Kaven Hall. Of the two cases, Case 2 will require more materials because additional steel frames will need to be added within the existing building. The need for more materials will result in a higher project cost. Case 1 considers the existing building and the proposed addition as seismically separate structures and does not require extra reinforcement frames. Additionally, Table 31 in Section 7.4.1 shows that the allowable shear stress of 10 psi from *IBC* has been met. Therefore, Case 1 makes the construction process simpler because the new steel frames do not need to be integrated within the footprint of the existing building.

8.0 Project Management

According to the Project Management Institute (PMI), project management is defined as, "the application of knowledge, skills and techniques to execute projects effectively and efficiently (PMI, 2014)." Scheduling and Cost Analysis are two critical aspects of project management that are interconnected in their impact on the level of success of a project throughout its duration. Preliminary schedules and early budget estimates are important in ensuring that all project participants are fully aware of the financial and time line projections in the event that alterations and changes need to be made. The typical process that a project follows in the construction industry can be seen in Figure 32 below. Design changes made earlier in the planning phase result in less costly consequences and have limited impact on the scheduled completion date. In the proposed renovation of and addition to Kaven Hall, scheduling is also very important due to staging construction around the typical academic calendar. Cost and budgeting is also essential, as WPI may wish to administer a value engineering analysis to save money and explore alternative design options. This is especially key when considering the higher initial costs associated with green building technology and subsequent LEED requirements.

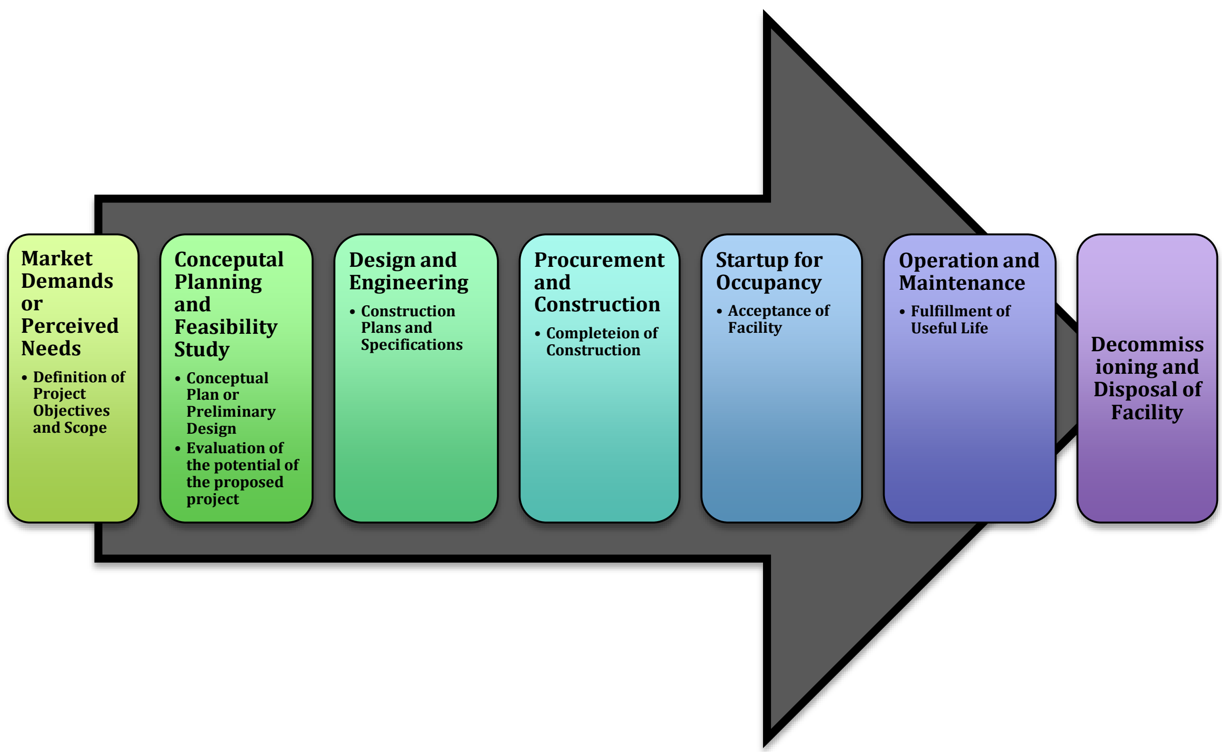


Figure 32: Typical Construction Project Process

8.1 Scheduling

The first step in creating a schedule is to determine how detailed and specific the list of activities will be. In preliminary schedules, masterformat and uniformat codes are used to create schedules that are broader in detail in which the most time-consuming and critical activities are included. As the project progresses farther into the design phase, the schedule will continue to develop with the addition of more detailed sub activities. This makes estimating the total project duration easier and more accurate because there is more information available to the project team. Projects are usually categorized as Level 0, Level 1, Level 2, or Level 3 based on the amount of detail associated with the different phases and activities. Table 38 below shows how these different levels are broken down in the construction industry (CADD Centre).

Table 38: Levels of Creating a Project Schedule

Levels of Creating a Project Schedule		
Level 0	Major Milestones Schedule	~ Includes major/key milestones on a calendar program level ~ Graphical representation of the overall project schedule time-line
Level 1	Project Summary Schedule	~ Summary of entire project on a time scaled calendar ~ Building block for all subsequent schedules
Level 2	Project Phase Summary Schedule	~ Breakdown of Level 1 schedule ~ Timeline and status of various phases of work as progress is reported
Level 3	Detail Schedule	~ Further detailing of Level 2 schedule ~ Detail plans of how to accomplish each of the phases and activities ~ Used by project team to review, plan, analyze, and control the project ~ Shows logical relationships between activities and a critical path

In the Kaven Hall project, a Level 1 schedule was developed to provide a summary of the entire project that also showed the activities on a time scaled calendar. There were also aspects associated with a Level 3 schedule that were included in this particular schedule such as the establishment of logical relationships and a critical path.

To begin the scheduling process, the assembly code format was used as a basis to develop approximately 25 activities/groups of activities that would later be sequenced in a systematic and logical order. An outline specification was used to help create the list of main activities and the sub activities that were included in each main activity. This specification was also later used to develop the cost estimate by displaying associated costs for each activity in the same worksheet.

Upon completing the initial activities list, it was crucial to make a plan and set out a list of priorities that should be considered for the duration of the project. The more realistic the expectations and timeline, the less likely there will be difficulties with finishing activities on time. This is especially important when staging construction and trying to work around an academic calendar on a college campus. An area of significant emphasis in this project was the desire to keep Kaven Hall open and in operation for as much time as possible due to the problems and inconveniences associated with relocating offices and classrooms during the construction process. It was decided that activities that overlapped in both the renovation of the existing building and the construction of the new addition would be scheduled for a time when school was not in session. Therefore, the idea of repetitive construction could be used to complete the tasks in both areas of the building at the same time or in succession with limited disruption to the day-to-day campus activities.

For the renovation, it was also important to understand that interior construction deemed as disruptive, due to noise and vibrations, would be completed outside of the 8am-5pm-time period on weekdays. This left early mornings, nights, weekends, and term breaks for this type of work to be completed. Unfortunately, with family dwellings and other businesses located in close proximity to Kaven Hall, early mornings and nights were less realistic options than the other aforementioned alternatives. In order to avoid delays, careful planning would be necessary to schedule non-disruptive activities during times when students and staff members occupied the building as long as there were no associated safety and health risks. This way, the project could stay on track without delays resulting from staging issues.

There was more freedom with scheduling the work in the addition. Although noise was still a factor due to the nearness of classrooms and offices, more work could be completed during the typical workday because the area will be completely closed off to students and staff. In order to help keep the schedule on track and finish the project in a timely manner, repetitive construction was used as much as possible. This meant that activities such as MEP rough-in and interior finishes would be completed on each floor and in each area of the building in succession, thus allowing for activities to progress as quickly as possible without losing quality. Also, by setting an overall completion date near the end of the summer, the building could be fit for occupation before it was actually turned over to the college. Final punch list items, commissioning requirements, and inspections could be completed after the building reached the point of substantial completion and an occupancy permit was issued. It was of critical importance that the set deadline was met. If it were not, classes that were scheduled in the new wing and professors who would have already packed up their current offices to move into the new location would have limited alternatives for temporary space.

8.1.1 Schedule Considerations

There were certain considerations that needed to be taken into account when scheduling many of the activities of the Kaven Hall project. In addition to the staged construction used to coincide with the Institute's academic calendar, another critical factor to consider is weather and its implications for building construction, especially in the New England region where seasonal weather often results in delays and setbacks (Construction Engineering, 1991).

The following three considerations were of the utmost importance in this project.

1) Do not start construction before early Spring (mid-March)
    a. Difficulty associated with earthwork in frozen ground
    b. Undesirable working conditions for laborers due to cold weather
2) Building Enclosure must be completed by late fall (end of Nov)
    a. Allows for interior work to continue during winter months in a heated and moisture protected environment
3) Concrete casting, fireproof spraying, and masonry work should not continue into cold weather months
    a. Above freezing temperatures are a requirement for accurate setting and curing

By scheduling the project in accordance with these parameters, delays occurring as a direct result of weather conditions could be drastically limited. In every project there will undoubtedly be events that happen that will causes setbacks such as unseasonable precipitation and late material deliveries, so it is critical to plan and account for these possibilities in advance as much as possible. As a result, management personnel, laborers, and owners will all be more likely satisfied with the final outcome and project turnover.

8.1.2 Activity Logic

After developing a list of activities that would be included in the construction schedule, durations were estimated and predecessors and successors were assigned to each activity. Following a Prototype Construction Duration Estimating System (CODES) guideline developed by the US Army Corps of Engineers (Construction Engineering, 1991), the number of weeks associated with each activity was estimated as well as typical predecessors and successors. For activities not included in the CODES guideline, such as stair construction, the *RS Means Building Construction Cost Data* reference was used to determine the daily output of work performed by a crew of laborers to complete a specific task.

Using the data provided in the CODES guideline as a basis, lag times were also assigned to certain activities such as placing concrete decks and interior finishes on each of the floors. Lag times are necessary with certain activities to allow for setting and curing of materials or to allow for multiple crews to move from area to area based on the work they need to perform. For instance, if an electrical crew begins work on the third floor and finishes their portion of work in one week, the start of the same type of work on the second floor should have a lag time of one week. Therefore, even though the entire duration of interior finishes on the third floor might be five weeks, the other finishes such as plumping rough-in, painting, and floor finishes do not need to be completed before finish work can begin on a different floor.

Table 39 below displays how the activities from the outline specification were divided and grouped into different schedule activities, the estimated duration and lag time of each activity, and whether the activity was related to the renovation or addition construction.

Table 39: Schedule Activities, Durations, and Lag Times

Schedule Activity	Associated Subactivities from Outline Spec	Duration (Weeks)	Lag Time (Weeks)	Renovation Activity	Addition Activity
Start		0	0	✓	✓
Mobilization		2	0	✓	✓
Site & Foundation	Site Work	5	0	✓	✓
	Standard Foundation				✓
Erect Steel Frame	Seismic Frames	4	0		✓
Erect Roof Frame	Roof Construction	1.5	0		✓
Stair Construction	Stairs	3	0	✓	✓
Roofing	Roof Coverings/Openings	2	0		✓
Install Elevator	Elevator	12	0	✓	
Place Concrete Deck	Slab on Grade	3	3		✓
	Floor Construction				✓
Fireproofing	Floor Construction	4	2		✓
Rough-In	Electrical (such as embedded conduit)	3	2	✓	✓
Enclosure	Exterior Walls	9	2		✓
	Exterior Windows				✓
	Exterior Doors			✓	✓
Interior Finishes 3rd/2nd/1st Floors	Partitions	3rd = 5 2nd = 8 1st = 9	3rd = 0 2nd = 1 1st = 2	✓	✓
	Electrical			✓	✓
	Plumbing			✓	✓
	HVAC			✓	✓
	Fire Protection			✓	✓
	Fittings			✓	✓
	Floor Finishes			✓	✓
	Ceiling Finishes			✓	✓
	Interior Doors & Finishes			✓	✓
	Fixed Furnishings			✓	✓
	Movable Furnishings			✓	✓
Clean-Up		5	0	✓	✓
Demobilization		2	0	✓	✓
Finish		0	0	✓	✓

By using *Primavera P6* scheduling software, all the aforementioned information could be entered into one database. This was extremely helpful in creating a visual of the project schedule and exploring the impact of different start dates. Using the 'run schedule' tool, it was very easy to change and update information such as lag times and the start dates. Anytime a change was considered, the schedule was re-run and all the information updated in seconds. The following figures (Figure 33, Figure 34, and

Figure 35) display the different types of information outputted from the software including the activity table, Gantt chart and Critical Path Method (CPM) diagram. The CPM diagram displayed in

Figure 35 is a replicated version of the one displayed by Primavera due to size constraints. The red arrows represent the critical path.

Activity ID	Activity Name	Original Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float
KHMQP	KavenHallMQP	42w	31-Mar-14	16-Jan-15	31-Mar-14	16-Jan-15	0w
A1000	START	0w	31-Mar-14		31-Mar-14		0w
A1010	Mobilization	2w	31-Mar-14	11-Apr-14	31-Mar-14	11-Apr-14	0w
A1020	Site and Foundation	5w	14-Apr-14	16-May-14	14-Apr-14	16-May-14	0w
A1030	Erect Steel Frame	4w	19-May-14	13-Jun-14	19-May-14	13-Jun-14	0w
A1080	Place Concrete Deck	3w	09-Jun-14	27-Jun-14	09-Jun-14	27-Jun-14	0w
A1040	Erect Roof Frame	2w	16-Jun-14	25-Jun-14	10-Sep-14	19-Sep-14	13w
A1090	Fireproofing	4w	23-Jun-14	18-Jul-14	23-Jun-14	18-Jul-14	0w
A1050	Roofing	2w	25-Jun-14	09-Jul-14	22-Sep-14	03-Oct-14	13w
A1110	Enclosure	9w	07-Jul-14	05-Sep-14	07-Jul-14	05-Sep-14	0w
A1060	Stair Construction	3w	09-Jul-14	30-Jul-14	06-Oct-14	24-Oct-14	13w
A1100	Rough-In	3w	21-Jul-14	08-Aug-14	18-Aug-14	05-Sep-14	4w
A1070	Install Elevator	12w	30-Jul-14	22-Oct-14	27-Oct-14	16-Jan-15	13w
A1120	Interior Finishing 3rd Floor	5w	08-Sep-14	10-Oct-14	08-Sep-14	10-Oct-14	0w
A1130	Interior Finishing 2nd Floor	8w	15-Sep-14	07-Nov-14	15-Sep-14	07-Nov-14	0w
A1140	Interior Finsihing 1st Floor	9w	29-Sep-14	28-Nov-14	29-Sep-14	28-Nov-14	0w
A1150	Clean-Up	5w	01-Dec-14	02-Jan-15	01-Dec-14	02-Jan-15	0w
A1160	Demobilize	2w	05-Jan-15	16-Jan-15	05-Jan-15	16-Jan-15	0w
A1170	FINISH	0w		16-Jan-15		16-Jan-15	0w

Figure 33: Primavera (P6) Activity Table for Kaven Hall Project

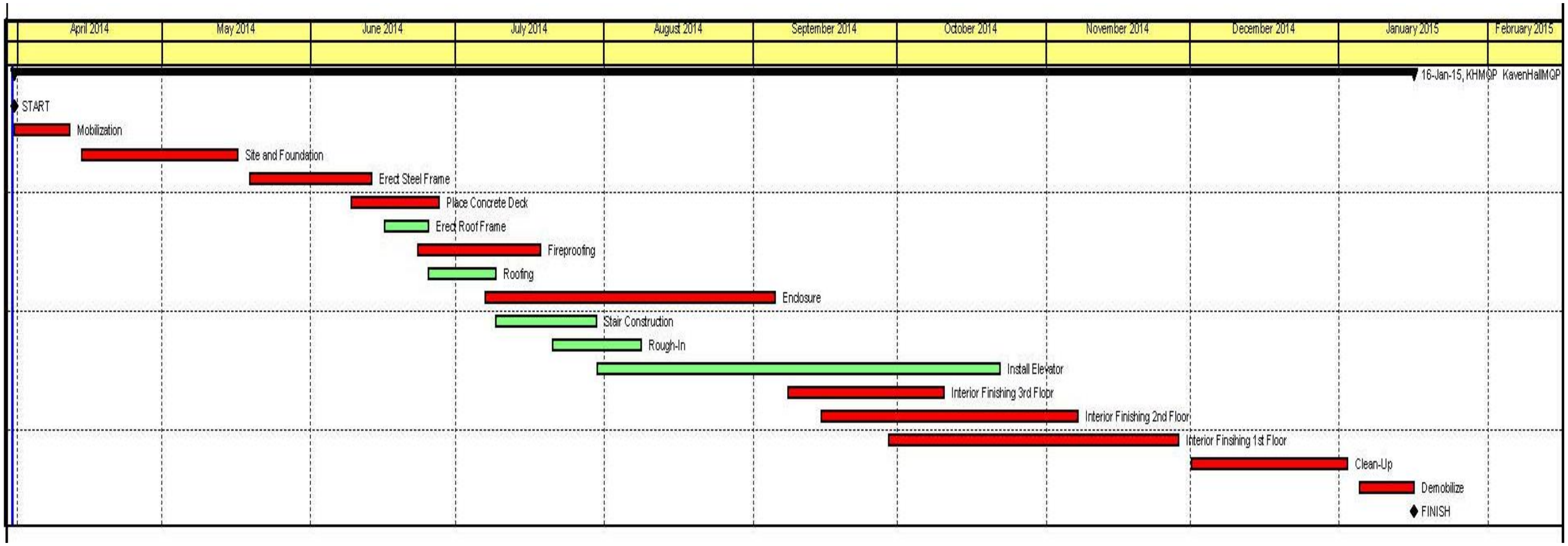


Figure 34: Primavera (P6) Gantt Chart for Kaven Hall Project

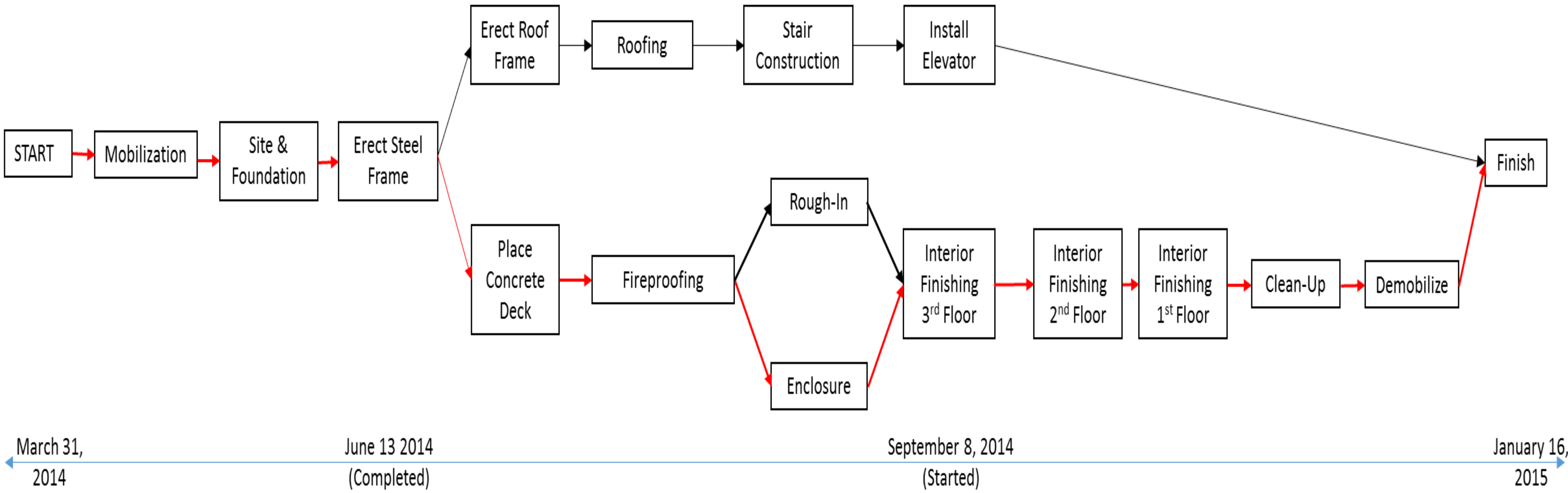


Figure 35: CPM Diagram for Kaven Hall Project

Several key pieces of information were gained from the scheduling run in *Primavera.* It was found that the Kaven Hall Renovation and Addition would take a total of 42 weeks, or approximately 10.5 months. Also, for a start date of Monday, March 31, 2014, the early finish date, assuming no time delays on the critical path, would be January 16, 2015. Moreover, by using a start date of March 31, 2014, all of the scheduling constraints discussed in Section 8.1.1 (regarding the time of year that activities could or could not happen) were also met.

Although this schedule was developed based on early estimates, it is a solid baseline that could be used by the construction team and owners/owner's representatives during the feasibility phase of the project planning. Its value lies in outlining the major areas of work and providing a sense of proportion for their time for completion. If the schedule meets the needs of the owner, then the rest of the feasibility study can continue as planned. If not, changes can either be made to the design of the project can be put off until a later time.

8.2 Cost Estimate

Along with the schedule, knowing a project's cost is essential to determining the feasibility of the project. The cost of materials, labor, and other aspects of the project must be reasonable in order for the construction's outcomes to be worthwhile. The outline specification that was developed as the first step of the scheduling phase was also used as initial input to the cost estimating process. Assembly sections corresponding to different phases of the construction process, such as the superstructure, finishes, and site work, were used to simplify the outline specification. Square footage and linear footage costs as well as lump sum estimates were then used to determine the cost for each of the activities/group of activities associated with the renovation of the exiting building and the additional of the new wing. A model of a 2-floor classroom in *RS Means* was used to compare the cost per square foot for the Kaven Hall project. For activities not included in this model such as fixed and movable furnishings, other models such as mid-rise office buildings were referenced due to their level of similarity to the proposed Kaven Hall design.

By comparing the cost per square foot with the models in *RS Means,* a new cost per square foot was calculated for the Kaven Hall project. This cost per square foot includes construction activities. The list of cost items and their corresponding costs per square foot as well as general conditions, architect's fees, and the location factor are listed in Table 40 below.

Table 40: Assembly Section Breakdown and Corresponding Activity Costs

	Assembly Sections		Description	Model Cost per SF	New Cost per SF	+/- change
A	SUBSTRUCTURE	Foundations	Standard Foundation	0.63	0.62	-0.01
			Slab on Grade (SOG)	2.48	1.79	-0.69
B	SHELL	Superstructure	Floor Construction	7.23	4.82	-2.41
			Roof Construction	4.00	2.67	-1.33
			Seismic Frames	0.00	2.46	2.46
		Exterior Enclosure	Exterior Walls	8.89	18.07	9.18
			Exterior Windows	0.00	9.20	9.20
			Exterior Windows	4.07	2.82	-1.25
			Exterior Doors	0.00	0.35	0.35
				0.66	0.44	-0.22
		Roofing	Roof Coverings/Openings	2.74	8.23	5.49
C	INTERIORS	Interior Construction	Partitions	7.23	3.78	-3.45
			Interior Doors & Finishes	5.27	5.27	0.00
			Fittings	4.76	1.24	-3.52
		Stairs	Stair Construction	3.00	3.69	0.69
		Interior Finishes	Wall Finishes	3.74	3.74	0.00
			Floor Finishes	4.86	4.86	0.00
			Ceiling Finishes	6.57	6.57	0.00
D	SERVICES	Conveying	Elevator	3.10	3.65	0.55
		Plumbing		18.81	18.81	0.00
		HVAC		19.00	19.00	0.00
		Fire Protection		3.30	3.30	0.00
		Electrical		24.62	24.62	0.00
E	FURNISHINGS & EQUIPMENT	Furnishings	Fixed Furnishings	0.00	2.92	2.92
				0.00	1.82	1.82
			Movable Furnishings	0.00	0.46	0.46
G	SITEWORK		Includes: Clearing & grubbing, site water & fire, site sanitary installation, Landscape maintenance, granite curbs, irrigation system, turf & grass, storm piping, temporary partitions, etc…	0.00	3.76	3.76

By taking the difference between the model square footage cost and the new square footage cost (Kaven Hall project) for each activity, a summation can be found, that when added to the total model square footage cost results in the square footage cost for the combined renovation of the existing building and the addition of the new wing. This cost was then multiplied by factors such as the square footage of the building, the general conditions and architect percentage fees, and the location factor for Worcester, MA. This gives the total project cost, which can again be divided by the square footage of the building to determine the cost per square foot for the entire project. This number is often useful in helping to compare the costs of similar projects of varying sizes.

Table 41 summarizes the calculations and costs for the entire proposed Kaven Hall project based on the information provided in Table 40 above.

Table 41: Summary of Kaven Hall Project Costs

Kaven Hall Project Costs		
Model Cost	$	130.27
Summary of Changes to Model Cost	$	24.00
Adjusted SF Cost	$	154.27
Building Area - Renovation and Addition (SF)		38,000.00
Building Area * Adjusted SF Cost	$	5,862,196.23
General Conditions (25%)	$	1,465,549.06
Subtotal - Construction	$	7,327,745.29
Architects Fee (5%)	$	366,387.26
Subtotal - Design and Construction	$	7,694,132.55
Location Modifier		1.10
Local Replacement Cost	$	8,463,545.81
Total Building Sq. Ft. Cost	$	222.72

In order to provide the project management team and the owner with a visual representation of the cost analysis, a pie chart was developed that easily depicts the budget distribution. The Shell, Interior, and Service related activities were the three areas to which a majority of the budget was allocated. Figure 36 below shows the overall budget distribution plus the individual breakdown of the activities comprising the Interiors section. Figures like this one can be manipulated in numerous ways as a tool to provide management personnel and owners with different types of information and comparative analyses, including what-if scenarios and benchmarking.

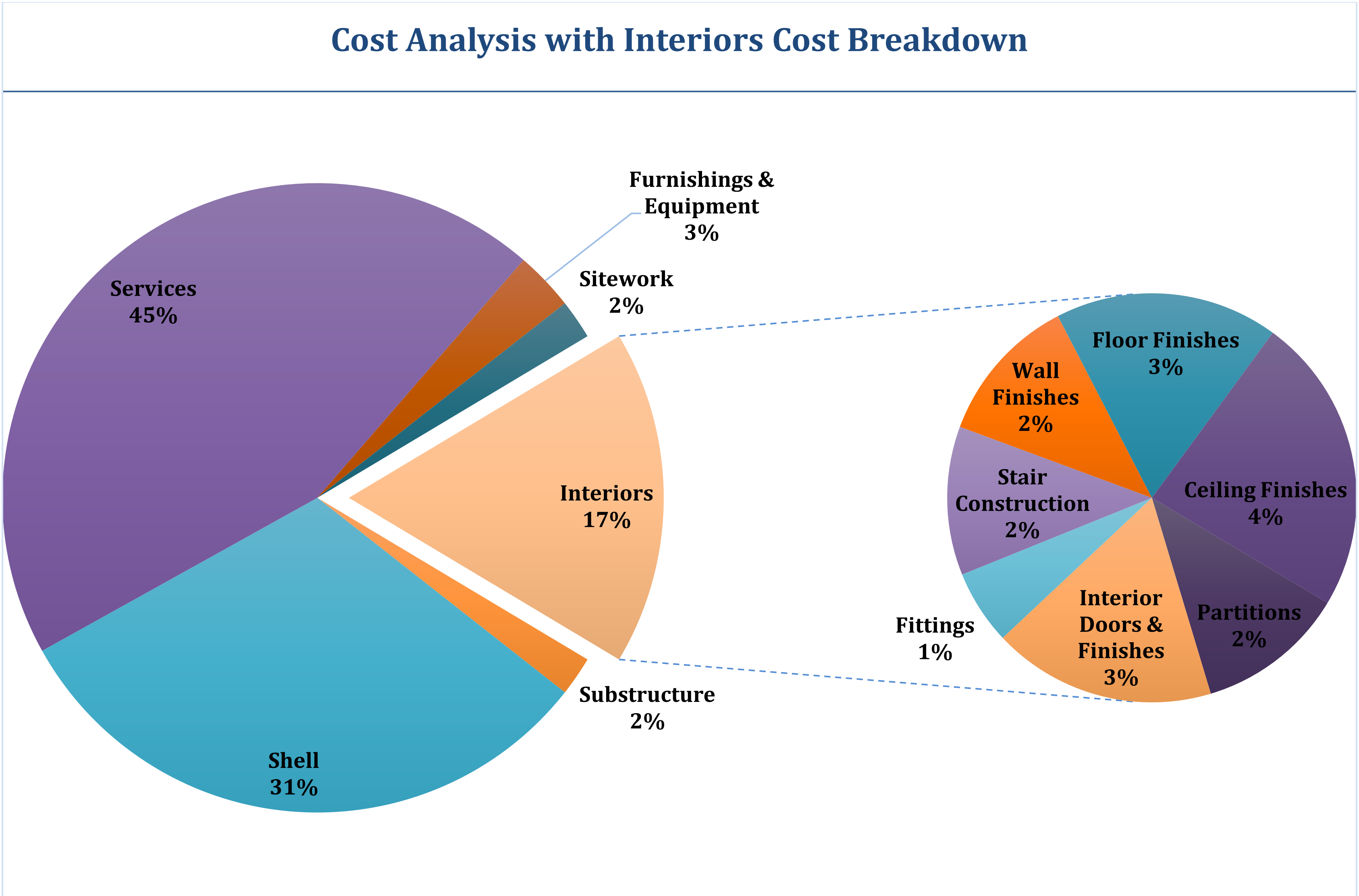


Figure 36: Cost Analysis with Interiors Cost Breakdown

9.0 Conclusions

The main goal of this project was to determine the most satisfactory design for providing additional spaces to Kaven Hall while also remaining conscious of the cost and environmental impacts that would result from the project. Interviews with WPI staff members and the review of applicable building code provisions provided critical insight and information needed to complete an evaluation of three different design options. Based on a set of criteria that included the amount of space provided and the feasibility of each alternative, an additional wing was found to be the most satisfactory option out of the possible alternatives.

Analyses of various building and design codes provided the information necessary to design both a renovation of the existing Kaven Hall building and the new wing. Egress improvements in the renovation consisted of new stairways and the installation of an elevator, which were defined to meet current building code provisions. The proposed layouts for the first and second floor of the new facility are shown in Figure 37. In the addition, an analysis of gravity and seismic loads was completed in order to design the structural steel frames. Two seismic cases were then evaluated to determine if the seismic design of the additional wing and existing building should be integrated into one structure, or detailed for two independent structures. Based on cost implications and overall structural integrity of the new facility, it was determined that the building would be designed as two separate structures. Finally, both a cost breakdown and schedule simulation were completed as part of an initial feasibility study of the proposed facility. The new addition will house classroom, office, and meeting spaces, while the renovations will add an elevator and new computer laboratory and classroom space; no physical laboratory facilities will be included. Based on preliminary estimates, the renovation of and addition to Kaven Hall was projected to take approximately 10.5 months and cost just under $8.5M.

From the research and calculations that led to these conclusions, recommendations were made to assist WPI in making a well-informed decision regarding the practicality of completing a project of this size and scope.

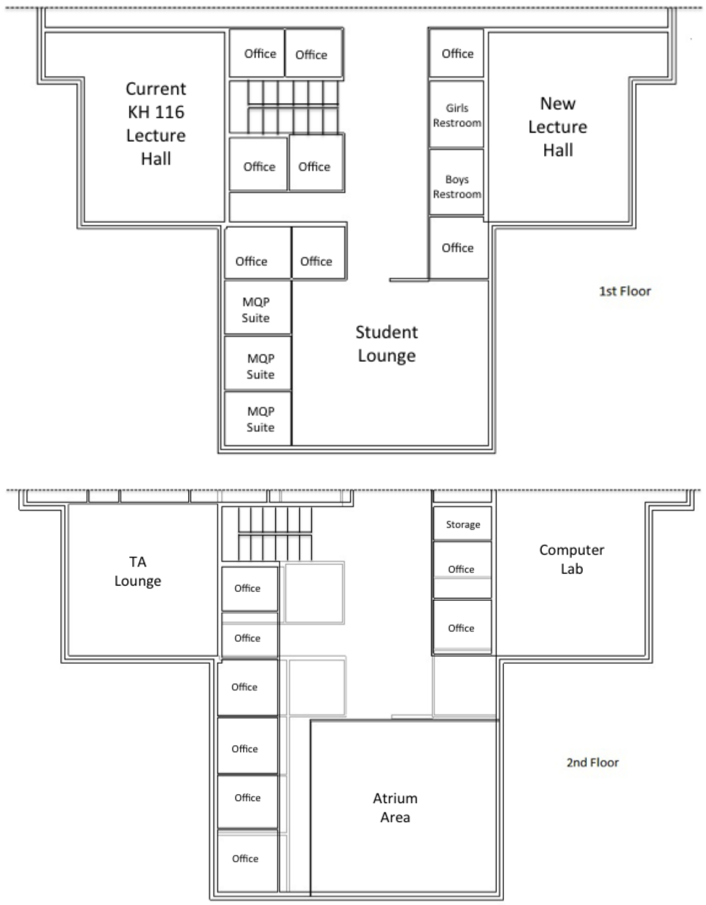


Figure 37: Proposed Layouts of First and Second Floor

10.0 Recommendations

From the project's results, the following recommendations were made. These recommendations aim to meet the space needs for Kaven Hall, based on the research, calculations, and analyses conducted in completed in this MQP.

Obtain recent structural and architectural drawings of Kaven Hall.
When this project was completed, original or as-built structural drawings and recent architectural drawings could not be found. These drawings are necessary to gain a better understanding of the practicality of redesign options and the amount of structural verses architectural changes that would be necessary.

Kaven Hall should be expanded with an additional wing.
Through the evaluation of the three design options, an additional wing provided the largest square footage, and allowed for phased construction, which enabled Kaven Hall to remain occupied and functional for the most time. The outcome of the evaluation rubric was that an additional wing was the most satisfactory design option.

Use the proposed floor plans and designs in order to achieve LEED Certification.
A building code analysis was completed in order to ensure the proposed floor plans were designed in compliance with *MSBC*, *IBC* and the *ADA*. The plans were also designed to achieve LEED Certification. For example, a wall in the additional wing was designed as a curtain wall to provide natural lighting, and public transportation access was made available. The implementation of these plans will help to continue WPI's mission to become a green campus

The additional wing should be built as a separate structure with seismic separation joints between the new construction and the existing building.
Two different investigations of seismic behavior and design were completed (see Section 7.4). The results indicate that the seismic design of the two buildings can be based on two separate structures. Furthermore, seismic of analysis of a single structure requires additional structural steel frames within the existing building, which adds extra costs and construction difficulties to the project.

Use the proposed project schedule to maximize the amount of time Kaven Hall can maintain occupancy.

The proposed project schedule's duration is about ten and a half months starting in early spring. By starting site preparation at the end of the school year, this allows for larger activities such as steel erection and concrete casting to be completed during the summer months, which limits their disruption to the use of Kaven Hall for teaching and research.

Future MQP reports can be done to further the research completed in this project. A project determining the location of structural walls in Kaven Hall would be useful in providing a more detailed seismic analysis of the building. If structural drawings cannot be obtained, the project team could undertake the task of developing these drawings using a scanning device. Also, a team could further the cost estimate by doing an in-depth value engineering analysis. This could be done in combination with a more detailed LEED investigation. Lastly, using the seismic workbook attached to this MQP, a group could perform a seismic analysis for masonry construction on any existing building through a pier analysis.

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Appendix A: Proposal

Worcester Polytechnic Institute:

Renovation and Addition of Kaven Hall

Major Qualifying Project Proposal

Submitted by:

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Samantha Meyerhoff

Project Advisor:

Professor Leonard Albano

Date Submitted:

October 16, 2013

Abstract

The purpose of this Major Qualifying Project is to provide additional spaces to Kaven Hall in order to meet the current and future needs of the faculty, staff, and students. A comparison and evaluation of alternative options will be investigated to determine the most feasible and appropriate option. The new space will be designed and integrated with egress renovations to the existing building. Overall, the project will be designed in adherence to LEED design specifications. A seismic analysis specific to masonry construction will effectively determine if the design is able to withstand a calculated set of lateral loads and forces. The project will also include a cost analysis and schedule that will determine the management that would be required to complete the renovation and addition to Kaven Hall.

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1.0 Introduction

As the enrollment of undergraduate and graduate students at Worcester Polytechnic continues to rise (need a source), the renovation and expansion of the campus is critical in order to ensure that the quality of education is not being sacrificed due to space limitations. According to Chuck Kornik, the Administrator of Academic Programs at WPI, it has become difficult to schedule and accommodate all the different classes with the current classroom space that exists at WPI. This in turn has led to classes being held at inconvenient times and in locations farther away from faculty offices.

The Civil, Environmental, and Architectural Engineering departments are currently located in Kaven Hall. Although most classes associated with these majors are able to take place in Kaven Hall, larger classes have to be moved to other buildings on campus because of occupancy requirements. On the other hand, labs associated with other departments that require computer labs and specific software are being moved into Kaven Hall, which often leads to lab spaces being booked for large portions of the day, making them unavailable for other students to use.

The objective of this project is to determine the space needs that will be required in order for WPI's campus to have sufficient space for current and future student enrollments. It will focus on renovating the existing Kaven Hall building, redesigning the current space and adding new space to meet the needs expressed by WPI faculty, staff, and students. Using past studies in addition to current research, three options will be investigated including the renovation of the existing attic, the addition of another floor within the current footprint, and an entirely new wing being added to the building. A decision will then be made in regards to which of the three options will be further analyzed and developed based on a predetermined set of criteria. The space needs versus the space available will be a critical factor in this determination process as will be the consideration of the anticipated needs of future generations. Figure 1 shown below shows the current location of Kaven Hall on the WPI campus and the area that is being evaluated as a potential space for the construction of an addition.

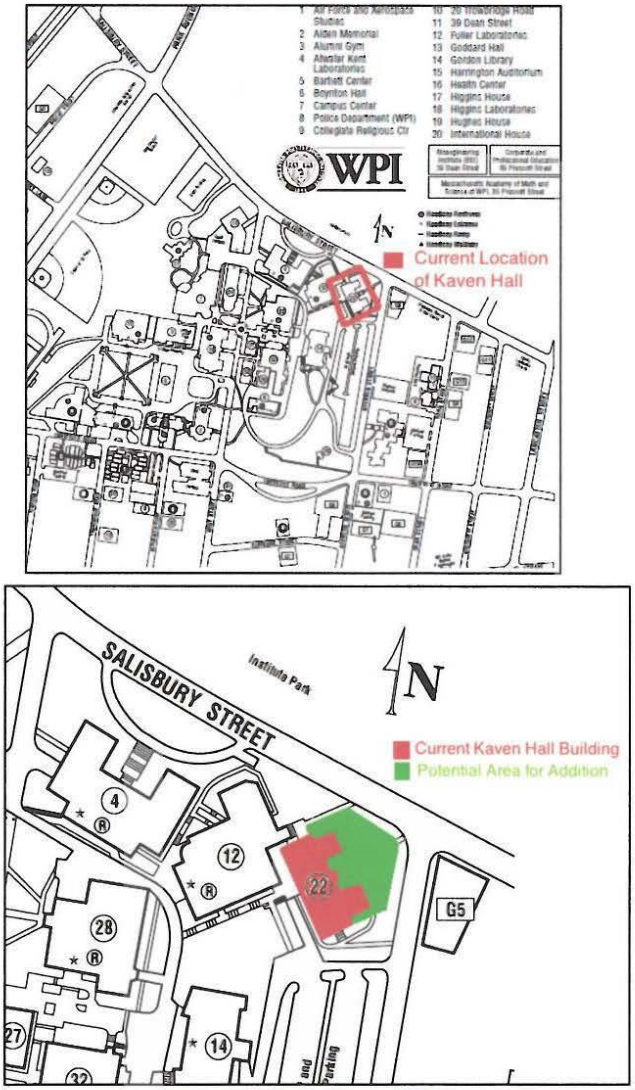

Figure 1: Current Location of Kaven Hall on WPI Campus (above) and Current Building with Potential Area for New Construction (below)

(Worcester Polytechnic Institute, 2013b)

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Scope of Work

There are numerous aspects to consider when designing and managing the major facets of a Major Qualifying Project (MQP). The time constraints of the project limit the scope to what we consider to be the most vital. This MQP will focus on the renovation and the design of additional space to Kaven Hall and a seismic analysis specific to masonry construction of the entire system to determine the feasibility of this type of project. There are three different options to be considered for the addition: an attached addition, an additional floor, or renovations to the attic. The choice will be made based on the educational space needs for WPI, the impact that construction will have on the department, the flexibility of construction, and the flow of the additional space. Recommendations from the CEE Department will also be considered. The reasoning behind why this addition and renovation is necessary will also be elaborated on later in the report.

The design aspects will need to be proposed such that all code requirements such as the *Massachusetts State Building Code* and the zoning requirements for the City of Worcester are met. ADA regulations and the guidelines established by the United States Access Board will also be essential for the design in order to ensure that the building is easily accessible. Only a certain set of requirements for Egress will be investigated due to the MQP's time constraints. These will include the redesign of the stairways to meet current building code requirements and the design of an elevator system to adhere to ASME requirements. It is also necessary for the structural design to satisfy *ASCE 7*, AISC, and ACI requirements, as these standards have been adopted within the *Massachusetts State Building Code* and are regulatory documents. Achieving LEED certification for the addition as well as the renovation is also essential, as WPI continues to move towards more green building initiatives on campus. LEED certification can range from certified buildings to platinum certified buildings based on a credit rating system. The various possible credits will need to be evaluated before construction begins in order to help determine certain design aspects and the projected level of certification that the building will achieve. These requirements will not only affect the type of design chosen, but also the possible room layouts, the types of materials selected, and the cost analysis of the project.

In addition to the design, project management is an essential aspect for a project of this magnitude. A project schedule must be determined once the design is finalized. This will involve the use of the scheduling software, Primavera. Constraints such as time limits will need to be investigated in order for the schedule to meet the needs of the owner. These types of constraints may also impact the design decisions made. With the project schedule, a cost estimate will also be calculated. Data from the *RS Means* and other lump sum values will be used to arrive at a construction cost estimate. Financial constraints will also need to be considered while creating the cost estimate. Constraints that should be considered due to their possibility of impacting the final cost and budget include the availability of materials, the type of financing used, interest rates, the cost and availability of specific subcontractors/companies, etc. The combination of these two management aspects will assist the owner in making an educated decision regarding the practicability of the project.

Capstone Design

The engineering design problem that this MQP addresses involves creating a new layout of the existing Kaven Hall while also designing an additional space to the building. For the renovation of the existing building and the design of the new space, current architectural and structural layouts will be utilized to aid in the design creation of a new set of plans. These new building designs will include LEED requirements for certification to make the structure more sustainable, and also will be in compliance with the ADA and the *Massachusetts State Building Code*. Multiple designs will be considered for the addition to ensure the most efficient use of the new space. Lastly, the analyses of both cost and scheduling will be necessary in order for project deadlines to be met. The constraints addressed in this report include: economic, environmental, sustainability, constructability, ethical, health and safety, social, and political.

Economic: Finances involved in construction are very important for choosing the most satisfactory design. The costs for structural members such as concrete and steel will be investigated when considering the structural design options. Data from the *RS Means* will be used to estimate the cost of construction, outlining the cost of each activity including elements such as structural materials, various systems in the building (water, mechanical, electrical, etc.) finishings and labor. Using this information, the total cost of the project can be determined and used as a tool to evaluate economic feasibility of the proposed solution.

Environmental: Construction of an addition can create negative impacts on the environment. In an effort to counteract these impacts, the site will be evaluated, and any activity that could be potentially harmful will be reconsidered. In addition, renovation work can have negative environmental effects, such as dust, waste, and noise. Steps that can be taken to mitigate these effects include scheduling the noisiest activities during morning or evening hours when classes aren't in session (daytime when classes are not in session) and the community will not be disturbed, frequent sweeping and watering of areas prone to dust, using erosion and sedimentation control, and restoring vegetation to construction area upon the completion of site work (RWDI Inc.). The goal of this evaluation is to reduce the amount of environmental impacts the project will have.

Sustainability: In February 2007, the WPI Board of Trustees made an executive decision that required all new buildings on campus to meet a certain level of LEED certification. In the WPI community's efforts towards building a greener campus, the construction and designs of the renovations and addition for Kaven Hall will be LEED certified (Worcester Polytechnic Institute, 2013a). The requirements for LEED certification for new buildings and major renovations will be addressed in this report.

Constructability: For the design of the renovations for the existing building integrated with the addition to Kaven Hall, multiple building designs will be considered. Designs involving a standard and widely available element that involves a large amount of repetition in construction often are more effective in terms of cost and construction duration compared to elaborate designs with unusual member sizes. These options will be investigated and evaluated in order to choose the most satisfactory design for the addition based on the space needs, ease of constructability, and budget/schedule constraints.

Ethical: All aspects of the project will be in compliance to the Civil Engineering Code of Ethics. For the structural design and seismic analysis, the most recent design standards from ASCE will be utilized, as well as the newest version of the *ICC Building Code* and *Massachusetts State Building Code Amendments*. These resources will ensure that the project is completed in the safest manner.

Health and Safety: It is essential that the renovations and addition be designed such that safety standards are met. The architectural layout of the building will be designed to meet egress requirements such as stairway and hallway widths. Resources provided by the ADA will also be studied to meet the requirements for the addition of an elevator that will provide access to all floors of the building (United States Access Board, 2010). Additionally, occupancy requirements for the classrooms will be considered. This is important to ensure that building and fire codes are met and that the entire occupancy for each room can be safely evacuated in the case of an emergency. Lastly, the structural and seismic analyses specific to masonry construction will be developed using design loads that ensure the principal members are able to withstand all possible forces and verify that the building will be safe in all conditions.

Social: In order to address the social aspect of this project, the effect that the renovations to Kaven Hall will have on the rest of campus and the City of Worcester needs to be considered. For instance, depending on the length of construction, faculty office space and classrooms may need to be relocated. The schedule will need to be organized in such a way as to minimize the amount of time the building will not be accessible. This is especially important given the lack of additional available spaces on campus and the inconvenience that would be caused as a result of classroom and office relocations. Also, the transportation of materials and equipment to the site could have an impact on traffic conditions on the areas closest to Kaven Hall. The social constraints will be essential to making sure that campus is not negatively affected by the project.

2.0 Background

Regardless of the magnitude and scope of a project, every construction project comes with its own unique set of challenges and complexities. This is due to numerous factors that are required to seamlessly work and flow together to ensure an overall success at completion. This section is dedicated to understanding the relationship that these factors have to one another and the critical aspects that will have an effect on the development of the most satisfactory design of the three design proposals and the recommendations for the final construction project. During the planning phase, a through understanding of the current layouts and required space needs is necessary in order to establish ideas for functional layouts. The design that is developed must then adhere to both the *Massachusetts State Building Code* and *City of Worcester Zoning Ordinances* before construction can commence. Proposed renovations regarding egress in the existing building will be evaluated and must meet building codes while the structural design of the new space will need to consider the effect that gravity and lateral loads will have on principal members. Overall, the renovation and additional space will need to earn a specific set of credits outlined in the LEED Specification for New Construction and Major Renovations in order to receive the certification necessary to help WPI continue with its green building initiative. With a comprehensive understanding of the effect that these elements will have on the construction of this project, the most satisfactory design will be possible. Once the design is finalized, a cost estimate and schedule will be formulated. Combining these structural design and project management aspects will lead to a successful project.

2.1 Layouts

An understanding of the architectural layout of Kaven Hall is necessary when considering renovations and additional space. The architectural drawings obtained were done by Appleton and Associates in 1957. The content of the drawings differs greatly from what is currently in Kaven Hall due to the drawings' age and the renovations that have been introduced. Many of the classrooms, like the computer lab on the second floor for example, have been made smaller and have partition walls running through them. These drawings will be able to assist in further locating structural walls and partitions, which will govern any renovations that will be done. The architectural drawings also assisted in calculating the minimum space needs for Kaven Hall using dimensions of similar rooms currently in the building. The drawings of the basement, first floor, second floor and attic will be referenced in this report. However due to the WPI Facility Department's confidentiality agreement, we cannot include the drawings in the report.

2.2 Zoning

Zoning ordinances are a set of codes and regulations established by a city in an effort to, "improv[e] the living conditions of residents in existing dwellings, and assur[e] safety and quality in new construction" (City of Worcester, 2013a). These regulations include but are not limited to the types of structures that can be constructed in certain areas, the height of these buildings, and the minimum distance from roadways. *The City of Worcester Zoning Ordinance* provides charts and text outlining specific regulations while also providing a map showing the five separate districts into which the city has been divided: airport, business, institutional, manufacturing, and residential. As can be seen in Figure 2 below, the existing Kaven Hall building as well as the area that could be used for a potential addition, all lie within the institutional district (IN-S).

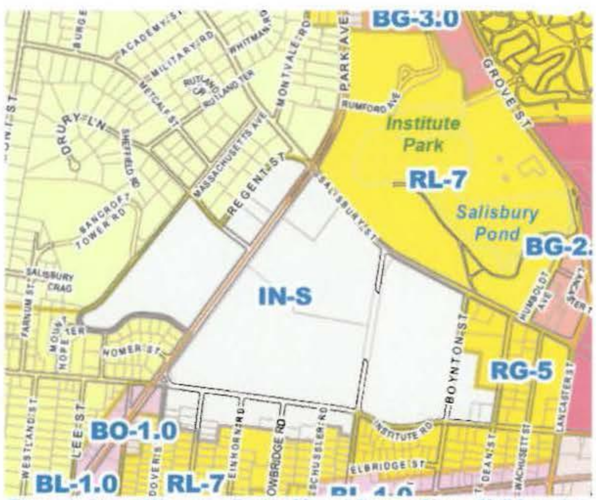

Figure 2: City of Worcester Zoning Map of Current Kaven Hall Location (City of Worcester, 2013b)

From the table that outlines the general permitted uses (Table 1), Kaven Hall would be classified as Institutional, Educational (IN-S) by the Zoning Ordinances because it adheres to the description of "Schools (K-12, college, University, or technical institute) non-profit" (City of Worcester, 2013c, p. 33).

Table 1: Permitted Uses By Zoning Districts

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
GENERAL USE - Continued

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
16. Place of worship	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
17. Radio/TV Transmission Tower	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	N	N	N	N
18. Recreational/service facility (non-profit)	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	Y	Y	N
19. Religious or educational use (EXEMPT)(See Art. XVII; M.G.L.c.40A, s.3)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
20. Schools (K-12, college, University, technical institute) non-profit	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
21. Schools (vocational, professional, other) profit	N	N	N	N	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	SP
22. Shooting Ranges – Indoor/Outdoor (see note 11)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	SP	N	N	N	N

Table 4.2 of the *City of Worcester Zoning Ordinance* summarizes some of the regulations that must be met when constructing within this particular district. A segment of this table is shown below in Table 2 (City of Worcester, 2013c, p. 44). As can be seen, there are no set height, area, and frontage requirements, but minimum front, side, and rear yard setbacks have been established, which will influence any extensions to the footprint of Kaven Hall.

Table 2: Permitted Dimensions By District

PERMITTED DIMENSIONS BY DISTRICT
TABLE 4.2 – Continued

DISTRICT	USE	LOT		YARD SETBACKS			HEIGHT		FLOOR TO AREA RATIO (Maximum)
		AREA (Minimum SF)	FRONTAGE (Minimum linear ft.)	FRONT	SIDE[1]	REAR	Maximum in stories[2]	Maximum in ft.	
				Minimum depth (linear ft.)					
IP-0.33	All	75,000	200	25	25	25	NA	50	0.33 to 1
ML-0.5				25		25		50	0.5 to 1
ML-1.0	All	NA	NA	10	NA	15	NA		1 to 1
ML-2.0						25		NA	2 to 1
MG-0.5				25		25		50	0.5 to 1
MG-1.0	All	NA	NA	15	NA	15	NA	NA	1 to 1
MG-2.0									2 to 1
IN-S									
IN-H	All	NA	NA	15	10	10	NA	NA	NA
A-1									

1 Not applicable to that portion of a semi-detached or attached single-family dwelling, where permitted, that shares a party wall or a double wall on or along a common side lot line with an adjacent unit

2 These designations indicate a height in stories plus an attic, as herein defined. The designation 2+ indicates a maximum of 2 habitable stories with a non-habitable attic and garage underneath, if provided. The story containing the garage is not considered habitable if the garage area occupies 50% or more of the entire story

2.3 Massachusetts State Building Code and ICC

When designing a building, it is essential to follow specific regulations set by the state in which it is being built. Each state has its own building codes, which dictate the construction requirements. The eighth edition of the *Massachusetts State Building Code (MSBC)* will be used for this project. The *MSBC* adopts the *International Building Code* and makes certain revisions for what is seen as best for construction in the State. This project will use the following chapters of these codes:

- Chapter 6: Types of Construction
- Chapter 7: Fire and Smoke Protection Features
- Chapter 8: Interior Finishes
- Chapter 9: Fire Protection Systems
- Chapter 10: Means of Egress
- Chapter 16: Structural Design
- Chapter 18: Soils and Foundations
- Chapter 19: Concrete
- Chapter 22: Steel

Local building codes contain the minimum design loads that are specific for the area's conditions such as snow, wind and earthquake loads. The *MSBC* also offers information about the accessibility for buildings and deflection requirements. By having a chapter on means of egress, hallways and stairways can be designed according to the codes and regulations outlined. It is necessary to follow the local building code to produce a sufficient design that also meets safety requirements.

2.4 Design Standards

The renovations and addition design for Kaven Hall will rely on building design codes and standards. The *Massachusetts State Building Code* has adopted many other building standards including the American Society of Civil Engineering Standards (*ASCE 7*), American Society of Mechanical Engineering Standards (*ASME 17.1*), American Concrete Institute Standards (*ACI 318*), and the American Institute of Steel Construction (AISC) Specification.

Each of these building standards will play an important role in the structural design portion of the project.

ASCE 7 provides the minimum design loads for buildings. These loads include the seismic, wind and other lateral loading that will be needed for the structural analysis of the building. *ACI 318* will be essential for the design analysis relating to concrete. These standards will provide the limit states and other requirements of the concrete design. Similar to the ACI 318, the 14th edition of the *AISC Steel Construction Manual* provides the limit states for the design of steel members. The manual also assists in the selection of the proper cross sectional area as well as the minimum and maximum spacing of bolts.

In addition to the structural standards, mechanical standards are needed for certain aspects of the project. In order to design an elevator, the American society of Mechanical Engineers (*ASME*) *A17.1* will be used. This standard provides the safety codes for elevator design. Elevator design also must conform to the National Fire Protection Association standards, including proper sprinkler and alarm systems. Elevators must also be up to the ADA codes, which provide the space occupation requirements.

2.4.1 Seismic Concerns for Masonry Construction

The seismic analysis of Kaven Hall is essential because of the impact that architectural and structural redesigns will have on the existing and new masonry walls. The seismic concerns for masonry construction can be found in the *Masonry Standard Joint Committee (MSJC) Code*. The primary concern is the anchorage of the masonry walls. *MSJC Code* requires that the masonry walls are anchored to the roof all floor diaphragms, and foundation anchorage to provide lateral support (MSJC, 2011). The specific lateral forces that the anchored connections must resist are dependent on the seismic zone of the building's location. Therefore, the seismic zone also plays an important role in the seismic analysis of masonry construction. The zones are given numerical values such that the lower the value, the lower the seismic hazard. A map of the United States and its seismic zones are shown in Figure 3.

Figure 3: Map of Seismic Zones for the United States (Irving Materials Inc., 2013)

2.4.2 Egress Requirements for Designs

The redesign of the renovation and the new design of the additional space will be impacted by the egress requirements set forth by *ADA* and the Occupational Safety and Health Administration (OSHA). These requirements include corridor width, stairway width, travel paths, and the accessibility of escape routes as outlined in *ADA 4.3 and Appendix* (United States Access Board (2010). Additional requirements that OSHA has specified in Standard *1910.36* include the number of exit routes from an area based on occupancy, the use of fire resistant materials between exits and other areas of the facility, the capacity/size/height of the exit route, and the types of hinged doorways that are permitted.

2.4.3 Alternative Structural Schemes

Upon completion of the space needs evaluation for Kaven Hall, the proposed idea that was selected will need to undergo another evaluation. This second evaluation will deal with alternative structural schemes that will be considered the best-fit options for the specific space that is being designed. Different aspects that will be considered for the design of the structural schemes will include alternative bay sizes, column sizes, and framework designs.

2.5 Leadership in Energy and Environmental Design (LEED)

The United States Green Building Council (USGBC) has developed the LEED program in an effort to "change the built environment" to satisfy green building requirements. The LEED program has put forth a rating system that categories every type of building or project into a specific group that is based on a unique prerequisite and credit system that determines the level of certification that the facility can receive. The main categories that these credits are broken down into are Sustainable Site, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality (U.S. Green Building Council, 2013*c).* Out of a possible total of 110 points, projects' certification level is determined based on the following breakdown:

- Certified: 40-49 points
- Silver: 50-59 points
- Gold: 60-70 points
- Platinum: 80+ points

U.S. Green Building Council. (2013a)

In addition to this information, clearly defined steps that are necessary in the process of registering a project for LEED certification are provided on the USGBC website. The five steps that are outlined are: Choosing a rating system, registering and payment, submitting the certification application, the review process, and the final certification decision. The website and additional contact options make the USGBC a very user-friendly website that provides owners, designers, and contractors with all the information necessary to plan and construct a successful LEED certified facility.

2.6 Cost Analysis

To determine the cost estimations for the project, data from the *RS Means* will be used. *RS Means* is an estimation database specifically designed for construction that provides cost information. The information includes labor costs, material costs and equipment costs. The values are determined based on the U.S. averages and are adjusted depending on the location within the country, the size of the project, the time of year, and the quality of work. For any values that cannot be determined using *RS Means* references, lump-sum costs will be determined based on research from local subcontractors, and additional research from sources including *Building News International,* the *General Construction Cost Review Guide (GCCRG),* and publications issued by the American Society of Professional Estimators.

2.6.1 Evaluating Alternative Options

A cost analysis of the alternative structural schemes discussed in Section 2.4.1 will be conducted to help determine which option will be elaborated on and designed in more detail in this report. Cost is always a factor that owners and designers must consider when planning a project as there is often a maximum allowed budget that cannot be exceeded in order for the project to continue past the design phase.

With cost as a main objective, it is important to consider multiple structural options in the hopes that one meets the personal needs and budget of the owner. Depending on the level of flexibility in the budget, a more in depth and complex design may be feasible, but for this project, the aim is to provide a design that meets the needs of the owner by the most effective cost means necessary.

2.6.2 Completing the Design Work

The renovation and addition of new space to Kaven Hall will consist of numerous types of design work, all of which will have different impacts on the final cost analysis. One of the main differences will be the complexity involved with the renovation work verses the new construction. A design evaluation will be necessary in order to understand the impact that certain changes and additions will have on the project's budget. Main factors that need to be considered for both renovation and new construction are outlined in Table 3 below.

Table 3: Factors to Consider for Renovation and New Construction (Cruickshank, 2013)

Renovation	New Construction
• Structural Integrity • Architectural Merit • Thermal Benefits • Hazardous Material • Location • HVAC Systems • Community Connection	• Sustainable Features • New Technology • Better Use of Space • Easier Prioritization • Efficient Layout • Maintenance Savings

In this project, both renovation and new construction will be defined, which requires merging designs from both areas. By taking all of these considerations into account, an informed decision can be made regarding the design changes that will occur in the renovation as well as the new designs that will be associated with the construction of the additional space. A final design evaluation will help to understand the costs associated with each activity and the impact that each will have on the final cost proposal of the project.

2.7 Schedule

As construction projects continue to grow in complexity and design, scheduling methods have been becoming increasingly more sophisticated. *Primavera* scheduling software has most recently come out with the P6 Professional Project Management version of their software that has the ability to organize up to 100,000 activities, track progress, compare alternative options, and is an efficient visual tool used for monitoring time and performance. This software will be utilized in the project management portion of this project to create a network of activities (CPM diagram) with corresponding durations and adjusted floats. This enables the management team to track progress and have an accurate means of tracking work-in-place verses time while also providing the owner with accurate deadlines for major milestones and the project as a whole.

The scheduling challenges that will have the greatest impact on this project are related to staging construction around the academic school year and determining the possibility of keeping sections of the Kaven Hall building open and in operation. In order for the building to be used in the fall, the construction project would have to be at a certain phase by the end of the summer. Also, minimal construction and renovations can be done within the building once school is back in session. Due to the current space needs for WPI, all of the civil and environmental courses cannot afford to be relocated to other academic buildings. There also is not enough office space on campus for the department's professors to be relocated. Therefore, the project schedule must be created such that the building is at least partially available for professors and students.

3.0 Methodology

There are a set list of tasks and sub activities that must be completed in order to accomplish the problem statement and goal outlined for this MQP. These tasks and the work to be completed have been broken down into areas of emphasis with some activities happening simultaneously and others requiring a sequential timeline. These major topics are outlined below in Table 4.

Table 4: Methodology Tasks, Activities, and Resources

Tasks/Topics	Activities	Plan for Completing Tasks/Resources	
Determine space needs and propose a redesign layout for Kaven Hall	Redesign layout for Kaven Hall renovation and the new addition	Obtain current architectural and structural drawings (Meet with William Spratt)	WPI Facilities documents
	Current space Needs	Interview with Charles Kornik, WPI scheduling documents	Bar graphs and charts related to current sceduling and classroom usage
	Research old MQPs (Previous attic plans)	Research--Gordon Library	
	Design a new architectural layout	Use current architectural and structural drawings as a basis to layout a new floor plan that meets all the required space needs	
	Occupancy loads for sizes of rooms	Obtain information from Charles Kornik and the Mass Building Code	
Structural Design	Gravity Loads	ASCE 7	
	Lateral Loads	ASCE 7	
	Typical Bays	LRFD, ASCI, MSBC	
Design of Typical Footing and Foundation (if needed for addition)	Site Conditions	MSBC, Additional Research	
	Loading	Structural Design, ACI, ASCE 7	
Renovation impovements within existing Kaven Hall	Egress--Stair Requirements	Mass. Building Codes, ADA	
	Egress- Installation of an Elevator	Using architectural and structural layouts to determine area of building to install system	ASME 17.1
	LEED requirements	LEED website, checklists outlining credit system for New Construction and Major Renovations	
Seismic Anaysis	Effect of forces on principal members of the **system**	ASCE 7	
	Lateral Loads	ASCE 7	http://www.eng.auburn.edu/users/staylor/seismic_loads_calcs.PDF
Design to meet LEED requirements	Evaluate checklist system BEFORE any deisgn takes place	LEED	
	Choose a set of certain criteria to address in report (materials, site improvements, curtain wall, etc...)	LEED, RS Means	
	Determine the ROI for the selected components	LEED, RS Means, Research	

Scheduling	Estbalish tasks/milestones/durations	Research, Primavera
	Create project schedule	Primavera
Cost Analsyis	Materials	RS Means
	Labor	RS Means
	Lump sum of various systems	RS Means
	Total cost/lazy s-curve	Additional Research
Writing MQP Proposal	Abstract, Introduction, Scope of Work, Capstone Design, Background, Methodology, Deliverables, Schedule, Conclusions, References	Divide research tasks and writing sections Each person then edits the other sections and adds any additional information that they have researched A final read through with complete fomatting will be done before the final submittal
Final Report	Further development of proposal sections in addition to sections: results, analysis, calculations, appedices, etc...	Each person will be involved with every section of the report, with one person taking the lead and doing the reseach necessary to obtain the necessary equations and relevant information Each person will be responsible for checking the calculations and editing the writing of all sections A schedule of activities has been created to stay on track and finish the MQP final report by the scheduled deadline (end of C term 2014)

3.1 Space Needs

A critical first step that should be considered is the actual space needs that Kaven Hall requires. Meetings and interviews with the Director of Facilities Operations, William Spratt and the Administrator of Academic Programs, Charles Kornik, will create a better understanding of the current and future space needs of this particular academic building. Additional research into previous MQP reports will also aid in the understanding of the current available space and the alterations that can be made to the structure. After obtaining all the preliminary information, an evaluation of the additional space options will be conducted.

The three proposed options that will be considered as possible solutions to address space needs are:

- The refurbishment of the current attic space
- The addition of a 3rd floor within the current footprint of the building
- The design and addition of a new wing

Each of these options will undergo an evaluation using a predetermined set of criteria in an effort to determine which proposal will be developed in greater detail. According to Au (2000), "It is important to evaluate facilities rationally with regard to both the economic feasibility of individual projects and the relative net benefit of alternative…projects." Each of the options for this project will be evaluated on:

- The amount of additional space that will be provided (square footage)
- The circulation & flow of the space
- The ability to maintain building occupancy during construction
- Flexibility of the space in terms of design potential and layouts

3.1.1 Evaluation of Three Proposed Space Options

A standard system of evaluation will need to be created in order to determine which of the proposed space options is the most suitable for this specific project. The first task that will be done is to categorize the list of criteria into a hierarchy system where certain options carry more weight than others in the final decision process. A visual representation of this system can be seen below in Figure 4.

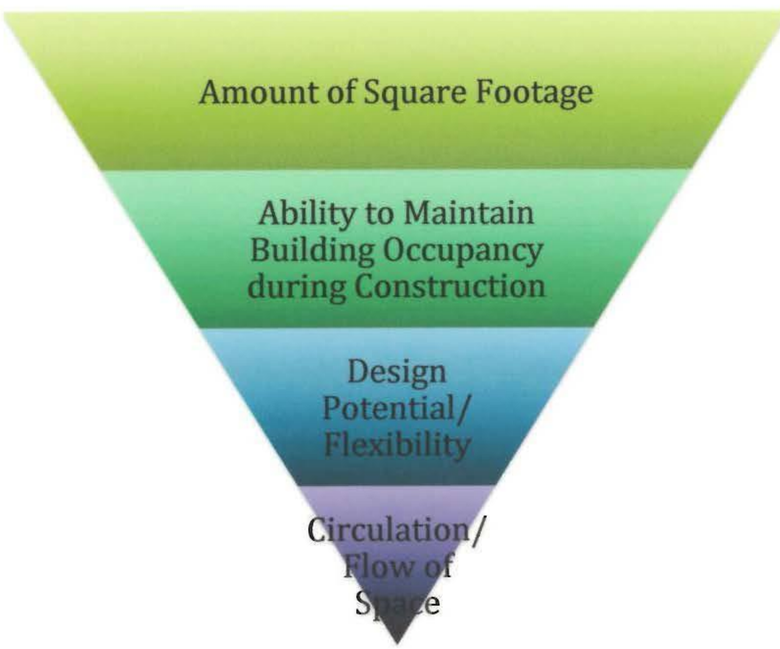

Figure 4: Evaluation Factors for Proposed Space Options

Each option will then be rated with respect to each criterion based on a specific set of guidelines outlined for each category. Then, based on the hierarchy system, the rating for each criterion will be multiplied by a weighting factor that was established based on the level of importance that each criterion has in the final decision making process. The total score for a given option will be given by the simple sum of the weighted ratings values. A table summarizing this scoring technique is shown below in Table 5. The purpose of using these evaluation techniques is to avoid any possible bias and ensure that each option is being evaluated in the same manner.

Table 5: Evaluation of Proposed Space Options Scoring Tool

		0	1	2	3	Weighting Factor
Amount of Sq. Footage	Attic 3rd Floor New Wing	Does not meet space needs	Close to meeting space needs	Provides acceptable space needs	Exceeds space needs	4
Ability to Maintain Building Occupancy during Construction	Attic 3rd Floor New Wing	No occupancy throughout entire construction	No occupancy for more than half of construction	No occupancy throughout summer months	Almost full occupancy throughout entire construction	3
Design Potential/ Flexibility	Attic 3rd Floor New Wing	No design flexibility	Numerous constraints to design flexibility	Few limitations to design flexibility	Full design flexibility of space	2
Circulation/ Flow of Space	Attic 3rd Floor New Wing	No flow of space	Limited flow of space	Acceptable flow of space	Excellent flow of space	1

Upon the completion of this evaluation, an option will be chosen that best meets the needs of Kaven Hall based on the summation of the final scores.

3.2 Architectural/Structural Layouts and their Evaluation

Current structural drawings of Kaven Hall will provide the basis for the new architectural layouts. By knowing where current columns and structural walls are located, the redesign of specific areas will be facilitated. Building code and occupancy requirements will also be necessary in the layout of lecture halls and classrooms to ensure that specific class sizes can be accommodated. Also, *ASCE 7* codes will be utilized to structurally design the new space area by taking into consideration gravity and lateral loads in order to design a typical bay. An architectural layout will then be created for the new space, and a Revit model of the entire system will be created in an effort to provide a visual of the final product.

3.3 Footings and Foundation Design

If the project takes the form of designing an additional wing for Kaven Hall, the design of a typical foundation and footers will be included in the scope of the work. Current site conditions will need to be considered and the structural aspects will be designed in accordance to *ACI 318* and *MSBC* standards.

3.4 Egress Renovation Improvements

As part of the renovation of Kaven Hall, a through update to the current means of egress is important. This includes updates to the current stairways to meet *Massachusetts Building Code* and Fire Safety Regulations and the addition of an elevator that complies with ASME standards. Current architectural and structural drawings of Kaven Hall will aid in determining the location of the new elevator system and coinciding mechanic shaft.

3.5 Seismic Evaluation and Analysis of Exterior Masonry Walls

Upon the completion of the structural and architectural design of the existing Kaven Hall and the additional space, a seismic analysis specific to masonry construction will be preformed for the entire system. This will be done in accordance with *ASCE 7* standards and taking into account gravity and lateral loads to determine the forces on the principal members of the structure. This is a critical evaluation in order to assess the feasibility in completing a construction project with these specific design parameters.

3.6 Leadership in Energy and Environmental Design (LEED) Considerations

In an effort to comply with WPI's recent mission of building a more environmentally friendly and "green" campus, LEED certification will need to be obtained for this project. A checklist that outlines criteria that must be met to earn a specific level of certification for a project categorized as 'New Construction and Major Renovations' will be evaluated to determine which aspects will be considered for this facility (U.S. Green Building Council, 2013c*)*. The return on investment (ROI) of these elements will play a role in determining which will or will not be further developed. By evaluating the list of criteria and the specific points system for this group before the planning process begins, design and material alternatives can be evaluated that will contribute to the delivery of a LEED certified building. If the rating system is not examined critically before the design process, time delays and additional costs may be incurred in order to accommodate alterations and changes later in the construction phase.

3.7 Scheduling

All the information obtained through interviews and research will be used to develop a design and construction schedule that highlights major activities and milestones of the project. The schedule is important in understanding what activities rely on the completion of others and if some can overlap and take the form of a fast-tracked schedule. The schedule is also important to help the owner make decisions regarding the best time for construction to take place. With WPI being an active campus, the current occupants of the building will most likely need to be relocated for a set duration of the construction phase. An interview with a member of the facilities staff at WPI will be conducted to discuss alternative construction options and the possibility of staged construction. This will have a significant impact on the schedule of the project and whether the current building can remain open for any portions of the project's duration (i.e. summer construction versus academic year construction options).

An accurate timeline will help with the owner's decision making process as well as ensuring that equipment and materials are delivered and on-site when they are needed to avoid delays once construction has started. This, in effect, will have an impact on the cost analysis if the original schedule begins to deviate in any type of way. The schedule for a project of this scope will use Primavera (P6) software to create a network diagram and lazy s curve which ultimately will help to coordinate all activities and cash flow throughout the different phases of the project's delivery.

3.8 Cost Analysis and Estimation

A cost analysis of the entire project from beginning to completion will be performed as part of the project management portion of this proposal. This will include the structural design, egress renovations, and all environmental design considerations that are developed to meet LEED requirements. Material and equipment cost, and labor calculations will also be included. These values will be obtained from *RS Means* and additional estimates for the building's systems that were not designed for (electrical, plumbing, etc…) will also be included. Overall, the cost estimate of the entire project should provide the owner with the information necessary to be able to make an informed decision about whether to move forward with the project.

3.8.1 Cost Evaluation for a Structural System Standpoint

In an effort to provide the owner with the most cost effective design, a series of cost evaluations should be developed that take into account the various design options that are available. By providing a cost breakdown for separate structural design systems, owners and project management personnel can more clearly understand how the money is being divided amongst the different areas of the project. This will assist with making a final judgment decision about which design proposal will be selected for construction. Also, by providing a detailed breakdown of the costs in the early phases of design and construction, expenditures can be tracked and compared to help the project stay on course and within the proposed budget.

4.0 Deliverables

In order to display the results gathered during the project process, deliverables will be created. Architectural and engineering drawings will illustrate the designs, and tables will summarize the key outcomes from the scheduling and cost estimating procedures. The preparation of the deliverables will follow the order that the Methodology sets forth. Table 6 below gives an overview of the deliverables that will result from this project.

Table 6: Deliverables to be Produced

Final Deliverables	**Notes**
Evaluation of Three Options Table	To compare and contrast three design options
Code Analysis	Referring to ASCE 7, ACI, ASME, etc.
Engineering Drawings	Bay sizes, column design, etc.
Supporting Calculations	For masonry seismic design and structural design
Architectural Drawings - Floor Layouts	For renovations integrated with new space
Revit Model of Proposed Design	3-Dimensional model of building including new space
Project Schedule	Created in Primavera
Cost Estimation	Including cost per square foot, material cost, labor cost and any additional costs
Final Report	All deliverables will be included

The first deliverable will be a table containing an evaluation of three design options for additional space. The current minimal space needs will be stated, and compared to what each design option has to offer. Each option will also have a breakdown of the qualitative characteristics discussed in the Methodology. The summary table will compare and contrast the three designs, and show how the designs were weighed so that the most satisfactory option could be chosen.

In order to further develop the design of the chosen option, a building code analysis will be included. This process is essential for the renovation portion of the project. The analysis procedure performed will be illustrated in a flow chart. The use of the *MSBC* criteria could change the locations of partition walls, which will then alter the location of columns. Therefore, a deliverable of engineering drawings will be completed. The drawings will display the bay sizes and column designs, in addition to the current, as well as additional beams and columns displaying the corresponding seismic analysis. A separate deliverable for the supporting calculations for the building frame's structural and masonry seismic analysis will be included. In addition, the building code analyses will alter the architectural layout of the building due to the change in hallway and stairway widths. A deliverable of architectural floor plan drawings will be required. Floor plans of the first floor, second floor and attic will be drafted on Revit, as well as a layout of the additional space. A three-dimensional Revit model of the finished design will also be included. This will assist in the readers in visualizing what would be the finished product of the report.

Once the design portions of the project are completed, a schedule will be created for the project using Primavera software. The list of activities will be formulated along with each of their durations, start and finish dates, and total float. A network diagram will display the relationship between the activities and include the critical path. The most satisfactory schedule will be formulated based on the time constraints that the project will entail. The final deliverable will be the cost estimate displayed in a table. It will include the cost of all materials needed for the project, and the labor costs based on the length of the project schedule. A total cost will be formulated into a cost per square foot, and then compared to costs of similar renovation and addition projects. Depending on cost and time constraints, the schedule and cost estimate may need to be adjusted individually to ensure the most satisfactory results.

Last, the final report will be a compilation of all of the aforementioned deliverables. The report will describe and illustrate the building and the detailed processes followed to create the deliverables.

5.0 Schedule

Schedule of Anticipated Completion Dates																							
Milestones	A Term			Break	B Term								Break			C Term							
Week Ending	10/5/2013	10/12/2013	10/19/2013	10/26/2013	11/2/2013	11/9/2013	11/16/2013	11/23/2013	11/30/2013	12/7/2013	12/14/2013	12/21/2013	12/28/2013	1/4/2014	1/11/2014	1/18/2014	1/25/2014	2/1/2014	2/8/2014	2/15/2014	2/22/2014	3/1/2014	3/8/2014
Proposal Writing																							
Evaluation of Options																							
Architectural Layout																							
Proposal Submission																							
Preparation for Analysis																							
Structural Design																							
Seismic Analysis																							
Autocad Structural Drawings																							
Architectural Drawings																							
MQP Draft																							
Preparation for PM																							
Cost Estimation																							
Project Schedule																							
MQP Draft																							
MQP Revisions																							
MQP Final																							

6.0 Conclusion

The deliverables produced by this project will require skills and knowledge from many different aspects of the civil engineering field. Structural engineering will be used for the seismic analysis of the masonry building. From this analysis, the reader will be able to understand the loading that the building must be designed to withstand. The final result will give a full overview of the design of the frame of the building, including columns and beams. In addition, the architectural design of the floor plans is expected to successfully satisfy the current space needs for Kaven Hall. Sustainability aspects will be considered when architecturally designing the building to satisfy LEED Certification requirements. Construction project management will assist in developing a construction plan to execute the project. The schedule and cost estimate will display the important management aspects, and show how the design of the building will therefore be cost effective, and can be completed in the time frame required. The final report will help the reader gain knowledge on the architectural and structural designs, schedule and cost of the renovations and addition to Kaven Hall.

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Appendix B: Stair Design

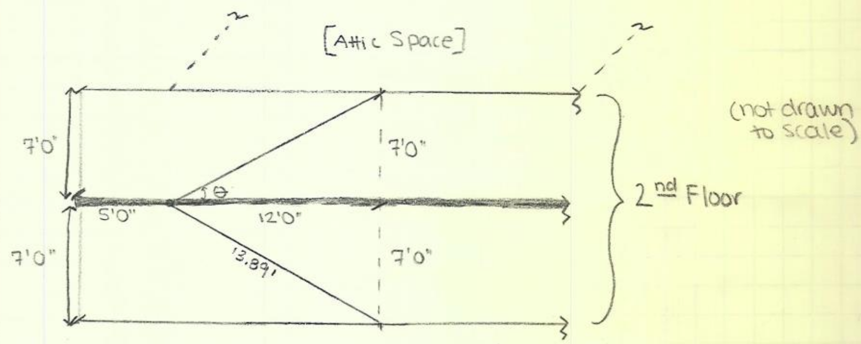
Stair Design

Design Loads:

DL = 50 psf
LL = 100 psf

F_y = 50 ksi
E = 29,000 ksi

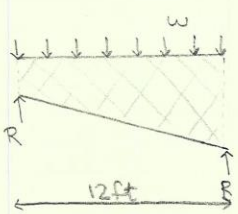
Factored $W_u = 1.2DL + 1.6LL$
$= 1.2(50\,psf) + 1.6(100\,psf)$
$= 220\,psf$



$a^2 + b^2 = c^2$
$(7')^2 + (12')^2 = c^2$
$\sqrt{49+144} = c$
$c = 13.89\,ft$

$\cos\theta = \frac{A}{H}$
$\cos^{-1}\left(\frac{A}{H}\right) = \cos^{-1}\left(\frac{12'}{13.89'}\right) = 30.24°$
$\theta = 30.24°$
$30° < 30.24° < 50°$ ✓ OK
(OSHA requirement)

Stringer 1:



Length = 12.00 ft
Trib width = 2.5 ft
Angle = 30.24°

Area = (12ft)(2.5ft) = 30 ft^2

$W_u = (2.5\,ft)(220\,psf) = \frac{550\,lb/ft}{1000\,lb/K} = 0.55\,k\text{-}ft$

(AISC Table 3-2)

Try: W8x10

$I_x = 30.8\,in^4$

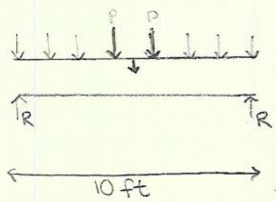
$\phi M_n = 32.9\,k\text{-}ft$

$R = \frac{(W_u)(13.89')}{2} = 3.82\,K$

$M_{max} = \frac{W_u L^2}{8} = \frac{(0.55)(13.89)^2}{8} = 13.26\,k\text{-}ft$

Check: 32.9 k-ft > 13.26 k-ft ✓ OK

Landing Beam 1:



Length = 10 ft
Trib Width = 2.75 ft
$W_u = (2.75\text{ ft})(220\text{ psf}) = 0.605$ k-ft

From Stringer 1 ⇒ P = 3.82 k

$R = \frac{W_u L}{2} = \frac{(0.605)(10')}{2} = 3.025$ k
$+ 3.82$ k
6.845 k

$$M_{max} = \frac{W_u L^2}{8} + \frac{PL}{2} = \frac{(0.605)(10')^2}{8} + \frac{(6.845\text{ k})(10\text{ ft})}{2}$$

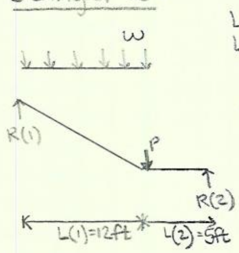
$M_{max} = 41.79$ k-ft

Try: W10x12

$I_x = 53.8\text{ in}^4$
$\phi M_n = 46.9$ k-ft

Check: 46.9 k-ft > 41.79 k-ft ✓OK

Stringer 2:



Length (1) = 12 ft
Length (2) = 5 ft
$W_u = 0.55$

P_u from Landing Beam 1 = 6.845 k

$$R(1) = \frac{W_u L(1)(\tfrac{1}{2}L(1) + L(2)) + PL(2)}{L(1) + L(2)}$$

$$= \frac{(0.55)(12)(6+5) + (6.845)(5)}{17} \Rightarrow R(1) = 6.28\text{ k}$$

$$R(2) = \frac{W_u L(1)(\tfrac{1}{2}L(1)) + PL(1)}{L(1) + L(2)}$$

$$= \frac{(0.55)(12)(6) + (6.845)(12)}{17} \Rightarrow R(2) = 7.16\text{ k}$$

Try: W 10x12
$I_x = 53.8\text{ in}^4$
$\phi M_n = 46.9$ k-ft

OR

Try: W12x14
$I_x = 88.6\text{ in}^4$
$\phi M_n = 65.3$ k-ft

Larger safety factor

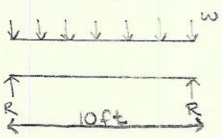
$\frac{R(1)}{W_u} = \frac{6.28\text{ k}}{0.55} = 11.4$ ft from left = x

$M_{max} = R(1)(x) - (\tfrac{1}{2} W_u x^2) = (6.28)(11.4) - (\tfrac{1}{2})(0.55)(11.4)^2$

$M_{max} = 35.85$ k-ft

Check: 65.3 k-ft > 35.85 k-ft ✓ OK

Landing Beam 2:



Length = 10 ft
W_u = 0.605 k-ft
R = 3.025 k

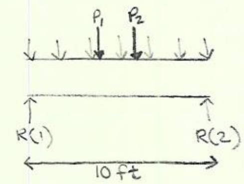
$M_{max} = \frac{W_u L^2}{8} = \frac{(0.605)(10')^2}{8} = 7.56$ k-ft

Try: W8x10

$I_x = 30.8 in^4$
$\phi M_n = 32.9$ k-ft

Check: 32.9 k-ft > 7.56 k-ft ✓ OK

Floor Beam:



Length = 10ft
W_u (floor gravity load) = 0.96 k-ft
$P_1 + P_2$ = 7.64 K

Note: $P_1 = P_2 = 3.82$ Kips

$R = \frac{(0.96)(10ft) + 7.64\ K}{2} = 8.62$ K

Try: W10x12

$M_{max} = \frac{W_u L^2}{8} + \frac{PL}{4} = \frac{(0.96)(10)^2}{8} + \frac{(7.64)(10)}{4}$

$I_x = 53.8 in^4$
$\phi M_n = 46.9$ K-ft

M_{max} = 31.1 K-ft

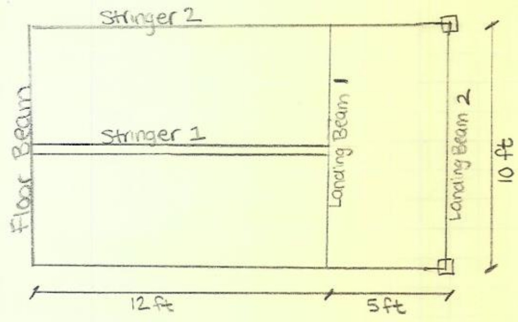
Check: 46.9 K-ft > 31.1 K-ft ✓OK

Column:

Try: W8x15 r_y = radius of gyration = 0.876
A = 4.44
Pu (from Stringer 2 & Landing Beam 2) = 3.025 K + 7.16 K = 10.185 K
R = 20.37 K
KL = (1.0)(14 ft) = 14 ft

Table 4-22 AISC: ϕF_c = 6.19 ksi
ϕP_u = 27.48 K > 20.37 K ✓OK

Member Selection: Stair Design	
Member Type	Member Size
Stringer 1	W 8 x 12
Stringer 2	W 12 x 14
Landing Beam 1	W 10 x 12
Landing Beam 2	W 8 x 10
Floor Beam	W 8 x 15
Column	W 8 x 15



(not drawn to scale)

Appendix C: Elevator Design

Elevator Design

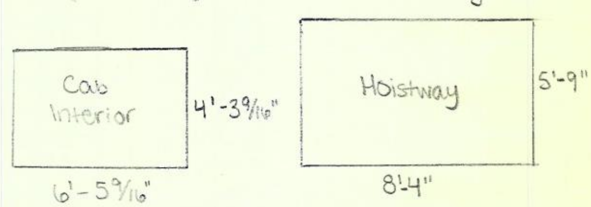
Dead Load of Slab = 60 psf
Dead Load of Floor Finish & Lighting = 15 psf

Total Dead Load = 75 psf

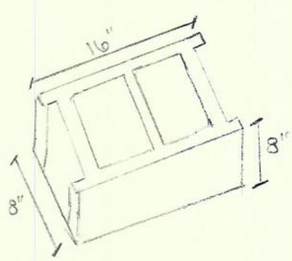
Live Load (IN) = 100 psf

Factored Loading = 1.2DL + 1.6LL
= 1.2(75psf) + 1.6(100 psf)
= 340 psf

From (Otis, 2013): 2500 lb capacity

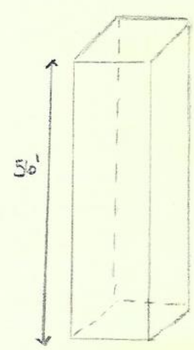


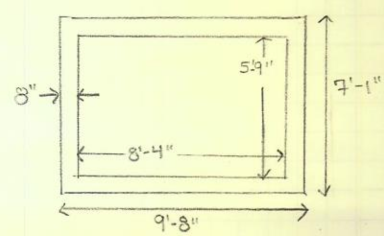
Use of CMU Masonry block for Elevator Shaft



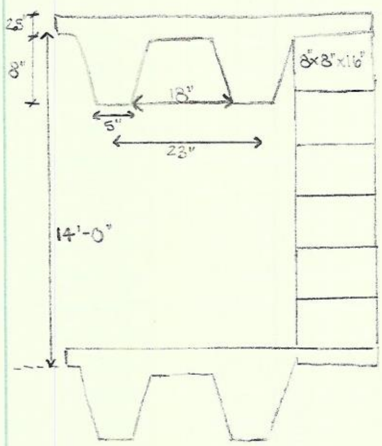
V = 1024 in³
W = 32 lb/block
F'c = 1,500 psi

Shaft dimensions
56' × 9'-8" × 7'-1"
= 3,834.44 ft³





Cross Section



Top Sectional Area

(9'-8" + 5'-9")(8")
= (116" + 69")(8") = 1480 in²
× 2 (walls)
2,960 in²

Height of shaft = 56' = 672"
Height of each block = 8"
672"/8" = 84 blocks ↕

Length of shaft = 5'-9" = 69"
Length of each block = 16"
69"/16" = 4.3125 blocks ↙

Width of shaft = 9'-8" = 116"
Length of each block = 16"
116"/16" = 7.25 blocks ↔

Total # of Blocks Needed:

2(7.25 * 84) = 1218
2(4.3125 * 84) = 724.5 → 725
} 1943 blocks

Car door dimensions:

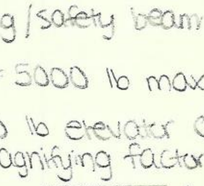
3'-6" x 7'-0" = 27.5 blocks
* 4 floors
110 blocks

→ 1943
− 110
1833 blocks
* 32 lb/block
58,656 lbs.

ACI 530
- four - 14' tall sections = 56'-0"
  ↳ exceeds limitations & therfore requires bracing / safety beam

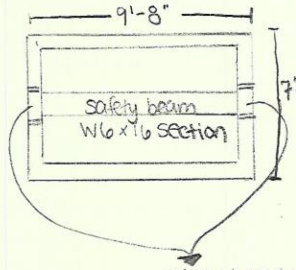
Safety beam = 5000 lb max load
(2500 lb elevator capacity with a dynamic magnifying factor of 2)

Try W 6x16
I-beam



weight = 16 lb/ft
* 9.5 ft
152 lb

Steel bearing pads (2) at top of hoistway/shaft help to disperse load distributed to safety beam
↳ necessary in case of failure



$5000\,lb + 152\,lb = \frac{5{,}152\,lb}{2} = 2{,}576\,lbs/\text{steel pad}$

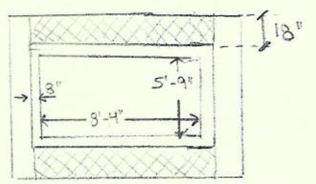
$\frac{2{,}576\,lb}{64\,in^2} = 40.25$ psi per pad (bending)

Total Loading of Masonry Wall & Safety Beam per Unit Area ➡ 58,656 lbs
↳ use 60,000 lbs for safety measure

$\frac{60{,}000\,lb}{2{,}960\,in^2} = 20.3\,psi$

$20.3\,psi + 40.25\,psi \cong 61\,psi < 1500\,psi$ ✓OK

$1.2DL + 1.6LL = 1.2(3\,floors * 75\,psf) + 1.6(100\,psf) = 430\,psf$



(Not drawn to scale)

$\frac{18"}{12"/1} = 1.5' \times 9'\text{-}8' = 14.5\,ft^2$
$* \; 2$
$29\,ft^2$

$430\,psf * 29\,ft^2 = 12{,}470\,lb$

Area of wall to support slab ⇒ 9'-8" * 8" = 928"

$\frac{12{,}470\,lb}{928"} = 13.44\,psi$

Max Possible Loading of any section of Masonry Wall

$(40.25\,psi + 20.3\,psi + 13.44\,psi) = 73.99\,psi = 74\,psi < 1500\,psi$
✓OK

Appendix D: Outline Specification

	Assembly Sections		Description			Unit	Unit Cost	Model Cost per SF	New Cost per SF	+/- change
A	SUBSTRUCTURE	Foundations	Standard Foundation	Strip Footing System	Poured Concrete; strip and spread footings (including excavation)	S.F. Ground	42.25	0.63	0.62	-0.01
			Slab on Grade (SOG)	Slab On Grade System	5" reinforced concrete with vapor barrier and granular base	S.F. Slab	5.36	2.48	1.79	-0.69
B	SHELL	Superstructure	Floor Construction	Floor Construction	Open web steel joists, slab form, concrete	S.F. Floor	14.46	7.23	4.82	-2.41
			Roof Construction	Roof Construction System	Metal deck on open web steel joists, columns	S.F. Roof	8	4.00	2.67	-1.33
			Seismic Frames	Structural Steel Framing	A992 Steel Frames	Per Ton	2600	0.00	2.46	2.46
		Exterior Enclosure	Exterior Walls	Exterior Walls	Face brick with concrete wall block back-up (steel frame)--includes insulation	S.F. Wall	29.4	8.89	18.07	9.18
			Exterior Windows	Exterior Window System (20% of wall)	Aluminum Dbl hung, insulated glass, 2'-8" x 6'-8"	Each	1235	0.00	9.20	9.20
			Exterior Windows	Exterior Window System (15% of wall)	Glazing Panel, 3/8" thick, tempered	S.F. Wall	30.6	4.07	2.82	-1.25

			Exterior Doors	Exterior Door Systems	Alum. & glass, w/o transom, narrow stile w/ panic hardware 3'-0" x 7'-0"	Each (5)	2675	0.00	0.35	0.35
				Exterior Door Systems	Alum. & glass, w/o transom, wide stile w/ dbl door hardware 6'-0" x 7'-0"	Each (3)	5625	0.66	0.44	-0.22
		Roofing	Roof Coverings/Openings	Shingle and Tile	Slate Roofing, Strip shingles, 4" slope, shingles, 3/16" thick, 8.0 PSF	PER SF	n/a	2.74	8.23	5.49
C	INTERIORS	Interior Construction	Partitions	Drywall Partitions/Stud Framing System	Gypsum board on metal studs	3.78	PER SF	7.23	3.78	-3.45
			Interior Doors & Finishes	Metal Door/Metal Frame System	Single Lead Hollow Metal (200 SF Floor/Door)	1052	EACH	5.27	5.27	0.00
			Fittings	Fittings	Chalkboards, toilet partitions		SF of Floor	4.76	1.24	-3.52
		Stairs	Stair Construction	Stairs	Concrete Filled Metal Pan	10025	PER FLIGHT (14)	3.00	3.69	0.69
		Interior Finishes	Wall Finishes	Wall Finishes	95% paint, 5% ceramic tile	3.74	SF of Surface	3.74	3.74	0.00

			Floor Finishes	Floor Finishes	70% vinyl composition tile, 25% carpet, 5% ceramic tile	4.86	SF of Floor	4.86	4.86	0.00
			Ceiling Finishes	Ceiling Finishes	Mineral fiber tile on concealed zee bars	6.57	SF Ceilin g	6.57	6.57	0.00
D	SERVICES	Conveying	Elevator	Elevators and Lifts	One hydraulic passenger elevator, capacity: 2500 lbs, services up to 5 floors, 100 FPM	138700	PER UNIT	3.10	3.65	0.55
		Plumbing		Toilet and Service Fixtures, supply and drainage, oil fired hot water heater, and Rain water drainage	Lump Sum Estimate	18.81	PER SF	18.81	18.81	0.00
		HVAC		Heating and Cooling generating systems, terminal and package units, etc.	Lump Sum Estimate	19	PER SF	19.00	19.00	0.00
		Fire Protection		Sprinklers, light hazard, standpipes	Lump Sum Estimate	3.3	PER SF	3.30	3.30	0.00

		Electrical		Electrical service distribution, lighting and branch wiring, communications and security, and other electrical systems	Lump Sum Estimate	24.62	PER SF	24.62	24.62	0.00
E	FURNISHINGS & EQUIPMENT	Furnishings	Fixed Furnishings	Fixed Furnishings	Furishings, blinds-interior, venetian-aluminum, stock, 2" slats, economy	2.92	SF	0.00	2.92	2.92
				Fixed Furnishings	Seating, Lecture hall, pedestal type, economy	230	EACH (300)	0.00	1.82	1.82
			Movable Furnishings	Movable Furnishings	Office furniture standard room set, economy, per room	585	PER ROOM (30)	0.00	0.46	0.46

G	SITEWORK		Includes: Clearing & grubbing, site water & fire, site sanitary installation, Landscape maintenance , granite curbs, irrigation system, turf & grass, storm piping, temporary partitions, etc…	Site Work	Lump sum estimate	Per SF	0.02	0.00	3.76	3.76

Kaven Hall Project Costs	
Model Cost	$ 130.27
Summary of Changes to Model Cost	$ 24.00
Adjusted SF Cost	$ 154.27
Building Area - Renovation and Addition (SF)	38000.00
Building Area * Adjusted SF Cost	$ 5,862,196.23
General Conditions (25%)	$ 1,465,549.06
Subtotal - Construction	$ 7,327,745.29
Architects Fee (5%)	$ 366,387.26
Subtotal - Design and Construction	$ 7,694,132.55
Location Modifier	1.10
Local Replacement Cost	$ 8,463,545.81
Total Building Sq. Ft. Cost	$ 222.72

Appendix E: LEED 2009 for New Construction Checklist

LEED for New Construction and Major Renovations (v2009)

SUSTAINABLE SITES	**POSSIBLE: 26**
Construction activity pollution prevention	REQUIRED
Site Selection	1
Development density and community connectivity	5
Brownfield redevelopment	1
Alternative transportation - public transportation access	6
Alternative transportation - bicycle storage and changing rooms	1
Alternative transportation - low-emitting and fuel-efficient vehicle	3
Alternative transportation - parking capacity	2
Site development - protect or restore habitat	1
Site development - maximize open space	1
Stormwater design - quantity control	1
Stormwater design - quality control	1
Heat island effect - nonroof	1
Heat island effect - roof	1
Light polution reduction	1
WATER EFFICIENCY	**POSSIBLE: 10**
Water use reduction	REQUIRED
Water efficient landscaping	4
Innovative wastewater technologies	2
Water use reduction	4
ENERGY & ATMOSPHERE	**POSSIBLE: 35**
Fundamental commissioning of building energy systems	REQUIRED
Minimum Energy Performace	REQUIRED
Fundamental refrigerant management	REQUIRED
Optimize energy performance	19
On-site renewable energy	7
Enhanced commissioning	2
Enhanced refrigerant management	2
Measurement and verification	3
Green power	2
MATERIAL & RESOURCES	**POSSIBLE: 14**
Storage and collection of recyclables	REQUIRED
Building reuse - maintain existing walls, floors and roof	3
Building reuse - maintain interior nonstructural elements	1
Construction waste management	2
Materials reuse	2
Recycled content	2
MATERIALS & RESOURCES	**CONTINUED**
Regional materials	2
Rapidly renewable materials	1
Certified wood	1
INDOOR ENVIRONMENTAL QUALITY	**POSSIBLE: 15**
Minimum IAQ performance	REQUIRED
Environmental Tobacco Smoke (ETS) control	REQUIRED
Outdoor air delivery monitoring	1
Increased ventilation	1
Construction IAQ management plan - during construction	1
Construction IAQ management plan - before occupancy	1
Low-emitting materials - adhesives and sealants	1
Low-emitting materials - paints and coatings	1
Low-emitting materials - flooring systems	1
Low-emitting materials - composite wood and agrifiber products	1
Indoor chemical pollutant source control	1
Controllability of systems - lighting	1
Controllability of systems - thermal comfort	1
Thermal comfort - design	1
Thermal comfort - verification	1
Daylight and views - daylight	1
Daylight and views - views	1
INNOVATION	**POSSIBLE: 6**
Innovation in design	5
LEED Accredited Professional	1
REGIONAL PRIORITY	**POSSIBLE: 4**
Regional priority	4
TOTAL	**110**

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Appendix F: Structural Frame Design & Seismic Analysis

See attached electronic workbook.