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Maintaining the Integrity of Structural and Fire Protection Systems and Building Documentation in Historic Buildings: Washburn Shops Case Study

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GFS 1201
LDA 1204

Maintaining the Integrity of Structural and Fire Protection Systems and Building Documentation in Historic Buildings:

Washburn Shops Case Study

A Major Qualifying Project
Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the
Degree of Bachelor of Science
in Civil Engineering by

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Amanda Bowden

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Paige Hanson

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Alexandra Marokhovsky

Date:
March 1st 2012

Approved:

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Professor L. D. Albano

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Professor G. F. Salazar

Abstract

As buildings age, facilities management becomes an issue for institutions like Worcester Polytechnic Institute. Throughout a building's lifecycle, drawings become inaccurate, code compliance becomes dated, and safety hazards emerge. This project developed a framework to investigate and update structural and fire protection systems to ensure code compliance and to generate a comprehensive Building Information Model for functional documentation.

Washburn Shops, built as one of the first buildings at WPI in 1867, provides a case study for this facilities management framework.

Capstone Design Experience

Included in the Major Qualifying Project is the capstone design experience, consisting of three components. First is a description of the design problem. Next is the approach to this design problem and finally a discussion on how the ABET General Criterion's realistic constraints are addressed. This section will discuss each component and its relation to fulfilling the requirements of this MQP.

Design Problem

Washburn Shops, one of the two original historic buildings on the Worcester Polytechnic Institute Campus, has recently been found to have structural and documentation issues. During the renovation project this year, these were called to the attention of WPI Department of Facilities. The contractors, who were performing exterior masonry work, discovered the exterior walls of Washburn to be hollow except for supporting columns between each of the windows of the original building. The structural system provided by these walls is not sufficient according to standards and poses structural issues in the area of seismic design. Fixing this problem requires an innovative design and in fixing it, the building may have to be brought partially or entirely into compliance with the *Massachusetts State Building Code*. The university and facilities office did not know details of the building and the construction of the walls until this project because complete and appropriate documentation does not exist.

Washburn was to serve as a model to develop a framework for the larger issues that other historic buildings have. Aging structures can develop problems throughout their lifecycle that a framework for facilities management can address.

Approach

To approach this problem, the project team analyzed the issue of facilities management for historic buildings. A framework was created to assess a structure that has developed issues similar to that of Washburn Shops. This framework was based on knowledge from past coursework in areas of materials of construction, construction project management, structural engineering and design, fire protection engineering, 3D object-oriented parametric software, Autocad design, and individual research efforts. The work done to investigate and update structural and fire protection systems to ensure code compliance and to generate a comprehensive Building Information Model can be applied to other aging buildings.

This framework provided a base for documenting the current condition of Washburn visually, structurally, historically and for reviewing its compliance with the *Massachusetts State Building Code* (*MSBC*) 8^{th} edition. Building Information Modeling was then utilized to create a 3D digital model of the building and to document the most recent renovation project conducted in 2011. After this model was created, the team investigated options to design solutions for the structural and fire protection systems. Through an iterative process these issues were examined and solutions were delivered to WPI Department of Facilities.

Realistic Constraints

According to the ABET General Criterion, there are several realistic constraints that should be considered in a major design experience to incorporate engineering standards. The following sections detail the five constraints that are addressed by this MQP: Economic, Manufacturability, Health and Safety, Social and Political.

Economic

In suggesting future designs, economic constraints were considered. Some solutions to the structural and code violation issues may not be economically feasible. The resultant costs from the proposed designs that are deemed appropriate were highlighted in this project. The economic loss is weighted against the design benefits in order to provide the appropriate solutions.

Manufacturability

The manufacturability of the proposed solutions must be considered. If it is not a feasible design to produce, then it is not practical suggestion. Alternative designs were proposed to avoid a manufacturability or constructability limitation. The materials of design as well as methods and resources required during construction are considered.

The Building Information Model created facilitates the analysis of the design constructability when working on Washburn in the future because all information is now combined in one comprehensive model.

Health and Safety

Health and safety is a significant consideration in any construction project, as it is in the suggested designs. The designs proposed that address the areas of non-compliance also address health and safety. Building codes account for the health and safety of its occupants. By meeting these codes, Washburn will be safer for its users. Both the structural and fire system safety issues have been addressed by the project team's designs.

Social

Any changes on the WPI campus would have social implications. The extent of the designs and the affect the construction would have on the study body are considered. The proposed designs implications to the campus were considered from all sides, the student, the faculty, and the school. Renovation projects can affect the regular campus activities, creating disruptions, safety issues and educational opportunities.

Political

Washburn is a historical and high-valued sentimental building in the minds of students, alumni, faculty and staff. It represents the inception of a university to which many have strong ties. Construction and alterations involving this building will have a political implication within the WPI community. The team considered the reaction and standpoint of WPI officials when selecting the most appropriate design solutions.

Authorship

All members contributed to the success of this project and worked together to complete this report. Table displays the sections of study written and completed by each member.

Section	Author
Abstract	Paige
Capstone Design Experience	Amanda
Acknowledgements	Amanda
Introduction	Amanda & Paige
Maintaining Outdated Masonry Buildings	Paige
Project Documentation	Alexandra
Building Information Modeling	Amanda
Building Codes	Alexandra & Paige
Past Construction Methods and Regulations	Alexandra
Case Study: Washburn Shops	Paige
Scope of Work	Paige
Building Assessment Methodology	All
Building Code Study- Structural	Alexandra
Building Code Study-Fire	Paige
Current Drawings and Model	Amanda
Future Options Methodology	Amanda & Paige
Building Solutions- Structural	Alexandra
Building Solutions- Fire	Paige
BIM Future	Amanda
Conclusions and Recommendations	Alexandra

The signatures below indicate acceptance of the above.

Amanda Bowden

Paige Hanson

Alexandra Marokhovsky

Acknowledgements

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A special thanks to Chris Salter of WPI Department of Facilities who has been integral throughout the project. We would like to thank Mr. Salter for all his support and sponsorship of our endeavors along with the other staff in the WPI Department of Facilities.

We would also like to thank Frank Horanzy of WPI, Dave Guertin of Culter Associates, and Steve Susca of Hoffman Architects. The contributions of these individuals were indispensable and we are greatly appreciative.

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1.0 Introduction

Facilities management becomes a major issue for institutions with many older buildings on their campus. With increased age, the facility may no longer reach compliance with current building codes and the documentation becomes insufficient. As aged structures decay with time, it can become difficult to maintain the building without proper or accurate documentation.

This project explores the maintenance of historic buildings, investigating the areas of structural stability, fire protection safety, and building documentation. A framework was created to investigate these areas in order to provide solutions for institutions facing the problems of dated code compliance, old drawings that need to be updated and emerging safety hazards.

Worcester Polytechnic Institute's Washburn Shops was used as a case study to consider code compliance issues and to create a Building Information Model (BIM) of the facility. Washburn serves as a guide for many institutions that face these problems. Built in 1867, Washburn Shops is one of WPI's founding buildings. Originally, Washburn's purpose was to serve as a space for machine shops and classrooms however, over the past 145 years, the building has been renovated many times to keep up with the needs of WPI. The most recent renovation efforts were in 2011 and involved exterior restoration. During this renovation, building code compliance and outdated documentation became concerns of WPI.

Washburn, like other aged facilities, has unique structural and fire safety issues. By creating a code compliance checklist, areas of non-compliance were outlined in regards to these categories and workable design solutions were proposed with estimated costs. The building was also documented in its entirety in a comprehensive BIM model, including the three-dimensional layout and the renovation data.

The project team's work for the WPI Department of Facilities provides a comprehensive study of Washburn in regards to code compliance and a BIM model. This information can be used by WPI in future renovation projects.

2.0 Background

This chapter will outline the background research that needs to be done in order to evaluate an existing building on documentation and building codes. After these areas of research have been presented in a broad sense, the team presents this information specific to the case study of Washburn Shops. The purpose of this case study is to provide a specific example of the challenges that institutions face as buildings age. First is an explanation of why maintaining older buildings can be difficult with particular focus on maintaining a building's structural integrity and fire protection system. The next section expresses the importance of project documentation for future construction and how many older buildings lack this information. Next is a section overviewing BIM (Building Information Modeling) software, such as *Autodesk Revit,* in which the importance of this technology relating to documenting a building's drawings, code compliance, and structural integrity is explained. Next, a summary of building codes presents the applicable codes that would bring a building up to current standards. The last three sections detail the building that was chosen as a case study for this project: Washburn Shops (shown in Figure 1). The history, the most recent renovation and the scope of work for this project are explained in these three sections.

Figure 1: Washburn Shops

2.1 Maintaining Outdated Masonry Buildings

One of the largest issues institutions like Worcester Polytechnic Institute (WPI) face is keeping historic buildings maintained and safe. This is a never-ending battle because once one building has been renovated; another one is in dire need to be reconditioned. This cycle is particularly hard to keep up with because of the financial investment that must be made for repairs that are often not noticeable from exterior of the building. It can be hard to convince a benefactor to invest in a project that won't aesthetically change a building when other potential projects involve constructing a state-of-the-art, brand new building. Two main areas that fall under this issue are the level of structural stability and the level of fire protection provided to the building.

2.1.1 Structural Deficiency

Masonry structures in particular have been popular construction types for these historical buildings. However in the past, these buildings have been constructed with insufficient materials and by using inadequate design techniques compared to current procedures (Triantafillou, 1998). Thus, many old, masonry buildings are deficient for present use.

The walls of aged masonry structures are not usually reinforced which is one of the largest structural issues. The bricks that compile the masonry walls create a very sturdy wall under gravity loads however; the bricks are weak when attempting to resist earthquake loads (FEMA, 2009). The geometry of these masonry walls is also a structural issue for these types of buildings. Some masonry structures were built with a hollow cavity between the interior and exterior walls, for the purpose of insulation and to keep rainwater out of the building, without bricks connecting the two walls. This is an example of how older masonry building walls can be unreinforced when in fact grout could have been placed in these cavities for reinforcement.

Methods have been developed to fix these structural issues in older masonry building in order to strengthen these buildings. Below is a list of materials and methods that can be used to accomplish reinforcement:

- Filling cracks and voids with concrete
- Using shotcrete and steel to fill voids
- Steel ties between structural elements (Triantafillou, 1998)
- Anchoring masonry parapets
- Bolting walls to floors or roof
- Attaching columns or applying a layer of concrete to the wall (FEMA, 2009)

The most popular of these methods involves using a combination of shotcrete and steel or a fiber reinforced polymer (FRP) composite to reinforce the masonry walls (Triantafillou, 1998). Figure 2 below depicts this reinforcement.

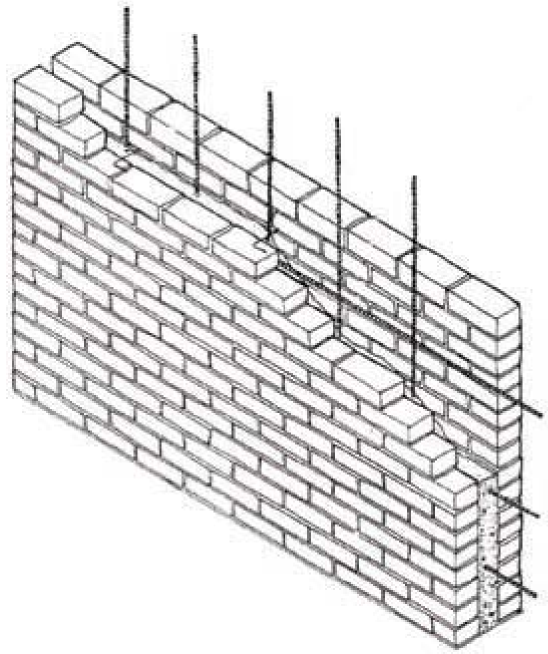


Figure 2: Shotcrete and Steel used to create Reinforced Masonry Walls (FEMA, 2009)

Choosing the correct method for reinforcing an older masonry building varies case by case and a structural analysis/assessment can provide helpful information as to which option would be the best for a particular building while still be cost efficient.

2.1.2 Fire Protection Deficiency

Many violations can be discovered when inspecting an older building that has been renovated numerous times, but occasionally these violations are overlooked time and time again. An explanation of this situation is given by Chad Duffy, who worked as a sprinkler contractor in Las Vegas, inspecting fire protection systems, and now works as a staff consultant at NFPA.

Duffy explains that when inspecting an older building, the fire protection system is inspected according to the codes used at that time. The order of inspection process is outlined in Figure 3.

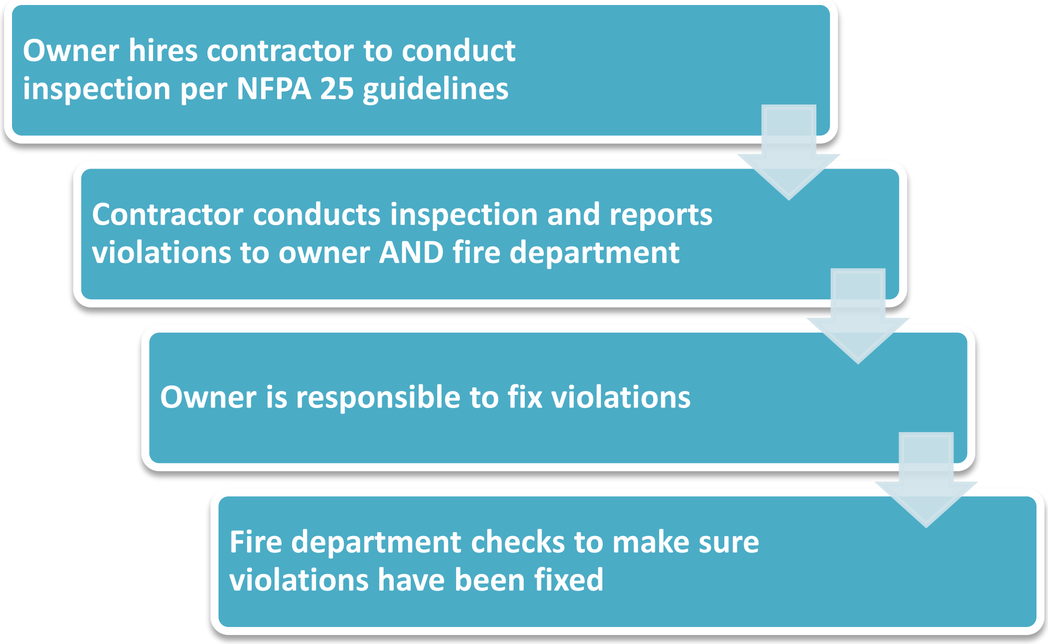


Figure 3: Fire Protection System Inspection Process

This process shows that the violations of the system are ultimately the responsibility of the owner. The fire department enforces the correction of the violations and sets a time limit upon the owner in which to fix these violations (depending on the severity of the violation). However, with a large number of buildings to overlook and other responsibilities, the fire department may not have enough time to enforce the correction of all these violations.

An example of the code violations delays is the Las Vegas Casino Buildings. Duffy describes that the Casinos are renovated so frequently and so many buildings are being worked on at the same time, many casinos have code violations that haven't been fixed in years. However, now that the economy has slowed down, these violations are being enforced more strictly than before and owners of casinos have to fix their fire protection systems within a certain amount of time.

Examples of these violations from renovations can be moving walls, changing occupancies, or new storage. Duffy states that some of the key elements he looked for in sections were:

- Sprinkler spacing
- Obstructions
- Occupancy change
- Check valves: functioning, right position
- Proper signals sent to panels
- Proper pressure

This list is by no means all-encompassing but highlights important areas not to overlook during the inspection (Duffy, 2012).

In Massachusetts, the Authority Having Jurisdiction (AHJ) is the local fire department. The division of fire safety in the Massachusetts Department of Fire Services acts like a free consulting service for the local departments when help is needed. Dana Hangensen is an engineer for the division of fire safety and explains some of the concerns within the industry.

Hangensen explains that one responsibility of these fire departments with renovations is to double-check that the given drawings are accurate to the existing building. Another large responsibility is to make sure the building has been maintained properly, according to *NFPA 25*. For example, if the building has changed occupancy, the building owner must hire a contractor to evaluate the building. Another problem area for the local fire department is receiving drawings from engineers who have never been on the building site but have signed off on the drawings. This practice violates the code but also creates extra work for the local fire department that may not be manageable.

In many towns and cities, the local fire department is responsible for enforcing violations relating to the fire protection system, but ultimately, the owner is responsible for keeping the fire protection system up to code (Hangensen, 2012).

2.2 Project Documentation

Building plans, specifications, and other supporting documents all are a part of construction project documentation. A complete set of construction documents includes a couple of different components. Building plans or drawings are the principal construction documents. They are composed of several different plans, from floor plans to site plans to foundation designs. Figure 4 shows an example of a floor plan. The main sections of drawings

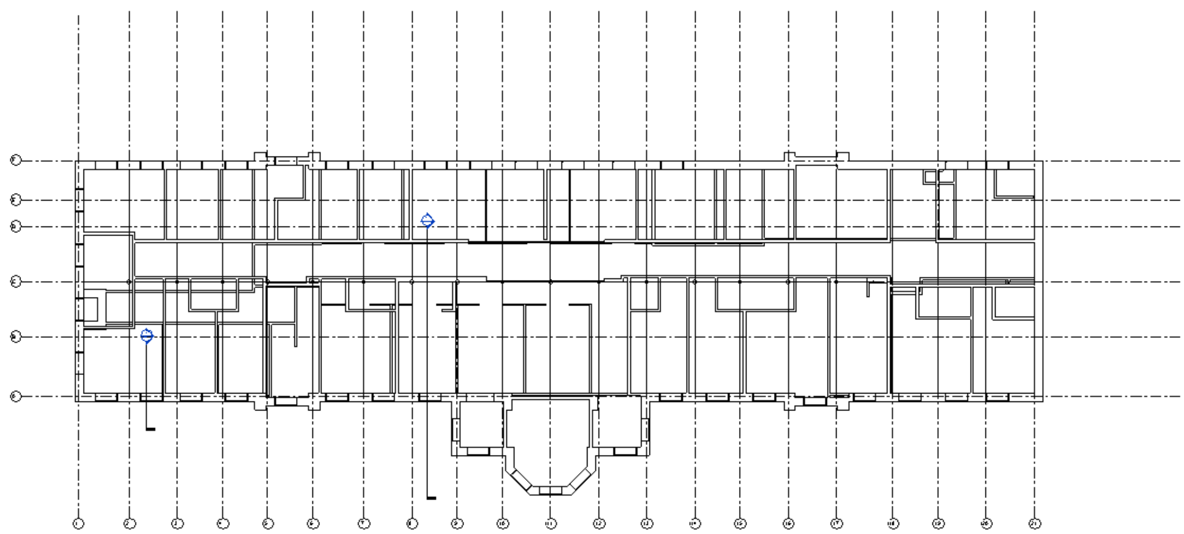


Figure 4: Floor Plan Example

are broken down into architectural drawings, elevations, structural drawings, mechanical drawings and electrical drawings (Turner, 2011). Figure 5 is an example of a front elevation, recreated in Autodesk Revit. Construction documents also include specifications or the "spec book." This is a reference that specifies the different materials and techniques used in order to construct the project. In addition there are other supporting documents like supplemental instructions that also make up construction project documentation (Turner, 2011). The processes in which these construction documents have been recorded have changed over the years however their importance has always been apparent.

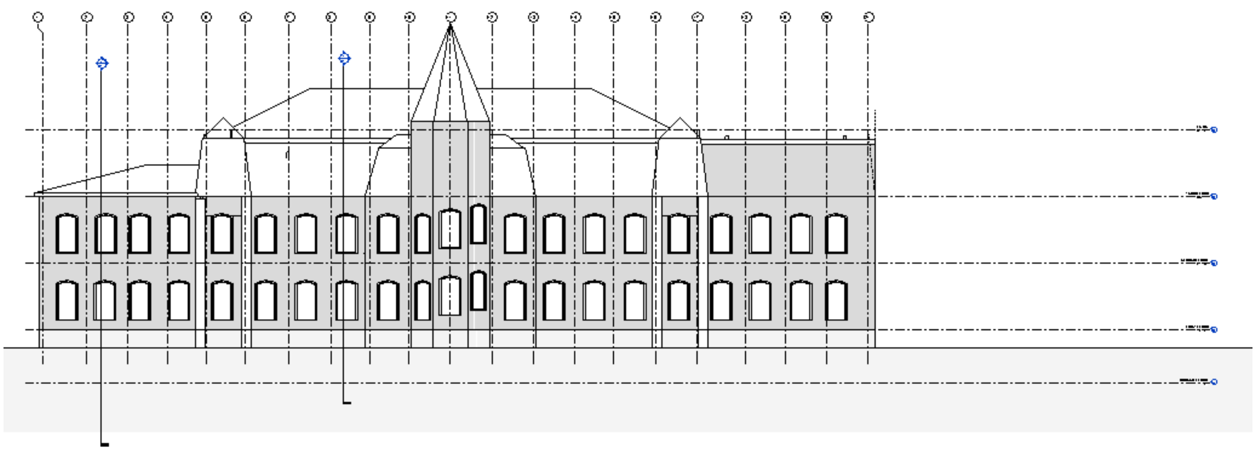


Figure 5: Front Elevation Example

2.2.1 The Importance of Project Documentation

Documentation of a project is important throughout the lifecycle of the building, from before construction to maintenance and renovations. These documents have multiple purposes. One is to provide instructions to the contractors on how to build the structures (Turner, 2011). These drawings help to make sure all members of the team have the same understanding on what is being constructed, what it is being constructed of, where and when. Another objective of these documents is to leave the owner with the as-built description of the building to help maintain the building and map out what was done. In addition they provide a starting point for building renovations in the future (Turner, 2011). However, if documented incorrectly, the misinformation can cause misunderstandings among construction companies and can cause future renovations to be more costly (Kymmell, 2008). Incorrect construction documents can hinder future construction leading to misjudgments, extraneous effort and additional costs.

2.2.2 History of Project Documentation

Even in the 1800's the importance of project documentation was known. At this time the building layouts had to be hand drawn and traced to make copies for the different workers. In addition to the drawings, documents describing the structures also had to be hand-written and hand copied in order to share among workers (Burr, 2002). These early drawings were made up of "thin, uniformly inked ruled lines" and were usually drawn on a small scale and with very little detail (Burr, 2002). For example many drawings did not have dimensions or descriptions of materials used. At this time the architect was known as the "master mason" and he was the supervisor of construction (Burr, 2002). Furthermore, small decisions like window trims were made through "informal consultation" during construction (Burr, 2002). However as the architectural profession grew the separation of design and construction became more apparent and new documentations practices were introduced (Burr, 2002).

In the early and mid-1900's drawings would be documented on "light translucent media" and by blueprinting, they could be recreated with greater ease (Burr, 2002). These were at first white lines on blue background paper but eventually changed to blue lines on white paper when the Diazo process was introduced. In the 1970's however, a new project documentation process was introduced that advanced how construction drawings and documents were produced (Burr, 2002).

In 1950 the *United States air defense system* created the electronic graphic system, and in 1960 *McDonnell Douglas Automation Company*, which would later assist in introducing

Computer-Aided Design (CAD), was founded. In 1969 *Computervision* sold the first commercial CAD system, and this new technical advancement changed construction project documentation forever (Burr, 2002). CAD produced drawings with electronic qualifications that have improved the construction project documentation process by "minimizing many mistakes involving human error and maximizing the use of time" (Burr, 2002).

As CAD software systems became more developed and updated the transition was made from two-dimensional representations to three-dimensional. There were many companies creating new CAD programs and upgrading existing ones. *Autodesk* was founded in 1982 and produced *AutoCAD*, a CAD program that could run on a PC. In the years following this first release, *Autodesk* upgraded their *AutoCAD* program as well as created add-ons like *AutoSolid* and in 1991 it created *ArcCAD* to start its emergence into the Architectural field (Bozdoc 2003).

Autodesk Revit Architecture was the next major milestone in project documentation. Revit was created by Revit Technology Corporation in 1997, it focused on not only the model concepts but also incorporated 3D concepts. Autodesk acquired Revit Technology Corporation in 2002 and added Revit to its already successful AutoCAD products (History of Revit, 2011). Autodesk and other companies have continued to create new software to better project documentation and Building Information Modeling (BIM) is currently the newest solution to project documentation with its ability to integrate 3D modeling concepts with databases of information (Kymmell, 2008).

2.3 Building Information Modeling (BIM)

Building Information Modeling (BIM) is an innovative new concept emerging in the design and construction industry. A building information model integrates 3D modeling components with a database of information relating to the project (Kymmell, 2008). With this technology a project's physical and functional characteristics can be detailed and organized (Buckley, 2007). A BIM model can be used to view a building in three dimensions, track information associated with specific items and also to produce two-dimensional drawings to serve as as-built drawings.

2.3.1 Defining BIM

The phrase BIM was coined by *Autodesk* in 2002, but the growth of this technology has been happening for some time (Eastman, 2008). With the use of computer programs such as *Revit Architecture*, *Revit Structures* (Figure 6) and *AutoCAD,* a construction project can be simulated in a "virtual environment". "Virtual building implies that it is possible to practice construction, to experiment, and to make adjustments in the project before it is actualized" (Kymmell, 2008). BIM utilizes not only 3D modeling but parametric data attached to items to distinguish them and give a complete picture of the project. All facets of a project can be scheduled, estimated and visualized in one interactive

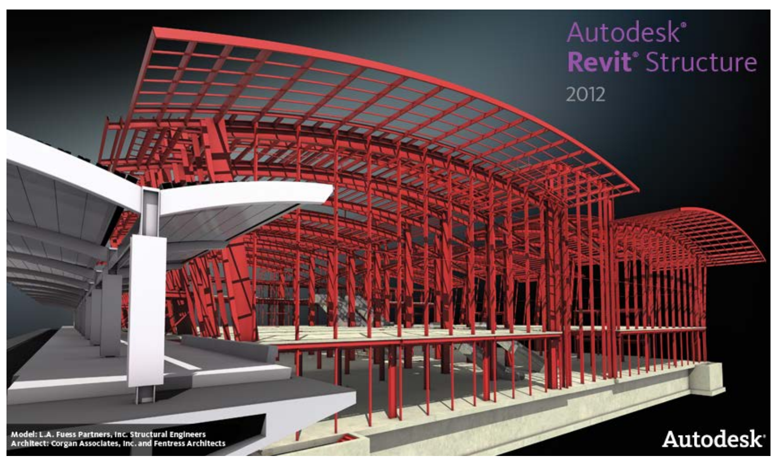


Figure 6: Autodesk Revit Structure

model. “The building information model is a project as well as a process simulation” (Kymmell, 2008). Planning and building a project virtually allows all aspects to be considered and communicated before anything needs to be finalized. “After all, if there is only one opportunity to do it right, it makes a lot of sense to prepare well for that single occasion virtually, and thereby reduce the inherent risks and improve the chances for success and efficiency” (Kymmell, 2008). Figure 7 is an example of a BIM 3D Model.

Figure 7: Example of BIM 3D Model (Reid, 2011)

BIM allows and encourages “integration among all the trades during design and construction phases”. This pre-coordination brings everyone “together on a project to ensure compliance” (Murphy, 2009). By reviewing the model and running clash detection, conflicts that can increase project cost and duration are able to be rectified immediately. In one example presented by Reid (2011), during virtual coordination meetings, a design team “spotted more than 7,200 potential mechanical and plumbing systems conflicts, whereas only one of those conflicts would have been discovered through a conventional review of 2D paper documents”. An additional “250 constructability issues were discovered via the model-based approach compared with six through the 2D process” (Reid, 2011). Discovering these issues prior to construction saved approximately $1.7 million, saving not only money but time.

"Building information modeling software can produce significant time savings, smooth project logistics and facilitate communication with both clients and subcontractors" (Rollins, 2008).

2.3.2 The BIM Advantage

Both contractors and owners are seeing the benefits of BIM. It has been shown to "reduce the number of change orders and requests for information that impede projects and increase their costs; improving the coordination between the architectural, structural, and mechanical systems designs to avoid conflicts, optimizing spatial allocations; and streamlining the material estimating processes" (Reid, 2011). BIM improves communication and fosters collaboration and "the best design processes are collaborative ones" (Behrens, 2009).

Building information modeling is not only a tool that can be optimized today but greater utilized in the future. "If all subcontractors aren't using BIM now, that day is fast approaching as they realize the impact it can have on their work… It is clear that BIM is a transformational technology that will be reshaping the field for years to come" (Rollins, 2008). BIM has a tremendous amount of potential that can continue to improve the design and construction field.

2.3.3 AIA Level of Detail

Drawings and building information models can be created with all different attributes and at different levels of detail. The AIA (American Institute of Architects) has set standards, which are dictated in the E202 document, on the level of detail (LOD) when completing a BIM model (Kal-Blue, 2011). Five levels have been defined from LOD 100 to LOD 500 (Kal-Blue, 2011).

The LOD 100 level is considered appropriate for conceptual design including overall building massing and whole building analysis. LOD 200 models consist of “generalized systems including approximate quantities, size, shape, location and orientation”. It is the schematic design or development. The LOD 300 level is equivalent to “traditional construction documents and shop drawings” (Kal-Blue, 2011). Simple definitions of each level are as follows:

100 Conceptual
200 Approximate Geometry
300 Precise Geometry
400 Fabrication
500 As-built

LOD 400 is suitable for fabrication and assembly, and is most likely to be used by specialty trades. The final level, LOD 500, represents the project “as it has been constructed including as-builts”. These models include completed parameters and attributes (Kal-Blue, 2011). Figure 8 displays and describes each level of detail.

Further breaking down the concept Figure 9 defines each level in terms of model content and authorized uses. The uses considered for each level are 4D scheduling, cost estimating, program compliance, sustainable materials, and environmental issues (Bedrick, 2011). Figure 10 provides example elements from a project and the detail of each element that would classify it in each level.

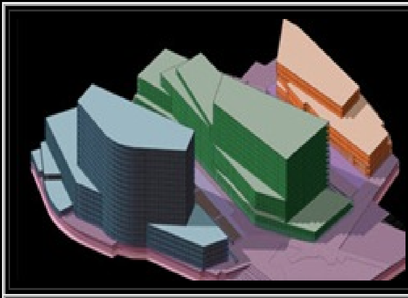
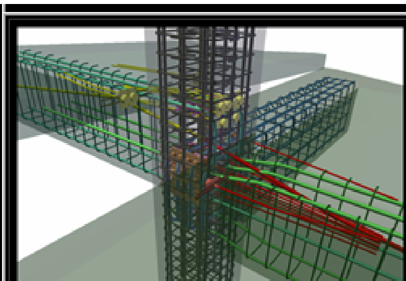
	LOD 100 - Essentially the equivalent of **conceptual design**, the model would consist of overall building massing and the downstream users are authorized to perform whole building types of analysis (volume, building orientation, cost per square foot, etc.)
	LOD 200 - Similar to **schematic design** or **design development**, the model would consist of "generalized systems or assemblies with approximate quantities, size, shape, location and orientation." Authorized uses would include "analysis of selected systems by application of generalized performance criteria."
	LOD 300 - Model elements are suitable for the generation of traditional **construction documents** and shop drawings. As such, analysis and simulation is authorized for detailed elements and systems.
 *Image courtesy of Mortenson Construction*	LOD 400 - This level of development is considered to be suitable for fabrication and assembly. The MEA for this LOD is most likely to be the trade contractor or fabricator as it is usually outside the scope of the architect's or engineer's services or would constitute severe risk exposure if such parties are not adequately insured.
	LOD 500 - The final level of development represents the project as it has been constructed - the as-built conditions. The model is suitable for maintenance and operations of the facility.

Figure 8: Outline of LOD (Van, 2008)

Level of Detail ->	100	200	300	400	500
Model Content					
Design & Coordination (function / form / behavior)	Non-geometric data or line work, areas, volumes zones, etc.	Generic elements shown in three dimensions - maximum size - purpose	Specific elements Confirmed 3D Object Geometry - dimensions - capacities - connections	Shop drawing/ fabrication - purchase - manufacture - install - specified	As-built - actual
Authorized uses					
4D Scheduling	total project construction duration phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	
Cost Estimating	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of generic element. E.g., generic interior wall.	Estimated cost based on measurement of specific assembly. E.g., specific wall type.	Committed purchase price of specific assembly at Buyout.	Record costs
Program Compliance	Gross departmental areas	Specific room requirements	FF&E, casework, utility connections		
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled/locally purchased materials	Specific manufacturer selections	Purchase documentation
Environmental: Lighting, Energy use, air movement Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Precise simulation based on specific manufacturer and detailed system components	Commissioning and recording of measured performance

Figure 9: LOD Descriptions (Bedrick, 2011)

Level of Detail ->	100	200	300	400	500
Element					
Interior wall	Not modeled. Cost and other information can be included as an amount per s.f. of floor area.	A generic interior wall, modeled with an assumed nominal thickness. Properties such as cost, STC rating, or U-value may be included as a range.	A specific wall type, modeled with the actual thickness of the assembly. Properties such as cost, STC rating, or U-value can be specified.	Fabrication details are modeled where needed.	The actual installed wall is modeled.
Duct run	Not modeled. Cost and other information can be included as an amount per s.f. of floor area.	A 3-dimensional duct with approximate dimensions.	A 3-dimensional duct with precise engineered dimensions.	A 3-dimensional duct with precise engineered dimensions and fabrication details.	A 3-dimensional representation of the installed duct.

Figure 10: LOD Examples (Bedrick, 2011)

To define the level of detail the AIA provides Model Element Tables as shown in Figure 11 below. The parties responsible for developing the model content are Model Element Authors (MEAs) and, per the AIA fill, out such tables to document the work and appropriate level of detail (Van, 2008).

§ 4.3 Model Element Table

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

				100 % Schematic Design		Design Development		Construction Documents		O & M			
Model Elements Utilizing CSI UniFormat™				LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	M
A SUBSTRUCTURE	A10 Foundations	A1010	Standard Foundations	100	SOM	200	WSP	300	WSP	500	TC		
		A1020	Special Foundations	-	-	-	-	-	-	-	-		
		A1030	Slab on Grade	100	SOM	200	WSP	300	WSP	500	TC		
	A20 Basement Construction	A2010	Basement Excavation										
		A2020	Basement Walls	100	SOM	300	SOM	300	SOM	500	TC		
B SHELL	B10 Superstructure	B1010	Floor Construction	200	SOM	300	SOM	400	SOM	500	TC		
		B1020	Roof Construction					400	SOM	500	TC		
	B20 Exterior Enclosure	B2010	Exterior Walls										
		B2020	Exterior Windows										
		B2030	Exterior Doors										

Figure 11: Sample Model Element Table (Van, 2008)

2.4 Building Codes

The purpose of building codes is to regulate the construction of facilities in order to protect the public's safety and general welfare. The *Massachusetts State Building Code* is controlled by the *Board of Building Regulations and Standards* (BBRS) (Massachusetts Department of Public Safety, 2011). The first edition of the *Massachusetts State Building Code* was developed in 1975 and has been edited over time to the current 8th edition (Guigli, 2011). This edition is based on the *2009 International Building Code* (IBC) which includes the *International Mechanical Code* (IMC), *International Existing Building Code* (IEBC), *International Fire Code* (IFC) and the *International Energy Conservation Code* (IECC). Figure 12 shows the *2009 International Building Code*. The 8th edition also includes amendments to the *IBC* to coincide with "Massachusetts laws and regulations and unique requirements" (Executive Office of Public Safety and Security, 2011). The 8th edition is comprised of different chapters relating to various types of building construction and their associated regulations. If general requirements and specific requirements of the different chapters do not agree with each other, then the most restrictive requirement is used (Executive Office of Public Safety and Security, 2011). In addition, any existing structures on the date the 8th edition is adopted shall remain unchanged

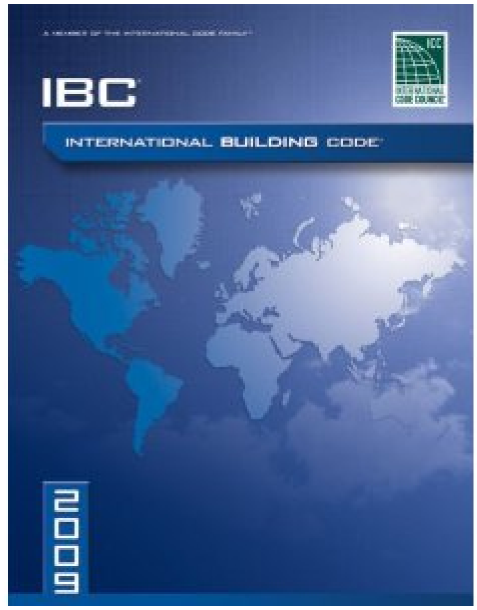


Figure 12: International Building Code

unless defined in the new edition or judged by the building official to need to change (Executive Office of Public Safety and Security, 2011).

Chapter 34 of the Massachusetts State Building Code applies to existing building regulations and is based off of *IEBC 2009* and MA amendments (Guigli, 2011).

2.4.1 Massachusetts State Building Code Chapter 34

There are three compliance methods for existing buildings according to the *IEBC*: the prescriptive method, work area compliance method and performance method. The compliance method used is up to the owner's discretion (Guigli, 2011). The level of compliance of existing buildings is based on the cost of work and the construction performed. If work costs less than $100,000, then only the new construction being done on the building must follow the regulations set by the 8th edition (Woodworth, 2011). If the scope of work costs more than $100,000 but less than 30% of "full and fair cash value of existing building," then only certain regulations are applied (Woodworth, 2011). If the cost of work is 30% or more of the "full and fair cash value of the existing building" then the entire building must adhere to the codes (Woodworth, 2011). As stated in the Code for any proposed work, with the issuance of a building permit, the building's compliance with the Code shall be evaluated. This evaluation usually includes the "evaluation of design gravity loads, lateral load capacity, egress capacity, fire protection systems, fire resistant construction, interior environment, hazardous materials, and energy conservation" (Executive Office of Public Safety and Security, 2011).

2.4.2 Seismic Codes for Existing Structures

In the past, earthquakes have not been major factors for structural designs in New England, unlike in California or along fault lines. However, recently earthquake magnitudes and frequency have increased, resulting in the Building Seismic Safety Council (BSSC) increasing seismic code regulations (Seismology and Structural Standards Committee, 2005). The BSSC created standards to ensure that buildings remain standing during a seismic event to protect lives and property and also the building does not deteriorate rapidly afterwards. The following table, Table 1, represents the different seismic force resisting systems along with their R, Ω_0, and C_d values that help building officials analyze the structures and determine if they comply with codes (State Board of Building Regulations and Standards, 2011). R is the Seismic response Modification. This factor helps to simplify the design process so only the linear elastic static analysis is needed to design the building (SEAOC Seismology Committee, 2008). Ω_0 is the seismic force amplification factor or the structural overstrength factor. It is used to calculate the realistic seismic force in a member from the elastic design seismic forces (SEAOC Seismology Committee, 2008). C_d is the deflection amplification factor. This factor helps to determine the maximum deformations that can be expected from the design seismic forces (SEAOC Seismology Committee, 2008). These factors can help determine compliance to the *Massachusetts State Building Code* provisions for seismic design.

Table 1: Seismic Force Resisting (State Board of Building Regulations and Standards, 2011)

BASIC SEISMIC-FORCE-RESISTING SYSTEM	*R*	Ω_0	C_d
Bearing Wall Systems			
Steel concentrically braced frame (CBF) with diagonal [3] or X-bracing			
CBF per 6th Edition SBC[2] except for Section 9.5 of 1992 AISC Seismic Provisions	3.5	2	3.5
Otherwise[4]	3	3	3
Steel CBF with V, Inverted V or K bracing			
V or Inverted V bracing per 6th Edition SBC[2]	3	3	3
V or Inverted V bracing, otherwise[4]	3	3	3
K bracing	1.25	1.25	1.25
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition	5	2.5	5
Reinforced concrete shear walls with reinforcing steel less than required by, or with spacing greater than permitted by Section 11.9.9 of ACI 318-08	1.5	1.5	1.5
Unreinforced concrete shear walls	1.25	1.25	1.25
Reinforced masonry shear walls			
Class A[5]	4.5	2.5	3.5
Class B[6]	2.25	2.25	2.25
Class C[7]	1.25	1.25	1.25
Unreinforced masonry shear walls	1.25	1.25	1.25
Light-framed walls sheathed with wood structural panels or diagonal sheathing	4	2.5	3
Other light-framed walls[10]	2	2	2
Building Frame Systems			
Steel concentrically braced frame (CBF) with diagonal [3] or X-bracing			
CBF per 6th Edition SBC[2] except for Section 9.5 of 1992 AISC Seismic Provisions	4	2	3.5
Otherwise[4]	3	3	3
Steel CBF with V, Inverted V or K bracing			
V or Inverted V bracing per 6th Edition SBC[2]	3	3	3
V or Inverted V bracing, otherwise[4]	3	3	3
K bracing	1.5	1.5	1.5
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition	6	2.5	5
Reinforced concrete shear walls with reinforcing steel less than required by, or with spacing greater than permitted by Section 11.9.9 of ACI 318-08	1.5	1.5	1.5
Unreinforced concrete shear walls	1.5	1.5	1.5
Reinforced masonry shear walls			
Class A[5]	5	2.5	4
Class B[6]	2.25	2.25	2.25
Class C[7]	1.5	1.5	1.5
Unreinforced masonry shear walls	1.5	1.5	1.5
Light-framed walls sheathed with wood structural panels or diagonal sheathing	4	2.5	3
Other light-framed walls[10]	2.5	2.5	2.5

Moment Resisting Frame Systems			
Steel moment frames			
Special Moment Frame per 6th Edition SBC[2]	8	3	5.5
Ordinary Moment Frame per 6th Edition SBC[2]	3.5	3.5	3.5
Moment frame, otherwise[4]	3	3	3
Reinforced concrete moment frames			
Class A[8]	5	3	4.5
Class B[9]	2.5	2.5	2.5
Dual Systems (See ASCE 7, Section 12.2.5.1)			
Steel concentrically braced frame (CBF) with steel moment frames (MF)			
CBF and Special Moment Frame, per 6th Edition SBC[2]	5	2.5	4.5
CBF and Moment Frame per 1st through 5th Editions SBC[2], except V, Inverted V or K Braced Frames	3.5	2.5	3.5
CBF and Moment Frame per 1st through 5th Editions SBC[2], with V, Inverted V or K Braced Frames	3	2.5	3
Otherwise	1.5	1.5	1.5
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition, with reinforced concrete moment frames, Class A[8]	6	2.5	5
Ordinary reinforced concrete shear walls, as defined in 8th Edition SBC, with reinforced concrete moment frames, Class A[8]	5.5	2.5	4.5

Notes:

1. Systems of previous editions of the State Building Code that meet the ductility requirements of the 8th Edition of the Code are not included in this table.
2. SBC refers to 780 CMR Commonwealth of Massachusetts State Building Code.
3. A diagonal brace is one that frames from a beam-to-column connection diagonally to another beam-to-column connection or to a column at its base plate.
4. The seismic resistance of the frame shall be based on its seismic connections being subject to two times the computed forces and moments resulting from seismic load.
5. Class A reinforced masonry shear walls have a minimum total area of reinforcement in the vertical and horizontal direction at least 0.0020 times the gross cross-sectional area of the wall, with a minimum area in each direction at least 0.0007 times the gross cross-sectional area of the wall. Maximum spacing of reinforcing steel bars in grouted cells or bond courses is 6'-0" in one direction and 4'-0" in the other direction, but not more than 1/3 of the length or height of the wall, whichever is less, in each direction. Class A walls satisfy other requirements for reinforced masonry of the base code.
6. Class B reinforced masonry shear walls satisfy all requirements for Class A walls, except that spacing limits for reinforcing steel bars are exceeded.
7. Class C reinforced masonry shear walls satisfy all requirements for reinforced masonry of the base code.
8. Class A reinforced concrete moment frames satisfy requirements of Sections 1113.5.1, 1113.5.1.1, 1113.5.1.2 and 1113.5.1.3 of 780 CMR 5th Edition and Sections 11.12.1.1 and 11.12.1.2 of ACI 318-83 for reinforcing of beam to column joints.
9. Class B reinforced concrete moment frames do not satisfy requirements for Class A reinforced concrete moment frames.
10. Wood siding over horizontal or diagonal boards, plaster on wood or metal lath, and stucco on metal lath may be used to resist in-plane shear, where the walls are anchored to floors and to the floor or roof construction above such that they can transfer the shear between floors and to the foundation. Gypsum sheathing, lath, wall board, drywall, fiberboard and particle board are not permitted to resist in-plane shear unless originally designed in accordance with 780 CMR for that purpose.

2.4.3 Massachusetts State Building Code Chapter 34 Appendix A

Appendix A1 of Chapter 34 was written to "reduce the risk of death or injury that may result from the effects of earthquakes on existing, unreinforced, masonry walls" (Cowen, 2011). The codes state that all masonry walls must comply with Appendix A1 if any of the following conditions are met: work area is more than 50% of the building; occupancy increases more than 25%; a change of occupancy to a relative hazard category of 1 or 2; and/or if there is a level 2 alteration (Mariani, 2011). In order to determine whether a building is in compliance with the *Code*, initial tests are done to assess the strength of materials. The minimum values are:

f'm= 300 psi

Em= 550,000 psi

f'sp= 0 psi (tensile splitting strength)

Vm= 20 psi (running bond)

Vm= 20 psi (fully grouted)

Vm= 10 psi (partially grouted, ungrouted, no running bond)

The masonry and the mortar must be tested separately in order to determine code compliance. Section A106.3.3 refers to masonry testing including minimum qualities of mortar and masonry as well as testing procedures and other testing regulations. The *Code* states that the qualities shall be determined by in-place shear tests unless this will cause the masonry unit to fail. In the case that in-place shear tests cannot be used, drilled core tests or hollow unit masonry tests should be used instead (International Code Council, 2007). Figure 13 shows an in-place shear test. Section A106.3.3.5 specifies the minimum quality of mortar; the data from the testing is used to determine the quality. The minimum quality of mortar shall be determined by the equation:

$$v_{to} = (V_{test}/A_b) - p_{D+L}$$

If v_{to} is less than 30 pounds per square inch or 207kPa, then the mortar shall be re-pointed and retested (International Code Council 2007). Section A106.3.3.6 regulates the minimum quality of masonry and states that f_{sp} shall be a minimum of 50 psi (Cowen, 2011).

Figure 13. In-place Shear Test

2.4.4 Wind Codes for Existing Structures

Buildings are often damaged by hurricanes, thunderstorms, and other high speed wind storms. The Massachusetts 8th edition follows the wind design provisions set in place by the *IBC*. The *IBC* states that all roof decks must be designed to withstand the wind pressures according to *ASCE 7* and the basic wind speeds in their area (International Code Council, 2007). Table 2 shows the different basic wind speeds in Massachusetts; Worcester is boxed (State Board of Building Regulations and Standards, 2009). According to the Massachusetts 8th edition building codes for existing structures, roof diaphragms will have to be re-evaluated if more than

50% of roofing materials are removed where the basic wind speed is greater than 90mph or in a special wind region. If the results of the building evaluation do not comply with the wind loads specified in the *IBC*, then the diaphragms and connections will have to be strengthened or replaced (Bonowitz, 2010).

Table 2: Massachusetts Basic Wind Speeds (State Board of Building Regulations and Standards, 2009)

TABLE 5301.2(4) MASSACHUSETTS BASIC WIND SPEEDS

<90 MPH	90 MPH		100 MPH		110 MPH
Adams	Acton	New Braintree	Abington	Middleton	Acushnet
Alford	Agawam	New Marlborough	Amesbury	Milford	Aquinnah
Ashfield	Amherst	New Salem	Andover	Millis	Barnstable
Becket	Ashburnham	North Brookfield	Arlington	Millville	Bourne
Bernardston	Ashby	Northampton	Ashland	Milton	Brewster
Buckland	Athol	Northborough	Attleboro	Nahant	Carver
Cheshire	Auburn	Northfield	Avon	Natick	Chatham
Clarksburg	Ayer	Oakham	Bedford	Needham	Chilmark
Colrain	Barre	Orange	Bellingham	Newbury	Dartmouth
Cummington	Belchertown	Otis	Belmont	Newburyport	Dennis
Dalton	Berlin	Palmer	Berkley	Newton	Duxbury
Egremont	Blandford	Paxton	Beverly	Norfolk	Eastham
Florida	Bolton	Pelham	Billerica	North Andover	Edgartown
Great Barrington	Boxborough	Pepperell	Blackstone	North Attleborough	Fairhaven
Greenfield	Boylston	Petersham	Boston	North Reading	Fall River
Hancock	Brimfield	Phillipston	Boxford	Northbridge	Falmouth
Hawley	Brookfield	Princeton	Braintree	Norton	Freetown
Heath	Carlisle	Royalston	Bridgewater	Norwell	Gay Head
Hinsdale	Charlton	Russell	Brockton	Norwood	Gosnold
Lanesborough	Chelmsford	Rutland	Brookline	Oxford	Halifax
Lee	Chester	Sandisfield	Burlington	Peabody	Harwich
Lenox	Chesterfield	Shirley	Cambridge	Plainville	Kingston
Leyden	Chicopee	Shrewsbury	Canton	Quincy	Lakeville
Middlefield	Clinton	Shutesbury	Chelsea	Randolph	Marion
Monroe	Conway	South Hadley	Cohasset	Raynham	Marshfield
Monterey	Deerfield	Southampton	Concord	Reading	Mashpee
Mount Washington	Dracut	Southbridge	Danvers	Rehoboth	Mattapoisett
New Ashford	Dunstable	Southwick	Dedham	Revere	Middleborough
North Adams	East Brookfield	Spencer	Dighton	Rockland	Nantucket
Peru	East Longmeadow	Springfield	Douglas	Rockport	New Bedford
Pittsfield	Easthampton	Sterling	Dover	Rowley	Oak Bluffs
Plainfield	Erving	Stow	Dudley	Salem	Orleans
Richmond	Fitchburg	Sturbridge	East Bridgewater	Salisbury	Pembroke
Rowe	Gardner	Sunderland	Easton	Saugus	Plymouth
Savoy	Gill	Templeton	Essex	Seekonk	Plympton
Sheffield	Goshen	Tolland	Everett	Sharon	Provincetown
Shelburne	Granby	Townsend	Foxborough	Sherborn	Rochester
Stockbridge	Granville	Tyngsborough	Framingham	Somerville	Sandwich
Tyringham	Groton	Wales	Franklin	Southborough	Scituate
Washington	Hadley	Ware	Georgetown	Stoneham	Somerset
West Stockbridge	Hampden	Warren	Gloucester	Stoughton	Swansea
Williamstown	Hardwick	Warwick	Grafton	Sudbury	Tisbury
Windsor	Harfield	Wendell	Groveland	Sutton	Truro
Worthington	Harvard	West Boylston	Hamilton	Swampscott	Wareham
	Holden	West Brookfield	Hanover	Taunton	Wellfleet
	Holland	West Springfield	Hanson	Tewksbury	West Tisbury
	Holyoke	Westfield	Haverhill	Topsfield	Westport
	Hubbardston	Westford	Hingham	Upton	Yarmouth
	Hudson	Westhampton	Holbrook	Uxbridge	
	Huntington	Westminster	Holliston	Wakefield	
	Lancaster	Whately	mm	Walpole	
	Lawrence	Wilbraham	Hopkinton	Waltham	
	Leicester	Williamsburg	Hull	Watertown	
	Leominster	Winchendon	Ipswich	Wayland	
	Leverett	Worcester	Lexington	Webster	
	Littleton		Lincoln	Wellesley	
	Longmeadow		Lynn	Wenham	
	Lowell		Lynnfield	West Bridgewater	
	Ludlow		Malden	West Newbury	
	Lunenburg		Manchester	Westborough	
	Maynard		Mansfield	Weston	
	Methuen		Marblehead	Westwood	
	Millbury		Marlborough	Weymouth	
	Monson		Medfield	Whitman	
	Montague		Medford	Wilmington	
	Montgomery		Medway	Winchester	
			Melrose	Winthrop	
			Mendon	Woburn	
			Merrimac	Wrentham	

2.4.6 Fire Codes- National Fire Protection Association (NFPA)

The National Fire Protection Association (NFPA) was established in 1896. Since then, NFPA is now responsible for 300 codes and standards. Currently, the association consists of 200 technical committees that include 6,000 volunteers. Besides codes and standards, NFPA also promotes other fire safety initiatives. These include “Fire Sprinkler Initiatives: Bringing Safety Home,” promoting the installation of residential sprinklers; “Firewise Communities” protecting communities against wildfires; and “Electric Vehicle Safety Training,” training for first responders in emergency situation dealing with electric vehicles.

A common misconception is that NFPA writes and changes the codes and standards within the association. In reality, the public submits proposals to alter a standard or code. Then every three years, the technical committees within NFPA vote on the proposals to change the current code or standard. These codes and standards are adopted by each state and are then made law. States are allowed to adopt any edition, add to, or subtract from any edition. Currently, Massachusetts uses the 2007 edition of *NFPA 13*, 2008 edition of *NFPA 72*, and the 2008 edition of *NFPA 25*. This project will focus *on NFPA 13, NFPA 72*, and *NFPA 25.*

NPFA 13

NFPA 13 is the National Fire Protection Association’s *Standard for the Installation of Sprinkler Systems*. The first edition of *NFPA 13* was released in 1896. At that time, the standard was referred to as *Rules and Regulations of the National Board of Fire Underwriters for Sprinkler Equipments, Automatic and Open Systems*. Since 1896, NFPA has released 59 editions, the most recent being in 2010. The standard’s current set of chapters with their emphasis are presented in Table 3.

Table 3: Focus of NFPA 13 Chapters

CHAPTER	EMPHASIS
General Requirements	• Level of Protection • Owner's Certificate
Classification of Occupancies and Commodities	• Occupancies (Light, Ordinary, and Extra Hazard) • Commodities Classes (Mixed, I-IV, Plastics, Papers, and Tissues)
System Components and Hardware	• Listings • Sprinklers • Aboveground Pipe and Tube • Fitting Pressure Limits • Welded Pipe and Fittings • Valves • Fire Department Connections • Alarm Devices
System Requirements	• Wet Pipe, Dry Pipe, Preaction, Deluge Systems • Systems for Piers, Terminals, and Wharves • Antifreeze Systems • Sprinklers • Refrigerated Systems • Cooking Equipment and Ventilation
Installation Requirements	• System Protection Area • Use/Application of Sprinklers Types • Position, Location, Spacing, and Use of Sprinklers • Types of Sprinklers • Pilot Detectors • Special Simulations • Piping Installations • System Attachments
Hanging, bracing, and restraint of system piping	• Installation • Protection against Earthquakes
Underground Piping	• Piping Materials and Fittings • Protections against Freezing • Testing and Acceptance
Design Approaches	• Occupancy Hazard Fire Control Approach • Special Design Approach
General Requirements for Storage	• System Types • Storage Applications • Room Design Method
Miscellaneous Storage	• Design Basis

CHAPTER	EMPHASIS
	• In-Rack Sprinklers
Protection of Commodities	• Sprinkler Types for Commodity Protection • High Expansion Foam
Plans and Calculations	• System Types • Working Plans
System Acceptance	• Approval of Systems and Mains • Acceptance requirements • Instructions and Signs
Marine Systems	• Components, Hardware, and Use • System and Installation Requirements • Design, Plans, and Calculations • Instructions and Maintenance
System Inspection, Testing, and Maintenance	• Inactive Sprinklers Abandoned in Place

The focus of this project mostly consisted of Installation Requirements from *NFPA 13,* and the details of these chapters are explained in following paragraphs.

The scope of *NFPA 13* defines the range of criteria that the document regulates. The main scope is found in Section 1.2.1 of *NFPA 13*: "This standard shall provide the minimum requirements for the design and installation of automatic fire sprinkler systems and exposure to protection sprinkler systems covered within this standard." The committees that produce *NFPA 13* are charged with the task of defining what a "reasonable degree of protection for life and property" is and including requirements to fulfill this "reasonable degree." The scope also states that this document provides protections in buildings where there is only one fire. *NFPA 13* states the requirements for protecting a building against a fire but it is the responsibility of building owners and their representatives to evaluate and apply appropriate sections of this standard.

The purpose of *NFPA 13* defines how the scope shall be accomplished. In Section 1.2.1 of *NFPA 13*, "The purpose of this standard shall be to provide a reasonable degree of protection for life and property from fire through standardization of design, installation, and testing requirements for sprinkler system, including private fire service mains, based on sound engineering principles, test data, and field experience." The purpose also uses the subjective term of "reasonable degree of protection" and defining this term is up to the discretion of the committees. Since this document may not include all materials and devices available, *NFPA 13* allows the use of other materials and devices as long as these items are listed and their installation is completed according to the listing requirements.

The application of *NFPA 13* states the items to which this document pertains. Section 1.3.1 of *NFPA 13* defines these items as:

1. Character and Adequacy of Water Supplies
2. Selection of Sprinklers
3. Fittings
4. Piping
5. Valves
6. All materials and accessories, including the installation of private fire service mains

"This standard shall also applies to 'combined service mains' used to carry water for both fire service and other uses as well as to mains for fire service use only" (*NFPA 13* Section 1.3.2). *NFPA 13* is responsible for covering requirements on these items only and items not in this document are under the responsibility of the listing organization.

Chapter 8 focuses on installation requirements. Section 8.1.1 states that “the requirements for spacing, location, and position of sprinklers shall be based on the following principles:”

1. Sprinklers shall be installed throughout the premises.
2. Sprinklers shall be located so as not to exceed the maximum protection area per sprinkler.
3. Sprinklers shall be positioned and located so as to provide satisfactory performance with respect to activation time and distribution.
4. Sprinklers shall be permitted to be omitted from areas specifically allowed by this standard.
5. When sprinklers are specifically tested and test results demonstrate that deviations from clearance requirements to structural members do not impair the ability of the sprinkler to control or suppress a fire, their positioning and location in accordance with the test results shall be permitted.
6. Clearance between sprinklers and ceilings exceeding the maximums specified in this standard shall be permitted. Provided that tests or calculations demonstrate comparable sensitivity and performance of the sprinklers to those installed in conformance with these sections.
7. Furniture, such as portable wardrobe units, cabinets, trophy cases, and similar features not intended for occupancy, does not require sprinkler to be installed in them. This type of feature shall be permitted to be attached to the finished structure.

The first, second, fourth, fifth, and sixth principles were the focus of this project. These principles apply to a set of sections within Chapter 8 of *NFPA 13* as shown in Table 4 on the next page.

Table 4: Applicable Sections of NFPA 13 Chapter 8

Principle	Applicable Sections of NFPA 13 Chapter 8
1. Sprinklers shall be installed throughout the premises	• 8.1 Basic Requirements • 8.2 System Protection Area Limitations •
2. Sprinklers shall be located so as not to exceed the maximum protection area per sprinkler.	• 8.3 Use of Sprinklers • 8.5 Position, Location, Spacing and Use of Sprinklers
4. Sprinklers shall be permitted to be omitted from areas specifically allowed by this standard.	• 8.3 Use of Sprinklers • 8.5 Position, Location, Spacing and Use of Sprinklers • 8.15 Special Situations
5. When sprinklers are specifically tested and test results demonstrate that deviations from clearance requirements to structural members do not impair the ability of the sprinkler to control or suppress a fire, their positioning and location in accordance with the test results shall be permitted	• 8.5 Position, Location, Spacing and Use of Sprinklers • 8.6-8.13 Sprinkler Types
6. Clearance between sprinklers and ceilings exceeding the maximums specified in this standard shall be permitted. Provided that tests or calculations demonstrate comparable sensitivity and performance of the sprinklers to those installed in conformance with these sections.	• 8.5 Position, Location, Spacing and Use of Sprinklers • 8.6-8.13 Sprinkler Types

The sections identified in Table 4 were the focus of the *NFPA 13* fire code study presented in this project. This list is abbreviated from a full list of sections that could have been analyzed in the project but time constraints warranted a focus of these sections from Chapter 8.

NFPA 72

NFPA 72 is the National Fire Protection Association's *National Fire Alarm and Signaling Code*. The first edition of *NFPA 72* was released in 1899 and was referred to as *NFPA 71-D General Rules for the Installation of Wiring and Apparatus for Automatic Fire Alarms, Hatch Closers, Sprinkler Alarms, and Other Automatic Alarm Systems and Their Auxiliaries*. It is particularly important for NFPA to release new editions of this code because technology for alarm systems is always evolving. The standard currently consists of chapters with emphasis presented in Table 5.

Table 5: Focus of NFPA 72 Chapters

CHAPTER	EMPHASIS
Fundamentals of Fire Alarm Systems	• Equipment and Personnel • System Fundamentals • Documentation • Impairments
Initiating Devices	• Requirements for Smoke and Heat Detectors • Fire Detectors • Smoke Detectors for Control of Smoke Spread
Protected Premises Fire Alarm Systems	• Performance of Circuits • System Features, Performance, and Integrity • Signal Annunciation
Notification Appliances for Fire Alarm Systems	• Audible and Visible Characteristics • Textual Audible and Visible Appliances • Standard Emergency Service Interface
Supervising Station Fire Alarm Systems	• Fire Alarm Systems for Central Station • Service Proprietary Supervising Station System • Communications Method for Supervising Station Fire Alarm Systems
Public Fire Alarm Reporting Systems	• General Fundamentals • Management and Maintenance • Alarm transmission equipment
Inspection, Testing, and Maintenance	• Application • Records
Single- and Multiple-Station Alarm and Household Fire Alarm Systems	• Purpose • Basic Requirements • Detections and Notification • Equipment Performance • Maintenance and Tests

The scope of work for this project primarily involved use of the following chapters: Initiating Devices, Protected Premises Fire Alarm Systems, and Inspection, Testing, and Maintenance from *NFPA 72*. The contents of these chapters are detailed in the following paragraphs.

The scope of *NFPA 72* governs what responsibility this code has. The scope is stated by *NFPA 72* Section 1.1.1 "*NFPA 72* covers the application, installation, location, performance, inspection, testing, and maintenance of fire alarm systems, fire warning equipment and emergency warning equipment, and their components." The code is responsible for providing the minimum requirements in each of the areas listed in the scope. *NFPA 72* does not mandate where a fire alarm system is necessary but does mandate how to install this equipment.

The purpose of *NFPA 72* defines how to accomplish the responsibilities of the scope. In Section 1.2.1, "The purpose of this Code is to define the means of signal initiation, transmission, notification, and annunciation; the levels of performance; and the reliability of the various types of fire alarm systems." This code is meant to also provide information necessary to modify or upgrade an existing system and establish minimum required levels of performance.

The application of *NFPA 72* defines what items fall into this code. Sections 1.3.1 defines fire alarm systems as the following:

1. Household Fire Alarms Systems
2. Protected Premises (local) Fire Alarm Systems
3. Supervising Station Fire Alarm Systems
    a. Central Station (service) Fire Alarm Systems
    b. Remote Supervising Station Fire Alarm Systems
    c. Proprietary Supervising Station Fire Alarm Systems
4. Public Fire Alarm Reporting Systems
    a. Auxiliary Fire Alarm Systems – Local Energy Type
    b. Auxiliary Fire Alarm Systems – Shunt Type

The systems listed in the application are used for any of the following purposes: notifying occupants to evacuate from the premise, creating communication between the premise and station, and notifying the fire department of a potential fire.

Chapter 5 focuses on initiating devices within a fire alarm system. The application of this chapter is "the performance, selection, use, and location of automatic fire detection devices, sprinkler waterflow detectors, manually activated fire alarm stations, and supervisory signaling devices" (*NFPA 72* Section 5.1.1). From this chapter, this project focused on the sections relating to detectors in a fire alarm system. Table 6 includes a list of the sections of Chapter 5 relevant to this project.

Table 6: Applicable Sections of NFPA 72 Chapter 5

Sections of Chapter 5
• **5.4 General Requirements** • **5.5 Requirements for Smoke and Heat Detectors** • **5.6 Heat-sensing Fire Detectors** • **5.7 Smoke-Sensing Fire Detectors** • **5.8 Radiant Energy-Sensing fire Detectors** • **5.13 Manually Actuated Alarm-Initiating Devices** • **5.16 Smoke Detectors for Control of Smoke Spread**

Chapter 6 focuses on fire alarm systems within protected premises. The application of this chapter is "the application, installation, and performance of fire alarm systems within protected premises, including fire alarm and supervisory signals" (*NFPA 72* Section 6.1.1). From this chapter, this project focused on the sections relating to annunciation in fire protection systems. Table 7 includes a list of the sections of Chapter 6 relevant to this project.

Table 7: Applicable Sections of NFPA 72 Chapter 6

Sections of Chapter 6
• **6.3 System Features** • **6.4 System Performance and Integrity** • **6.8 System Requirements** • **6.9 Emergency Voice/Alarm Communications** • **6.10 Two-way Communication Service** • **6.11 Signal Annunciation**

Chapter 10 focuses on inspection, testing, and maintenance. The application of this chapter is "the inspection, testing, and maintenance of fire alarm systems, their initiating devices, and notification appliances" (*NFPA 72* Section 10.1.1). The requirements of this chapter are also retroactive due to section 10.1.4 that states "The requirements of this chapter shall apply to both new and existing systems." Table 8 includes a list of the sections of Chapter 10 relevant to this project:

Table 8: Applicable Sections of NFPA 72 Chapter 10

Sections of Chapter 10
• **10.2 General** • **10.3 Inspection** • **10.4 Testing** • **10.5 Maintenance** • **10.6 Records**

NFPA 25

NFPA 25 is the National Fire Protection Association's *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*. The first edition of *NFPA 25* was released in 1940. At that time, the standard was referred to as *NFPA 13A Recommended Practice for the Inspection, Testing and Maintenance of Sprinkler Systems*. 11 editions of *NFPA 13A* were produced when, in 1993, *NFPA 13A* was officially withdrawn and replaced with *NFPA 25*. In 1988 a new standard, NFPA 14A *Recommended Practice for the Inspection, Testing, and Maintenance of Standpipe and Hose Systems* was adopted. However this standard only lasted one edition when it was also merged into *NFPA 25* in 1993. Since 1993, NFPA has released 5 editions of *NFPA 25* and the most recent being 2011. The standard's current set of chapters with their emphasis are presented in Table 9.

Table 9: Focus of NFPA 13 Chapters

CHAPTER	EMPHASIS
General Requirements	• Responsibility of the Property Owner • Impairments • Corrective Action • Records • Inspection, Testing, and Maintenance • Safety
Sprinkler Systems **Standpipe and Hose Systems** **Private Fire Service Mains** **Fire Pumps** **Water Storage Tanks** **Foam-Water Sprinkler Systems**	• Inspection, Testing, and Maintenance • Component Action Requirements
Valves, Valve Components, and Trim	• Control valves in Water-Based Fire Protection Systems • System valves • Pressure Reducing Valves and Relief Valves • Backflow Prevention Assemblies • Fire Department Connections
Obstruction Investigation	• Obstruction Investigation Prevention • Ice Obstruction
Impairments	• Impairment Coordinator • Tag Impairment System Impaired equipment • Preplanned Impairment Programs • Emergency Impairments • Restoring System to Service

This project mostly focused on the criteria presented for General Requirements and Sprinkler Systems from *NFPA 25*. The contents of *NFPA 25* are detailed in the following paragraphs.

The scope of *NPFA 25* defines requirements this document is responsible for. The main scope is found in Section 1.1 of *NFPA 25*: "This document establishes the minimum requirements for the periodic inspection, testing, and maintenance of water-based fire protection systems, including land-based and marine applications." However *NFPA 25* does not include the entire requirements for electrical components of automatic fire detection equipment for preaction and deluge systems. This standard addresses sprinkler, standpipe and hose, fixed water spray, and foam water systems.

The purpose of *NFPA 25* defines how the scope will be accomplished. This is presented in Section 1.2 of *NFPA 25*: "The purpose of this document is to provide requirements that ensure a reasonable degree of protection for life and property from fire through minimum inspection, testing, and maintenance methods for water-based fire protection systems. In those cases where it is determined that an existing situation involves a distinct hazard to life or property, the authority having jurisdiction shall be permitted to require inspection, testing, and maintenance methods in excess of those required by the standard." *NFPA 25* gives the authority having jurisdiction (AHJ) flexibility in this statement by allowing them to enforce excess requirements if a distinct hazard occurs because they are usually the person enforcing the standard.

The application of *NFPA 25* defines what tasks this document pertains to. Section 1.3 of *NFPA 25* explains this: "It is not the intent of this document to limit or restrict the use of other inspection, testing, or maintenance programs that provide an equivalent level of system integrity and performance to that detailed in this document. The authority having jurisdiction shall be consulted and approval obtained for such alternative programs." *NFPA 25* does not dent the use of alternative or new methods for inspection, testing, or maintenance but an AHJ must approve these in order to be compliant with *NFPA 25*.

Chapter 4 of *NFPA 25* concentrates on general requirements, meaning the requirements that apply to an entire water-based system for inspection, testing, and maintenance. This chapter “outlines the administrative guidelines for compliance with the standard” (*NFPA 25* Handbook, page 43). Table 10 presents a list of the sections from Chapter 4 that were relevant to this project.

Table 10: Applicable Sections of NFPA 25 Chapter 4

Sections of Chapter 4
• **4.2 Impairments** • **4.3 Corrective Action** • **4.4 Records** • **4.5 Inspection** • **4.6 Testing** • **4.7 Maintenance** • **4.8 Safety**

Chapter 5 focuses on sprinkler systems. The purpose of this chapter is to “provide the minimum requirements for the routine inspection, testing, and maintenance of sprinkle systems” (*NFPA 25* Section 5.1). This chapter includes an encompassing table of all of inspection, testing, and maintenance tasks to be completed with their corresponding frequency. From this chapter, the project focused on the sections listed in Table 11.

Table 11: Applicable Sections of NFPA 25 Chapter 5

Sections of Chapter 5
• **5.2 Inspection** • **5.3 Testing** • **5.4 Maintenance** • **5.5 Component Action Requirements**

2.5 Past Construction Materials, Methods and Regulations

Differences in past and present construction can be seen when comparing the materials used, the methods followed, and the regulations and specifications that were in place from year to year. As the years change, new construction materials are developed bringing new methods of construction as well as new regulations and specifications into place.

2.5.1 Past Masonry Materials

Masonry is "the art of cutting or squaring stones to be applied to the purposes of building or, in a more limited sense, it is the art of joining stones together with mortar" (Smeaton, 1867). The strength of masonry depends on different factors: the brick laying pattern, the joint type and the mortar type. Table 12, Table 13 and Table 14 describe these different factors. In addition the methods associated with brick laying can also affect the strength. If perpendicular joints are too close to each other, then the work can crack down these joints in a vertical direction. Also, if the bricks that form the outer and inner walls of a cavity wall are not connected together in some way, then the wall may become unstable and fail due to its own weight (Smeaton, 1867). The compressive strength of masonry varies due to the factors of strength of unit, geometry of unit, strength of mortar, deformation characteristics of unit and mortar, joint thickness, suction of units, water retention ability of mortar and brickwork bonding (Hendry, 1981).

Bricks are artificial stone, made of clay into hardened rectangular prisms by burning or exposure to the sun. Bricks have been used for building different structures for a long time for many reasons. Brick walls can provide not only structure and sub-division of space but also insulation and fire and weather protection. In addition brick is durable and reasonably inexpensive. The compressive strength of brick is relatively high and is another reason brick has been used for so long (Hendry, 1981). In the 1860's the best known way to create bricks was to make them during the spring and autumn seasons because they would dry more equally during these times. If left for the sun to harden the bricks in the summer, then the heat of the sun would make its surface appear to be hardened and cured thoroughly when the internal parts of the brick were not. When these sun-dried bricks were used in construction they would continue to dry and consequently shrink, and the plaster that was placed prior to shrinking would have to hold itself as the bricks underwent shrinkage. In addition the areas that were dried first on the brick, the external portions, would break off making the bricks lose some strength (Smeaton, 1867).

Mortar in the 1860's was usually composed of only lime, water and sand. The best method for creating mortar during that time was by saturating fresh lime with water. While this lime-water mixture was still hot it was poured onto the work and hardened into one solid mass. This approach was thought to promote the "strength and solidity" of the structure (Smeaton, 1867).

Table 12: Brick Laying Patterns (Maguire, 1987)

Brick Laying Pattern Name	Description
Running	• Stretchers only • Vertical joints centered above and below alternate course
1/3 Running	• Stretchers only • Vertical joints 1/3 of a brick away
Common	• First course of continuous headers • Five courses of continuous stretchers • Another course of headers
Stack	• All vertical joints aligned • Least strength
Flemish Common	• Course of stretchers and headers, alternating • Five courses of stretchers • Course of stretchers and headers, alternating
Flemish	• Each course has alternating headers and stretchers • Each header is centered above and below the middle of the stretcher
English	• Alternating courses of headers and stretchers • Headers are centered above stretcher joints • Every fourth vertical joint alignment is made on the stretcher joints only
English Cross	• Like English except all stretcher joints line up vertically

Table 13: Joint Striking Techniques (Maguire, 1987)

Joint Technique Name	Joint Technique Description
Flush Joint	• Made with brick trowel • Limited Water-tightness
Raked Joint	• Limited Water-tightness • Useful in creating shadows • Attractive
Concave Joint	• Most common joint • Watertight

Table 14: Mortar Types (Maguire, 1987)

Mortar Types	Mortar Type Description
Type M	• General use
Type S	• General Use with lateral forces
Type N	• Used for exterior walls exposed to extreme temperatures, above ground
Type O	• Used in load-bearing walls, in dry and moderately temperate environments

2.5.2 Past Methods

In the past, structural design was derived from the results of tests with idealized solutions and conditions. These tests included load capacity tests on walls and piers to determine different slenderness ratios and eccentricities and their effect on the structure. The designer, now known as the structural engineer, was permitted to make allowances for the actual end product by estimating effective wall heights or eccentric loading on it, using their own conventional rules or judgment (Hendry, 1981). Although these methods worked at the time, and produced satisfactory results, there were analytical design problems that arose from this empirical approach.

The designs of brick masonry structures were analytically problematic in three main ways. The first was allowing for the vertical loads amongst the various walls in the building to be distributed evenly. The second problem was in determining the eccentricity of the loading on the walls, and the third was allowing for adequate lateral load distribution amongst the walls. Although engineers now have structural analysis software programs to investigate and help them reason about these behaviors, in the past the conventional way in which these concepts were addressed in design calculations were by arbitrary assumptions made by the designer (Hendry, 1981).

2.5.3 Past Regulations

When comparing building codes from the early 1900's to current regulations, it is apparent that the codes from the 1900's are much more vague and less specific than the ones we have in place today. Table 15 shows the building codes relating to masonry and building structures in 1905. These codes have been built upon, year by year, up to the current codes. Codes become more specified with each year because engineers gain more experience with different materials and how they work together to build a structure and their resulting structural performance. Codes have also become more specific in order to reduce the margin for error in design and construction (Building Code, 1905).

Table 15: 1905 Building Codes

Structural Element	Code
Material Quality-Brick	• Brick used in all buildings shall be good, hard, well burnt brick • When old brick is used in any wall they shall be thoroughly cleaned before being used and shall be whole and good, hard well burnt brick
Material Strength – Brick and masonry	• The safe-bearing load to apply to brickwork shall be taken at: eight tons per superficial foot when lime mortar is used, 11.5 tons per superficial foot when lime and cement mortar mixed is used, and 15 tons per superficial foot when cement mortar is used • The safe carrying capacity of brick is 300 pounds per square inch of sectional area • The safe carrying capacity of brickwork in Portland cement mortar is 250 pounds per square inch of sectional area • The safe carrying capacity of brickwork in lime and cement mortar is 160 pounds per square inch of sectional area • The safe carrying capacity of brickwork in lime mortar is 111 pounds per square inch of sectional area
Material Quality -Sand	• Sand used for mortar in all buildings shall

Structural Element	Code
	be clean, sharp, grit sand, free from loam or dirt and shall not be finer than the standard samples kept in the office of the department of buildings
Material Quality - Cement	• Cement mortar shall be made of cement and sand in the proportion of 1 part cement and not more than 3 parts sand and shall be used immediately after being mixed • Cement must be finely ground and free from lumps • Cement and lime mix should be 1 part lime and 1 part cement and not more than 3 parts sand to each • Portland cement shall be held to mean such a cement as shall consist of a mixture of argillacous and calcareous materials calcined together and subsequently ground to an impalpable powder • Portland cement shall have a strength of at least 300 pounds per square inch
Material Quality-Timber	• All timbers and wood beams used in any building shall be of good sound material free from rot, large and loose knots, shakes or any imperfection whereby the strength may be impaired
Foundations	• In churches, school houses and places of public amusement or assembly they are to be the full dead load and 75 percent of the live load established by section 129 of this code • Every building except buildings erected upon solid rock or buildings erected upon wharves and piers on the waterfront shall have foundations of brick, stone, iron, steel or concrete laid not less than four feet below the surface of the earth on the solid ground or level surface of rock or on piles or ranging timbers when solid earth or rock is not found • When foundations are carried down

Structural Element	Code
	through earth by piers of stone, brick or concrete in caissons, the loads on the same shall be not more than 15 tons to the square foot when carried down to the rock, ten tons to the square foot when carried down to firm gravel or hard clay and eight tons to the square foot in open caissons or sheathe-pile trenches when carried down to the rock • Foundation walls shall be construed to include all walls and piers built below the curb level, or nearest tier or beams to the curb, or to the average level of the ground adjoining the walls, to serve as supports for walls, piers, columns, girders, posts and beams • Foundation walls shall be built of stone, brick Portland cement concrete, iron or steel
Walls	• The walls of all buildings other than frame or wood buildings shall be constructed of stone, brick, Portland cement concrete, iron or steel or if approved by the commissioner of buildings, other hard, incombustible material and the several component part of such building shall be as herein provided • In all walls of the thickness specified in this code the same amount of materials may be used in piers of buttresses • In all walls that are built hollow the same quantity of stone, brick or concrete shall be used in their construction as if they were built solid as in this code provided • No hollow walls shall be built unless the parts of the same are connected by proper ties either of brick, stone or iron, placed not over 24 inches apart • The inside four inches of any wall may be built of hard-burnt hollow brick, properly tied and bonded by means of full header courses every sixth course into the walls and of the dimension of the ordinary bricks • Where hollow tile or porous terra cotta

Structural Element	Code
	blocks are used as lining or furring for walls they shall not be included in the measurement of the thickness of such walls
Brick and Masonry Walls	• The walls and piers of all buildings shall be properly and solidly bonded together with close joints filled with mortar, they shall be built to a line and be carried up plumb and straight • The walls of each story shall be built up the full thickness to the top of the beams above • All brick laid in non-freezing weather shall be well wet before being laid • Walls or piers or parts of walls and piers shall not be built in freezing weather and if frozen shall not be built upon • All piers shall be built of good, hard, well burnt brick laid in cement mortar excepting that piers fronting on a street may be built of stone • All other walls built of brick or stone shall be laid in lime, cement or lime and cement mortar mixed • In computing the weight of walls a cubic foot of brickwork shall be deemed to weigh 150 pounds
Beams	• All wood beams and other timbers in any wall of a building built of stone, brick concrete or iron shall be separated from the beam or timber entering in the opposite side of the wall by at least eight inches of solid mason work, such as separation may be obtained by corbeling or by staggering the beams • No wood floor beams or wood roof beams used in any building hereafter erected except in a frame building shall be of a less thickness than three inches nor less depth than ten inches • Roof tier of wood beams shall be safely anchored with plank or joist to the beams of the story below until the building is enclosed • When compression members of trusses are of timber they shall be strained in the

Structural Element	Code
	direction of the fiber only • When timber is strained in tension it shall be strained in the direction of the fiber only • The working stress in timber struts of pin-connected trusses shall not exceed 75 percent of the working stresses established in section 138 of this code
Floor loads	• The dead loads in all buildings shall consist of the actual weight of walls, floors, roofs, partitions and all permanent construction • The live or variable loads shall consist of all loads other than dead loads • Every floor shall be of sufficient strength to bear safely the weight to be imposed thereon in addition to the weight of the materials of which the floor is composed • If to be used as a school or place of instruction not less than 75 pounds upon every superficial foot
Roof Loads	• The roofs of all buildings having a pitch of less than 20 degrees shall be proportioned to bear safely 50 pounds upon every superficial foot of their surface in addition to the weight of materials composing the same • if the pitch be more than 20 degrees the live load shall be assumed at 30 pounds upon every superficial foot measured on a horizontal plane
Wind Pressure	• all structures exposed to wind shall be designed to resist a horizontal wind pressure of 30 pounds for every square foot of surface thus exposed, from the ground to the top of the same, including roof in any direction • in no case shall the overturning moment due to wind pressure exceed 75 percent of the moment of stability of the structure • in all structures exposed to wind if the resisting moments of the ordinary materials fo construction, such as masonry, partitions, floors and connections, are not sufficient to resist

Structural Element	Code
	the moment of distortion due to wind pressure, taken in any direction on any part of the structure, additional bracing shall be introduced sufficient to make up the different in moments • in calculations for wind bracing, the working stresses set forth in this code may be increased by 50 percent • in buildings under 100 feet in height, provided the height does not exceed four times the average width of the base, the wind pressure may be disregarded
Vertical Supports	• every column, post or other vertical support shall be of sufficient strength to bear safely the weight of the portion of each and every floor depending upon it for support, in addition to the weight required to be supported safely upon said portions of said floors • for the purpose of determining the carry capacity of columns in dwellings, office buildings, stores, stables and public buildings when over five stories in height, a reduction of the live loads shall be permissible as follows: for the roof and top floor the full live loads shall be used, for each succeeding lower floor it shall be permissible to reduce the live load by five percent until 50 percent of the live loads fixed by this section is reached, when such reduced loads shall be used for all remaining floors
Factor of Safety	• one to six for timber • one to ten for natural or artificial stone and brick or stone masonry

2.6 Case Study: Washburn Shops

To fully understand the difficulties in maintaining a historic building and why code compliance issues exist, this project focused on one particular building: Washburn Shops, located on the WPI campus. This section will detail the history of the building along with the renovation projects that have taken place over the lifetime of this building.

2.6.1 Building Washburn

Figure 14: Washburn Tower

The first proposal for the construction of Washburn Shops was submitted to the Board of Trustees on December 2nd, 1865. Ichabod Washburn was, at first, the sole supporter of building Washburn Shops. Ichabod materialized his idea of a machine shop by supporting Stephen Salisbury and Emory Washburn's proposal of a school for Mechanics. Ichabod donated money from his business, Washburn Wires, in order to fund building and equipping a machine shop. The basis of the WPI's curriculum, theory and practice, originate from this decision (Tymeson, 1965). The building was finally accepted by the trustees in March of 1866 (Taylor, 1937). During the construction, Ichabod suffered from a paralyzing stroke and was unable to continue his work on the project. Considering the walls of the shop were only halfway up, the project could have collapsed. However, Ichabod's superintendent at the wire mill, Charles H. Morgan, took over to see the project through completion (Tymeson, 1965). Figure 14 depicts Washburn's Tower.

The entire building cost was between $12,000 and $15,000, and the completed building consisted of a main shop and a wing. The main shop footprint was 102 ft by 44 ft and three stories high. The wing was 65 ft by 25 ft and contained the engine room, boiler room and blacksmith shop. Figure 15 illustrates this layout. Within these rooms were two 20 H.P. boilers and a 20 H.P. steam engine. Iron and wood working were also housed within this wing, and the first class of apprentices started on February 20, 1872 (Taylor, 1937).

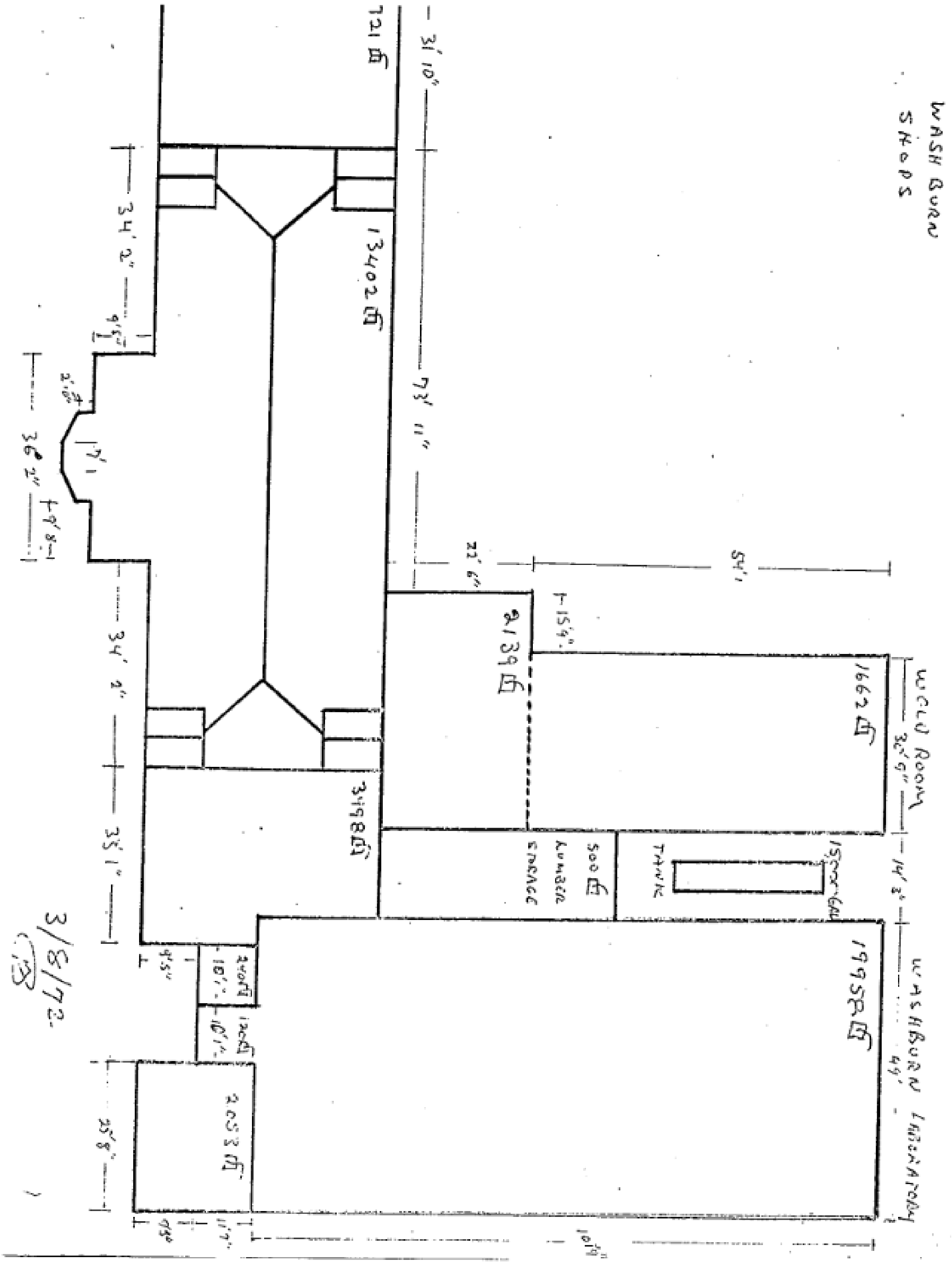


Figure 15: Layout of Washburn Shops 1972 (Pierce, 1972)

2.6.2 Renovating Washburn

In 1881, the Washburn Laboratory addition supplemented two wings on either side of the Shop. The south side, close to Boynton Hall, added a two-story wing with 2,721 ft^2. The north wing included two stories and a basement of 3,998 ft^2 (Pierce, 1972). These two additions gave more room to the expanding school for classroom and machine space.

2.6.3 Longevity of Washburn

A report was given to the George Hazzard, WPI's President at the time, by the Director of Planning in 1972 analyzing the future of Washburn Shops. Over the past 100 years of Washburn's life, the building has been suffering from the wear and tear from the machinery. It was discovered that the main building and south addition only had a crawl space underneath the floor and needed to be reinforced in order to continue handling the machinery loads. It was also determined that all the woodwork including the window frames, towers and flooring needed to be repaired. The conclusion of the report was a recommendation by the Director of Planning that Washburn should be completely rebuilt. This reconstruction was projected to cost the school $532,800 and decrease the available floor area by 7,000 ft^2 (Pierce, 1972). This proposal was rejected based on the historical value of the building but illustrates the importance of understanding how Washburn is structurally supported and maintained.

2.6.4 Washburn Documentation

Washburn Shops is an example of a building that lacks construction project documents. No record of Washburn's structural makeup currently exists. In addition the only original drawings that WPI Department of Facilities has refer to Washburn after its first renovation in 1881. In the year 2011 these documents were referenced for another renovation; however, the incomplete documents did not provide much assistance to the contractors (Salter, 2011). For example when renovation began on Washburn in the summer of 2011, it was realized that the bricks being taken out and replaced in the exterior wall were in fact essential to the structural integrity of the building. Work had to be stopped for the construction team to reassess what could be done to the building that wouldn't alter its structural integrity. This caused a delay in project schedule and a raise in construction costs. In addition, when trying to recreate the building's drawings that were available, their details were found to be inaccurate. For example the stairways on the individual floor plans did not match up when placed together in a 3D model (Salter, 2011). Because of the inaccuracies in the available drawings and the altogether lack of drawings for many aspects of the building, the 2011 renovations were delayed and the costs increased, showing the importance of project documentation for future building renovations.

The project team was provided with two of the most recent models of Washburn in *Autodesk Revit*. The first, pictured in Figure 16, was created by two WPI students, Mengling Wang and Holian Qu as part of a term project in spring 2010. The 3D model was created from 2D floor plans acquired from WPI Department of Facilities. In creating this model the students focused on space distribution and the floor layouts. Their model did not develop the roof structure on the third floor. The second model the team acquired is in Figure 17 This model was developed by Hoffman Architects during the most recent renovation project. The 3D model displays the structural aspects of Washburn focusing on the original building section.

Figure 16: Autodesk Revit Representation of Washburn from WPI Students (Wang, 2010)

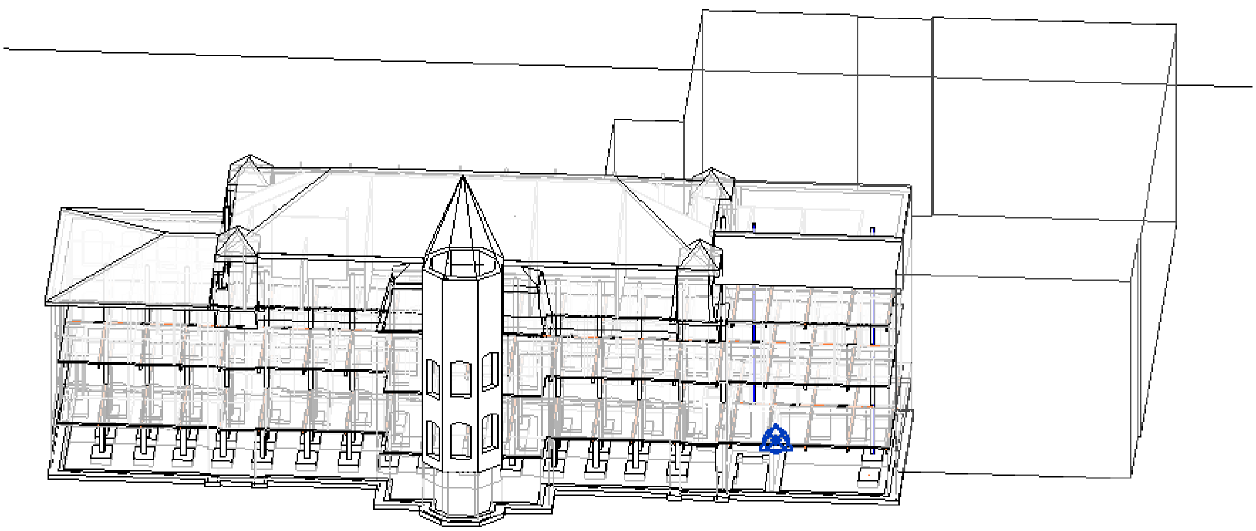


Figure 17: Autodesk Representation of Washburn from Hoffman

2.7 Current Construction

Construction on Washburn Shops started in the summer of 2011 to renovate the roof as well as select windows and masonry along the top portions of the building. This project was planned to be completed for October 10th, 2011. The architect, Hoffman Architects Inc. from

Hamden CT, worked with the construction manager, Cutler Associates Inc. from Worcester MA, on this approximately $1.6 million project (Figure 18).

The renovation scope of work slightly changed from the original plans but met the schedule. When the site work was being done before the renovation, workers discovered no insulation between the exterior and interior brick walls (Salter, 2011). The most concerning questions that arose from this situation are thermal and seismic stability. The tower walls were the only ones to be reinforced with bracing, and these did not contain any added insulation. Currently, the masonry walls of the original building only have a supporting column between each window and the addition's masonry walls are completely hollow between the windows (Guertin, 2011). A cross-section of the tower's masonry walls is shown in Figure 19.

Figure 18: Sign Announcing Renovation

Figure 19: Washburn Tower Masonry Wall Cross-Sections

The majority of the renovation work made changes to the upper portions of Washburn. The roof was entirely re-slatted, the top row of windows were replaced but kept the “divided light” style, and 31 window eaves were rebuilt with zinc coated copper. The before and after conditions of the windows are illustrated in Figure 20 and Figure 21.

Figure 20: Pre-Renovation Window Conditions

Figure 21: Window Renovation Work

Five of the arches along the top of the building had to be completely rebuilt during the renovation because of extreme cracking and age. More will most likely need to be replaced in the future. The wood roof structure itself was deemed to be strong however one beam in the tower was replaced due to rotting. The mansard roof also had rotting sections and falling concrete that were refurbished. The tower needed to be reinforced, and bracing was installed along the inside framing. Figure 22 details the new bracing as well as the old (Guertin, 2011).

Figure 22: Views of Tower Bracing

This restoration fixed many of Washburn's structural problems however there are still many that need to be addressed. During this project, workers discovered that the loading dock foundation was disturbed due to the repetitive motion of machines traveling through the area. Almost all the brick exterior walls are not reinforced for seismic loading and insulating the walls has not been addressed. The brick walls have the original mortar, a thin layer of lime and sand, holding them together (Salter, 2011). The combination of these issues will require innovative design solutions and renovation work in the future.

2.8 Scope of Work

When using Washburn as a case study for the ever-growing problems of maintaining historic masonry buildings, the current structural stability, fire protection safety and building documentation were investigated. This MQP project consists of two phases of work concerning WPI's Washburn Shops. The first phase assessed the current conditions to create a comprehensive picture of the building including a BIM model. After the study of current conditions was completed, the second phase involved outlining future options for design solutions and the use of the created model.

Not every historic masonry building will have the same issues that Washburn is facing, but this project is meant to be an example of the extensive work that needs to be investigated to operate and maintain older buildings. The upkeep of old buildings is a never ending cycle and the cost of maintaining a building for its lifetime should also be considered when planning new construction.

3.0 Building Assessment

The first section of the study of Washburn consists of assessment of the building's current conditions. The project team evaluated the structure through a study of the appropriate building codes and visually depicted it through the creation of a BIM model.

3.1 Methodology

The following methodology details the steps taken to complete the building assessment section of the project. Figure 23 outlines the process on the next page.

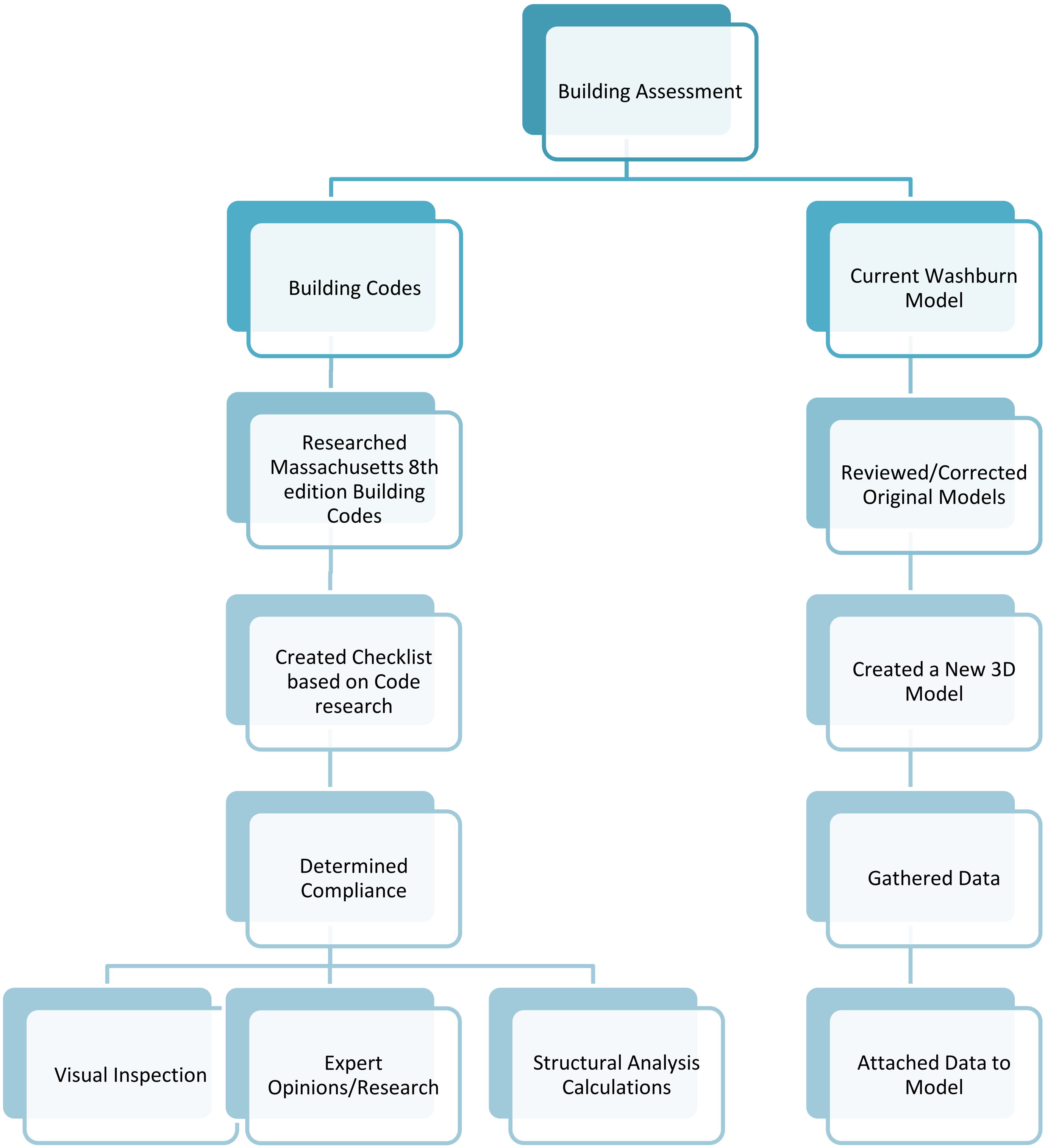


Figure 23: Building Assessment Methodology

3.1.1 Building Code Study

The building code analysis completed for Washburn was split into two different sections: structural and fire protection. To complete these analyses, the following steps below were followed. These steps were conducted for both the structural and fire protection code analysis.

Research on Massachusetts 8th Edition Building Code

The first step was to determine which code provisions were applicable to Washburn. The team based their analysis on the assumption that the scope of the renovation work within Washburn was sufficient to warrant the building to be completely updated for compliance with the current codes. Under this assumption, the *Massachusetts 8th Edition Building Code* stated to use three main codes for this building: The *International Existing Building Code* (*IEBC*), the *International Building Code* (*IBC*), and the *International Fire Code* (*IFC*). The *IEBC* was used for the structural analysis while the *IBC* and *IFC* were used for the fire protection analysis. The team also attended a conference on the *IEBC* to learn how engineers are using the IEBC to solve renovating issues with old buildings (SEAMass, 2011). Notes from this conference are included in Appendix 7.8.5.

Created Checklist based on Code Research

After research was conducted on the governing codes, the team created a checklist of relevant code sections. Every section of the code that pertained to Washburn was not included in the checklist because of time limitations and access to information. The code sections focused on were structural elements; seismic, wind and snow effects; sprinklers; and the fire alarm system. The checklist includes the element, code reference, exact code text, the team's interpretation of the text, any exceptions to this code, current compliance (yes/no), and current conditions. When first compiling the checklist, the last two columns (compliance and current conditions) were left blank. The next step, determining compliance, addresses the entries in these two columns.

Structural Code Checklist Breakdown

A checklist of structural codes, compiled from the *Massachusetts State Building Code*, weighed against Washburn's current, assessed, conditions can be found in Appendix 7.1. An example row of the checklist is shown in Table 16. Each row is referenced by an item number and letter if there is more than one row for a given element. The main structural elements of the building code were outlined in the element column of the checklist, and these include:

- Building materials
- Alterations to structural elements carrying gravity loads and lateral loads
- Seismic requirements
- Repairs to structural elements carrying gravity loads and lateral loads
- Change of occupancy
- Historic building guidelines
- Evaluations

These structural elements were the focus of the checklist because they were the main sections in the *codes* and/or they related directly to Washburn. Evaluations were included in the checklist because, although not directly relating to a building's structure, the method of evaluation does play a role in determining whether a buildings structure must be updated.

Table 16: Example Row of Structural Checklist

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
6.a	Repairs to gravity load carrying components	IEBC 506.2.3	Gravity load-carrying components that have sustained substantial structural damage shall be rehabilitated to comply with the applicable provisions for dead and live loads in the IBC. Snow loads shall be considered if the substantial structural damage was caused by or related to snow load effects. Undamaged gravity load-carrying components that receive dead, live or snow loads from rehabilitated components shall also be rehabilitated if required to comply with the design loads of the rehabilitation design.	Shall be rehabilitated to comply with the applicable provisions for dead and live loads in IBC	N/A	Yes	There was no substantial damage to Washburn's structure

Washburn has a unique structure in the way that its brick façade serves both the architecture and the structure of the building. Washburn's structure is made up of bricks formed into columns with the inner cavities being hollow (Figure 24). The shape mimics an enlarged hollow core masonry unit made out of brick. The structure of Washburn includes it brick façade, therefore appendix A of the *IEBC* was also reviewed in order to make an accurate structural code checklist. The structural elements that pertained to Washburn's unreinforced masonry bearing wall include:

- Alterations and repairs
- Materials
- Existing unreinforced masonry
- Lay-up walls
- Mortar tests
- Test Locations
- Number of tests
- Minimum quality of mortar

- Minimum quality of masonry
- Pointing
- Existing wall anchors
- Masonry shear strength
- Masonry compression
- Masonry tension
- Foundations
- Lateral forces on elements of structure
- Wall anchorage locations
- Wall anchorage requirements
- Minimum wall anchorage
- Wall anchorage at corners
- Ties and continuity

These elements were chosen to be used in the checklist because they either related directly to Washburn's most recent renovations, or they related to Washburn's unique structural components.

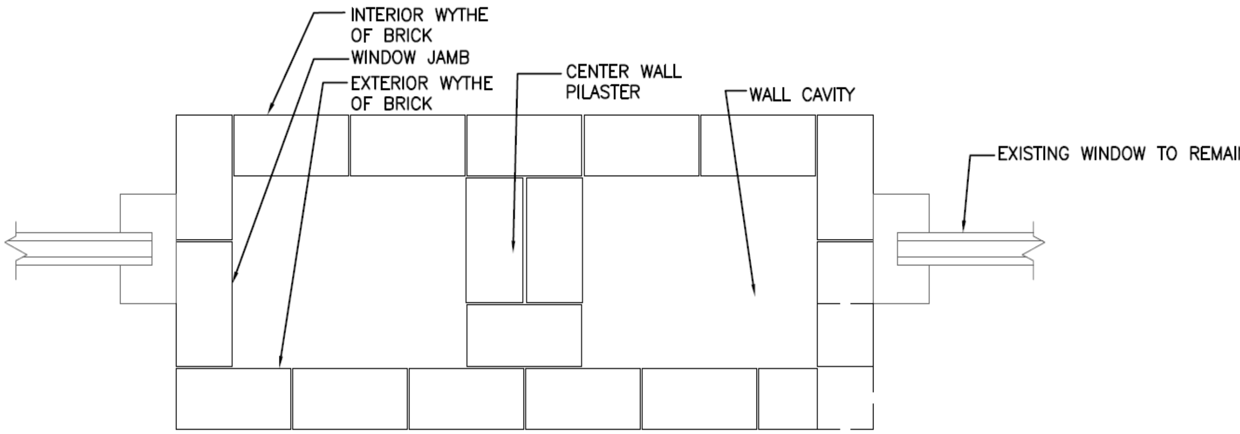


Figure 24: Washburn Structure Brick Column

In addition to the elements, the *code* reference number and actual code texts are also included in the checklist in the columns. These code texts were taken verbatim from *the 2009 IEBC*. The fourth column summarizes our interpretation of the code; the actual provisions can be lengthy with specific jargon so our interpretations include a more easily understood, shortened version of the *code*. The fifth column of the checklist has any exceptions to the codes - if there are no exceptions then N/A or not applicable was written in that column.

The *IEBC* has three different methods of assessing compliance: the prescriptive method, the work area method and the performance method. These three methods are outlined in different colors in the checklist, the blues are for the prescriptive method, the pink is for the work area method and the greens are for the performance method. If the different methods for the element state the same thing then they are black. For most existing buildings unless there is a problem with the building or the building code official deems the building unsafe, usually, the building is not required to be updated to comply with current codes.

For historical buildings the codes are even more lenient. Historical buildings can remain the same unless the building code official determines that it is either unsafe or significant or substantial damage has occurred. Washburn is WPI's second building and considered a historical building, therefore the building is compliant with the *IEBC*. However, our project makes the assumption that the renovations were extensive enough to allow for the building to be assessed to meet current codes; the checklist and compliance is based off of this assumption. The focus of this study was on all of the *building code* provisions pertinent to the structural design of Washburn so codes relating to the thermal regulations etc. were not considered.

Fire Protection System Checklist Break Down

The *Massachusetts State Building Code* has adopted the 2009 edition of the *International Building Code* (*IBC*), *International Existing Building Code* (*IEBC*), and *International Fire Code* (*IFC*). The *NFPA* codes and standards, *NFPA 13*, *NFPA 72*, and *NFPA 25*, discussed in Section 2.5.5 of this report, are referenced in both of the *IBC* and *IFC*. Table 17 indicates which sections of the *IBC* and *IFC* reference which *NFPA* documents.

Since Washburn is an existing building, the *IBC* does not directly apply to the building. First, the *IEBC* governs alternations made on an existing building and states when the *IBC* applies. The extent of the alterations made to a building control when the *IBC* is applicable as explained below in Table 18. The table shows that level 2 and 3 alternations must follow the *IBC*, and the project team assumed a renovation of at-least alternation level 2 for the code analysis.

Table 17: *NFPA* Documents Referenced in the *IBC* and *IFC*

NFPA Document	International Code Reference
NFPA 13 **Standard for the Installation of Sprinkler Systems**	***IBC* 903.3.1** Where the provisions of this code require that a building or portion thereof be equipped throughout with an *automatic sprinkler system* in accordance with this section, sprinklers shall be installed throughout in accordance with *NFPA 13* except as provided in Section 903.3.1.1.1
NFPA 72 **National Fire Alarm and Signaling Code**	***IBC* 904.3.5** Where a building fire alarm system is installed, automatic fire-extinguishing systems shall be monitored by the building fire alarm system in accordance with *NFPA 72*.
	***IBC* 907.3** Automatic fire detectors utilized for the purpose of performing fire safety functions shall be connected to the building's fire alarm control unit where a fire alarm system is required…The detectors shall be located in accordance with *NFPA 72*.
	***IBC* 907.5.2.2** Emergency voice/alarm communication systems required by this code shall be designed and installed in accordance with *NFPA 72*.
	***IBC* 907.6** A fire alarm system shall be installed in accordance with this section and *NFPA 72*.
	***IBC* 907.7** Upon completion of the installation, the fire alarm system and all fire alarm components shall be tested in accordance with *NFPA 72*.
	***IBC* 907.7.2** A record of completion in accordance with *NFPA 72* verifying that the system has been installed and tested in accordance with the *approved* plans and specifications shall be provided.
NFPA 25 **Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems**	***IBC* 903.5** Sprinkler systems shall be tested and maintained in accordance with the *International Fire Code*. ***IFC* 901.6.1** *Fire protection systems* shall be inspected, tested and maintained in accordance with the referenced standard *listed* in Table 901.6.1. **Table 901.6.1** Water-based fire protection systems: *NFPA 25*

Table 18: *IEBC* Levels of Alternations and References to the *IBC*

IEBC Level of Alternation	Applicable Codes
Level 1 • **Includes removal and replacement of items in building that serve the same purpose (*IEBC* Section 403.1)**	• Must maintain current level of fire protection • Use applicable codes from when building was built • *IEBC* Section 603.1
Level 2: • **Reconfiguration of a space or system** • **Addition or elimination of a window or equipment (*IEBC* Section 404.1)**	• Only applies to area that work is being done and in some cases the floor on which work is being done • Follow *IBC* • *IEBC* Section 704.1
Level 3: • **Work area exceeds 50% of aggregate area of the building (*IEBC* Section 405.1)**	• Only applies to area that work is being done and in some cases the floor on which work is being done • Follow *IBC* • *IEBC* Section 804.1

The three *NFPA* documents in Table 17 were the focus for the fire protection system code analysis of Washburn. *NFPA 13*, *NFPA 72* and *NFPA 25* are related to sprinkler installation, fire detection, and upkeep of sprinkler systems, respectively. Table 17 shows that comparing the code compliance of Washburn related to the three *NFPA* standards will be indirectly evaluating the code compliance of Washburn with respect to the *Massachusetts State Building Code* The applicable sections of *NFPA 13*, 72 and 25 that were identified in Section 2.5.4 of this report were used to select relevant code requirements for the Fire Protection System Checklist. The purpose of this checklist is to compare the existing condition of Washburn's fire protection system to current codes and standards to determine if this system would be compliant for new construction or renovations.

The Fire Protection System Checklist consists of six components for each code, and these are displayed as the columns in the checklist. Figure 25 depicts a row of this checklist for *NFPA 13*.

Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
Deflector Orientation	8.5.4.2	Deflectors of sprinklers shall be aligned parallel to ceilings, rods, or the incline of stairs.	Deflectors are parallel to surface above sprinklers	Yes	All deflectors inspected were parallel. See Figure.

Figure 25: Sample of Fire Protection System Checklist for *NFPA 13*

The six components are the element (general topic of the code), code reference (section number in respective code), code text, interpretation (the project group's operational definition of the code requirement), compliant (yes or no answer to whether Washburn complies with this requirement), and current condition (a summary of observations the project group has made relating to this code). The full Fire Protection Checklist is included as Appendix 7.2.

These three *NFPA* documents were chosen because evaluating Washburn on the entire fire protection system would be out of the time restraints for this project and include code sections that relate to a visual inspection of the building that was feasible for the project team. A compiled list of applicable sections is presented in Table 19.

Table 19: Applicable Sections for Fire Protection System Checklist

	Applicable Sections for Fire Protection System Checklist
NFPA 13	• 8.1 Basic Requirements • 8.2 System Protection Area Limitations • 8.3 Use of Sprinklers • 8.5 Position, Location, Spacing and Use of Sprinklers • 8.6-8.13 Sprinkler Types
NFPA 72	• 4.4 • 5.4 General Requirements • 5.5 Requirements for Smoke and Heat Detectors • 5.6 Heat-sensing Fire Detectors • 5.7 Smoke-Sensing Fire Detectors • 5.13 Manually Actuated Alarm-Initiating Devices • 5.16 Smoke Detectors for Control of Smoke Spread • 6.8 System Requirements • 6.9 Emergency Voice/Alarm Communications • 10.2 General • 10.3 Inspection • 10.4 Testing • 10.5 Maintenance • 10.6 Records
NFPA 25	• 4.1 Responsibility • 4.4 Records • 4.5 Inspection • 4.6 Testing • 4.7 Maintenance • 4.8 Safety • 5.2 Inspection • 5.3 Testing • 5.5 Component Action Requirements

The codes for the checklist were chosen from these sections for two reasons: available information and access to new information. Available information is considered to be any visual inspection the team can do without outside help (sprinkler obstructions, smoke detector spacing, frequency of manual pull stations, etc.). Access to new information refers to additional information that the WPI Department of Facilities provided the team (data from tests, access to locked rooms, history of system, etc.). Focusing on codes relating to areas that are difficult to access visually or gain information on, such as underground piping, electrical wiring, or design approaches, would be weak areas to clearly assess code compliance. The information the project team gathered on each code is included in the "current conditions" column of the checklist in Appendix 7.2.

Determined Compliance

Once the team had created a checklist of relevant code sections, the current conditions within Washburn were described. Visual inspection; expert opinions and research; and a structural analysis program completed this step. The last step was determining the compliance of each code element in the checklist. The team filled in a yes or no for the code element, depending on whether the code element was in compliance with the code section. The following sections explain these data-gathering activities in more detail.

Visual Inspection

The first visual inspection conducted was done during a tour of the roof renovation construction in October, 2011. During this tour, the team took pictures and was able to see the renovated conditions of the windows and roof. The team also visited Washburn to conduct a floor-by-floor inspection of the sprinkler and fire alarm systems. Measurements were also taken of mortar and bricks when available documents did not provide sufficient information.

Expert Opinions and Research

Expert opinions were useful when identifying elements that were not compliant. These experts deemed what was important when inspection a building, critical details of Washburn that were discovered during construction, and useful documents of Washburn. Interviews were conducted with a contractor who installed fire protection systems, a consultant who was previously an Authority Having Jurisdiction (AHJ), the WPI Director of Project Management and Engineering who was the WPI contact for the roof renovation and also supplied the fire protection system plans, an engineer from Hoffman Architects who supplied information and documents on the specifications of the roof renovation, and a contractor from Cutler Associates who supplied the team with pictures and plans from the roof renovation. Finally, research was conducted on masonry construction during the time Washburn was built (1872).

Structural Analysis Calculations

Determining the structural integrity of Washburn was important in determining its level of compliance. The following sections describe the steps and calculations performed in order to conduct a structural analysis of Washburn.

Determining Loading Conditions

The first step in analyzing the structure was to determine the loads appropriate for the application to the section of the structure being analyzed. The total wall length is 171.083ft and the wall section length is 8.54ft (Figure 26). The width of the wall section, determined as the solid wall thickness of the wall section, is 0.58ft wide (Figure 27). Figure 29 outlines the steps that were taken to determine each loading on the structure. The structural loads were broken down into each loading type: dead load, live load, snow load, wind load and seismic load.

Figure 26: Wall Section Length

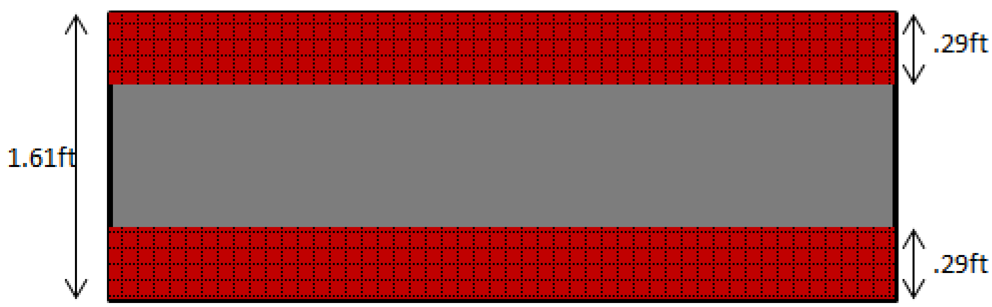


Figure 27: Wall thickness

The dead loads were broken down further into roof dead loads and floor/ceiling dead loads. The roof dead loads consisted of the weight due to a one-inch board load, ¼ inch slate load, and a timber frame load. The structural floor plans that were used as a basis for the load calculations included structural columns placed in the center of the structure for its entire length. These columns were spaced 8'-6" apart and are HSS10x0.375 columns (Round hollow Structural Section). The first floor plan with these columns can be seen in Figure 28 (other floors have the same column layout). The focus of the analysis was on the walls, so these columns were not assessed in the project and only the tributary area of the floor in relation to the wall section was used. The floor and ceiling dead loads, tributary to the wall section, were derived from allowances for a lightweight concrete slab, linoleum flooring, ceiling construction, MEP system, insulation and brick. Each of these loads was found through referencing different sources to find the average loads.

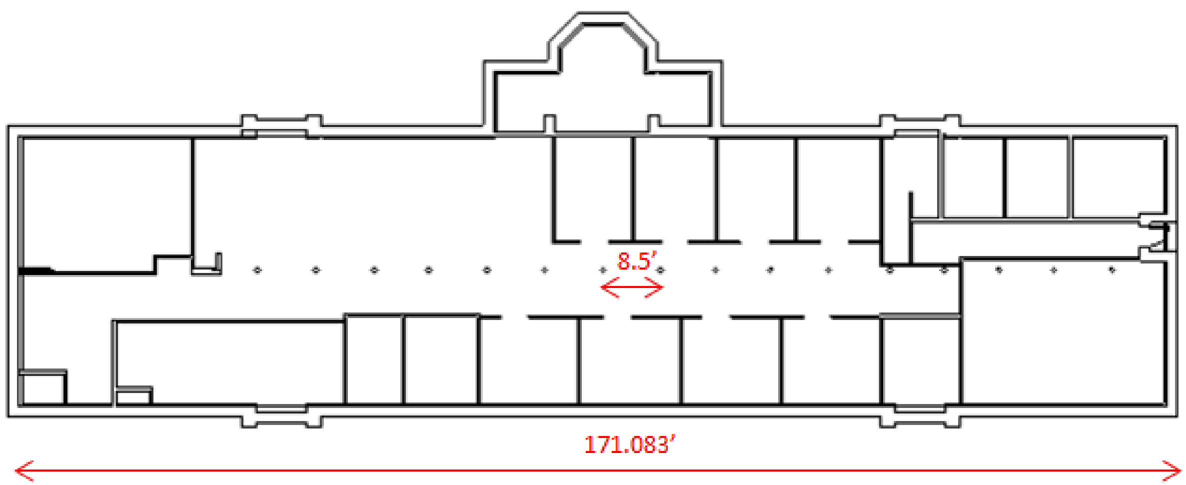


Figure 28: First Floor Column Layout

The live loads were determined only for the floor and not the roof because it was assumed that the snow load would govern over any nominal roof live load assumed for routine maintenance. These loads were also determined through researching various load references in the *IBC* and *Massachusetts Building Codes*. The floor live loads included a classroom live load and an open plan area live load. Although uniform live load values are specified for corridors, they were not considered in the analysis because a study of the layout indicated that the corridors are not within the tributary area supported by the exterior masonry wall section.

Design values for snow and wind loads were found through the provisions *Massachusetts State Building Code*. The *Code* has prescribed snow loads values for different areas of Massachusetts. The Worcester snow load of 35 psf was used in the structural analysis of the Washburn wall section.

The wind loads were determined by first selecting the appropriate exposure. The exposure was determined to be exposure level B, which refers to suburban areas, towns or city outskirts. Next Worcester was located in Wind load zone 2. The exposure and wind zone were used together with Table 1611.4 of the *Code* to determine the wind pressure loading.

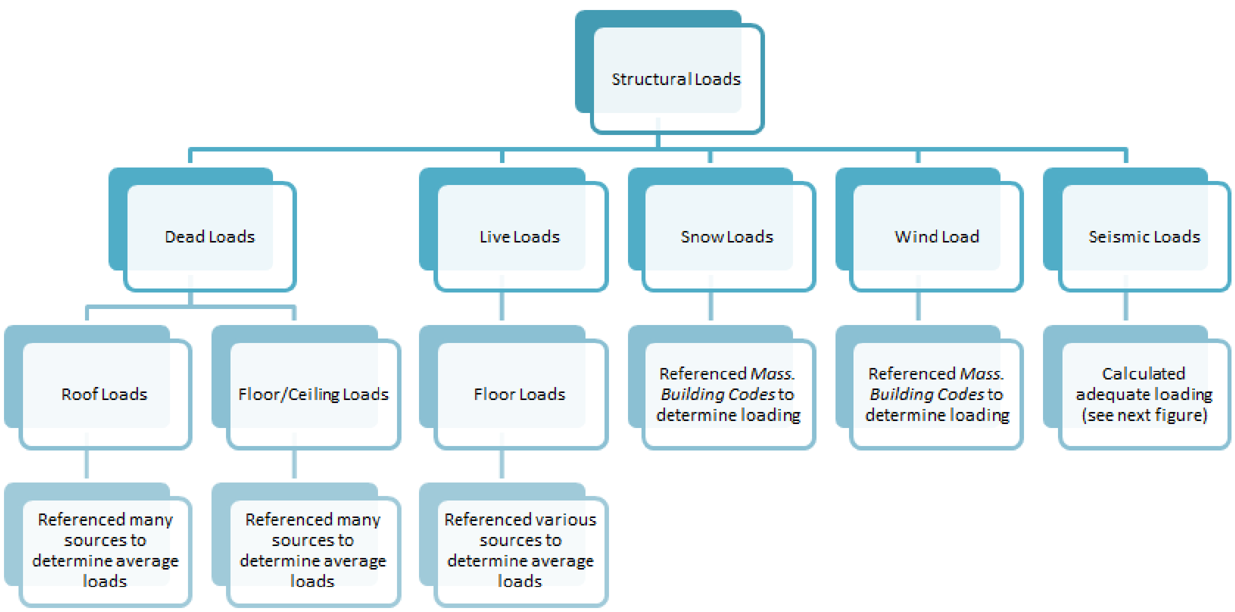


Figure 29: Structural Load Breakdown

The seismic loads were more complicated to determine. There were various restraints and steps to calculating the adequate seismic loading. The seismic loading acting on each floor was determined and the steps are summarized in Figure 30. The complete set of seismic loading calculations can be found in Appendix 7.4.1. The first step in seismic loading analysis is to find the acceleration parameters, values S_s and S_1. These were found through a contour map in *ASCE 7*. Next the site class was determined. There are site classes: A, B, C, D, E and F. These site classes depend on of the soil properties of the area. Site class D is the default site class. Adequate soil properties for the soil under Washburn was not available to the group therefore site class D was used. After the site class was determined, the site class coefficients, F_a and F_v, were found according to the site class. The MCE spectral acceleration values S_{Ms} and S_{M1}, were then calculated with the F_a and F_v site coefficients. The S_{MS} and S_{M1} values were then used to calculate the design spectral response acceleration parameters, S_{DS} and S_{D1}. C_W was then calculated and used to calculated the T_a (Period) value. The Ta value was compared to the design response spectrum and S_a was calculated from it. A design category for which Washburn falls under was then selected. There are design categories I, II, III, and IV. Washburn fell under design category II. The design category was then used to select the Importance factors, I_s, I_i, I_w, and I_e. R, Ω, C_d, and h_n limitations were found from table 12.2-1. They were selected in reference to a bearing capacity, ordinary plain masonry shear wall. C_s was determined and checked according to *ASCE 7* standards and then the design category was determined as design category B. From this C_{vx} was able to be calculated as well as V. Finally the seismic loading force, F_x for each floor were calculated.

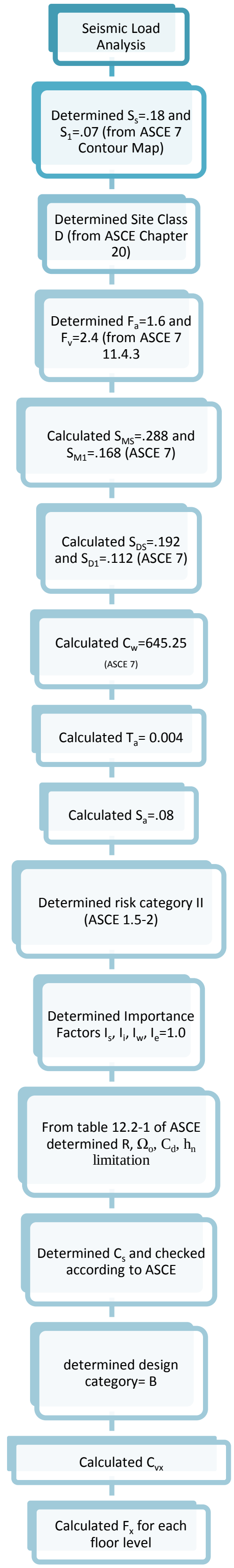


Figure 30: Steps to Seismic Analysis

Determining Gravity Loading

In order to determine the loading due to gravity on the structure the dead and live loads found in the above section were used. The full calculations can be found in Appendix 7.4.1. First the uniform loading on each level of the structure was determined using the load combination equations below.

$$W_R = (1.2 * W_{DR}) + (1.6 * W_S)$$

$$W_3 = (1.2 * W_{D3}) + (1.6 * W_{L3})$$

$$W_2 = (1.2 * W_{D2}) + (1.6 * W_2)$$

This uniform loading was then applied to the structure. Figure 31 depicts the uniform loading acting on the structure. The resultants of these uniform loads were then calculated so that one point load would be applied to the entire span of the wall section. This is shown in Figure 32. These point loads were used to find the reaction forces in each of the columns, which are the same as the total amount of load acting on the columns.

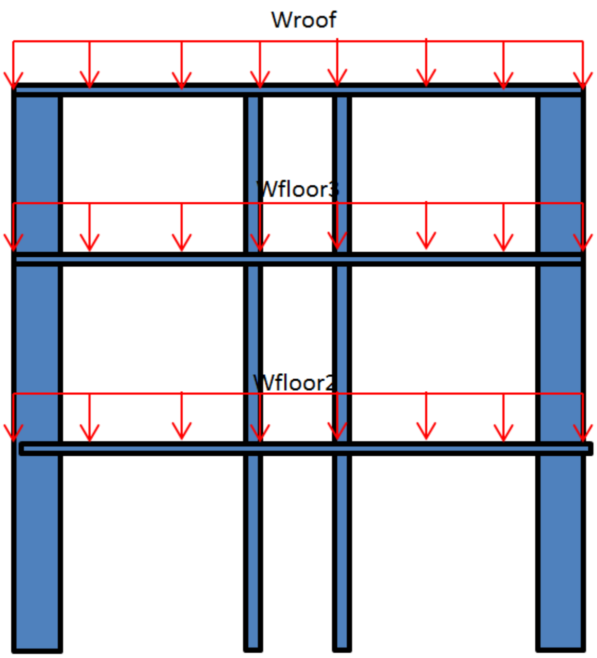


Figure 31: Uniform Floor Loading

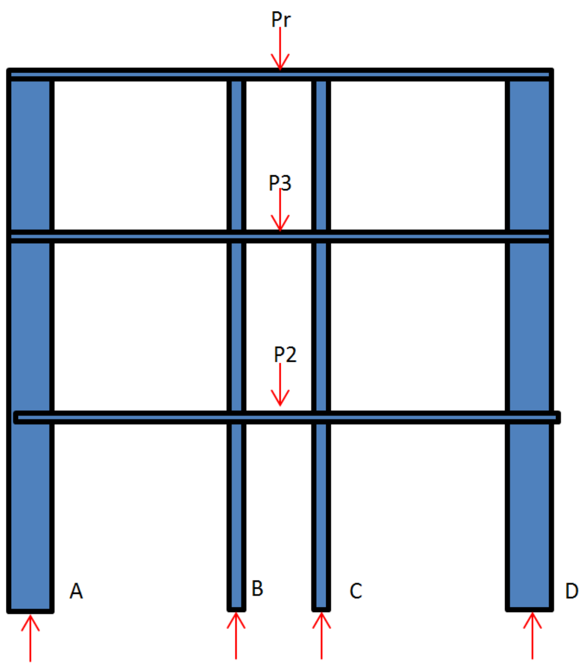


Figure 32: Point Load for each Floor

In order to find these reaction forces the structure was split to find the forces at the different levels in each column. Figure 33, Figure 34 and Figure 35 show the cuts of each section.

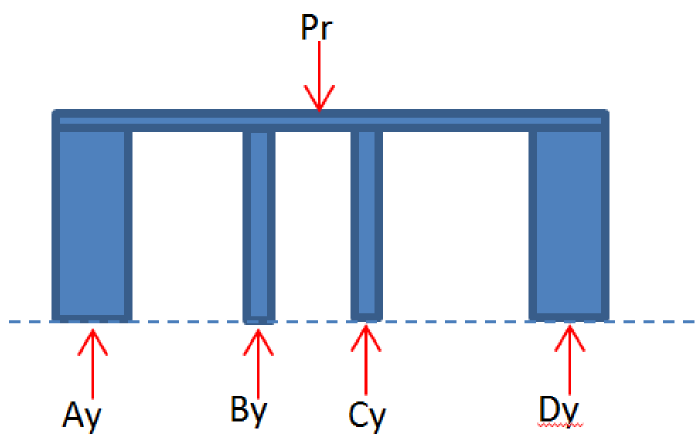


Figure 33: Roof Cut Section

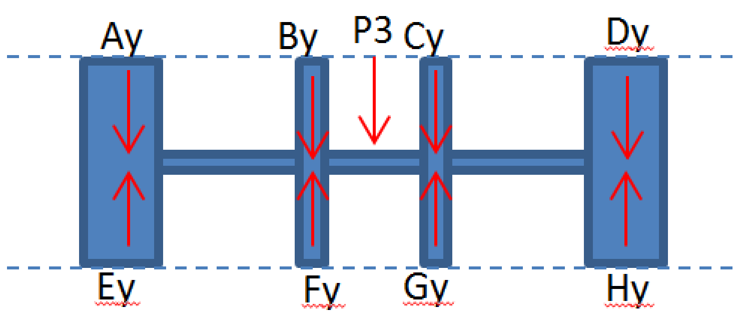


Figure 34: Floor 3 Cut Section

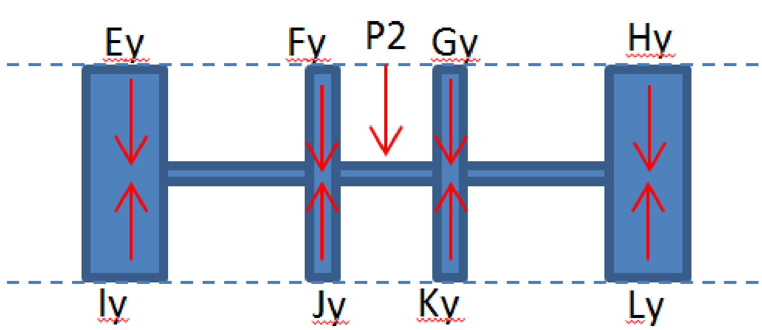


Figure 35: Floor 2 Cut Section

The total gravity force on each column was calculated and the point forces found are shown in Figure 36. These total gravity loads on each column were compared to the compressive strengths of the bricks and mortar in order to determine whether they could withstand the calculated gravity forces.

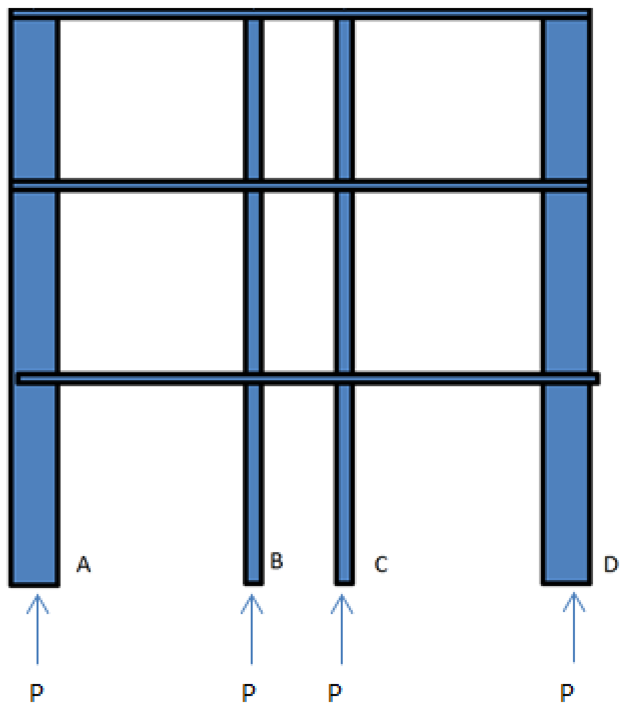


Figure 36: Reaction forces at each Column

Determining Seismic Loading

The loads on the wall structure due to the seismic forces were determined in order to fully investigate its compliance to *Codes*. The following equations were used to calculate the stress.

$$\sigma = \frac{Mc}{I}$$

where according to Figure 37 *and* Figure 38*:*

$$M = moment\ due\ to\ seismic\ forces = (F_R * h_R) + (F_3 * h_3) + (F_2 * h_2)$$

$$c = d_1$$

$$I = \sum I = 2\left(A_1 * {d_1}^2\right) + 2\left(A_2 * {d_2}^2\right)$$

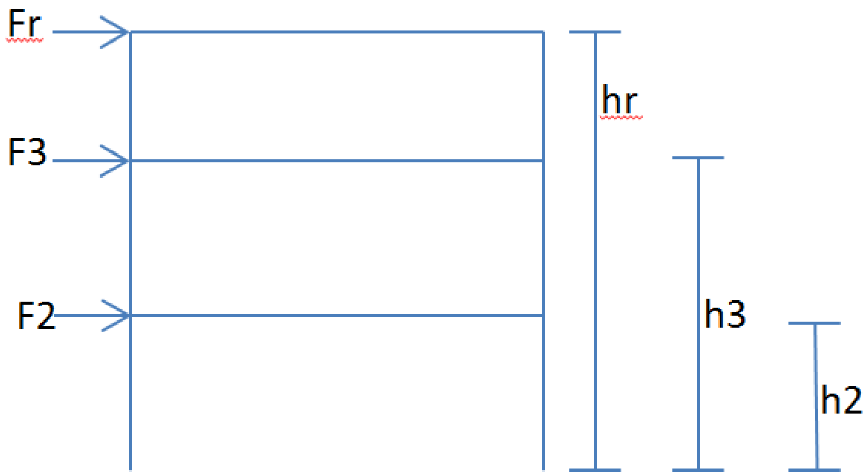


Figure 37: Seismic Forces Diagram

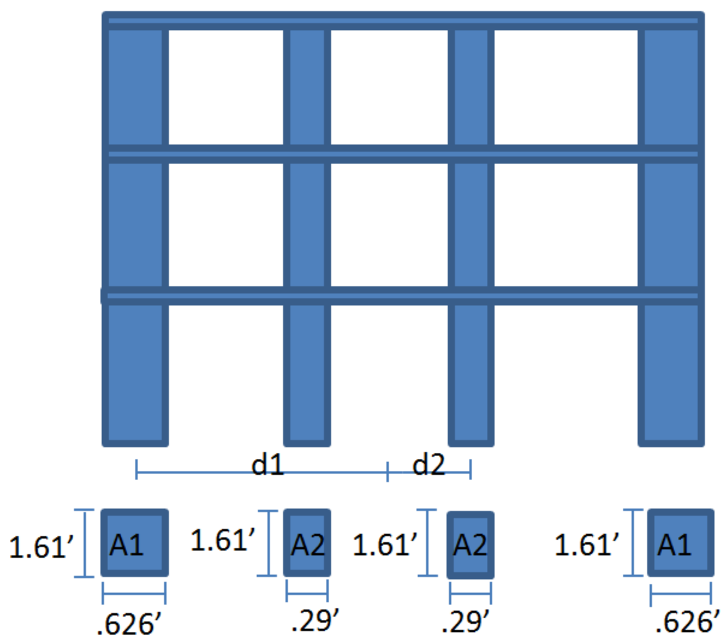


Figure 38: Column Areas and distances

Finally the force was found with the following equation.

$$F = \sigma A$$

Determining Wind Loading

The wind loading was assessed according to the current wind loading of Worcester now. This section summarizes the steps to calculate the shear force in the wall due to wind loading. Full calculations can be found in Appendix 7.4.3.

First the Uniform wind load was broken into Point loads at each floor; Figure 39 shows this. The equation used to find the point loads for each floor is shown below.

$$F_R = \frac{P_W * (height\ of\ roof\ cut\ section) * (solid\ wall\ thickness)}{2}$$

$$F_3 = \frac{P_W * (height\ of\ floor\ 3\ cut\ section) * (solid\ wall\ thickness)}{2}$$

$$F_2 = \frac{P_W * (height\ of\ floor\ 2\ cut\ section) * (solid\ wall\ thickness)}{2}$$

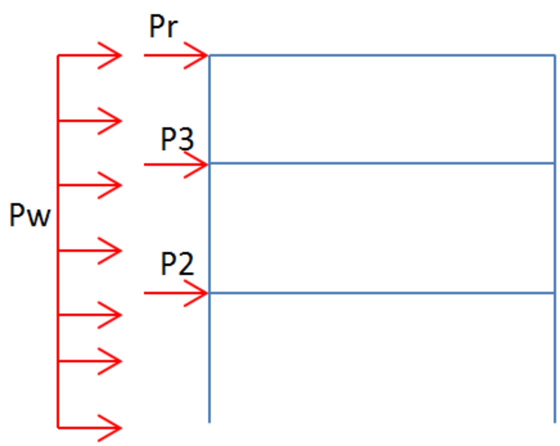


Figure 39: Wind Uniform and Point Loading

The roof and floor cut section heights can be seen in Figure 40. Once the wind load at each floor was calculated it was necessary to find the portion of the wind load on the wall section under study. The entire length of the wall was 171.083ft (l) while the wall section length was 8.54 (lx). Therefore to determine the tributary wind load the equations below were used.

$$Tributary\ wind\ load = (wind\ point\ load) * (\frac{l_x}{l})$$

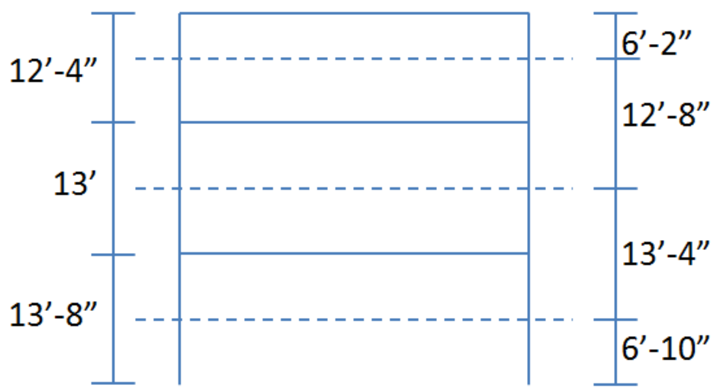


Figure 40: Floor Heights and Cut Section Heights

After the tributary wind load value was determined it was used to calculate the shear force in the wall at each cut section. Figure 41, Figure 42, and Figure 43 depict the wall and shear sections. The equations below were used to calculate the shear forces at each floor cut section.

$$V_R = \frac{F_R(\frac{l_x}{l})}{(l_x) * (solid\ wall\ thickness)}$$

$$V_3 = \frac{F_3(\frac{l_x}{l})}{(l_x - window\ length) * (solid\ wall\ section\ thickness)}$$

$$V_2 = \frac{F_2(\frac{l_x}{l})}{(l_x - window\ length) * (solid\ wall\ thickness)}$$

Figure 41: Wind Loading and Shear Roof Section

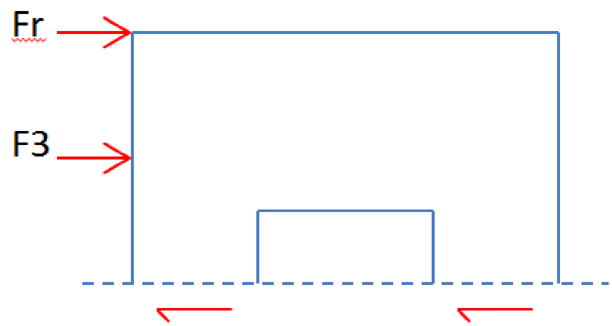


Figure 42: Wind Loading and Shear Floor 3 Section

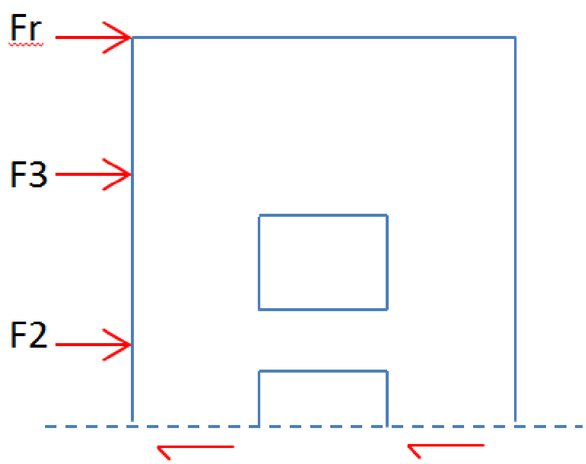


Figure 43: Wind Loading and Shear Floor 2 Section

3.1.2 Current Washburn 3D Building Model

To complete a current model detailing Washburn several steps detailed below were accomplished.

Reviewed/Corrected Current Model

The two versions of existing Washburn models were first compared and examined for inconsistencies and discrepancies. By examining the information that the models were based on and comparing observed current conditions, the initial strategy was to determine which of the two models was most accurate and to use this model as the base. The observed discrepancies were outlined in order to compare them, determine the correct information, and then update the base model to contain the correct information.

Created New 3D Model

After the inconsistencies were discovered, it was determined that rather than working off of one model and fixing the incorrect elements, it would be more beneficial to start a new model that integrates elements from both. This new model created by the project team was derived from the other, previous models and addressed the various discrepancies that were discovered.

Roof, dormers and additional windows were drawn onto the model. The third floor mansard level of Washburn required additional modeling and detail work to complete. After the model was corrected and expanded, it was a full three-dimensional model of Washburn. The following diagram, Figure 44 , details the steps taken to complete the 3D model. A more detailed explanation of the model work and results are described in Section 3.3.

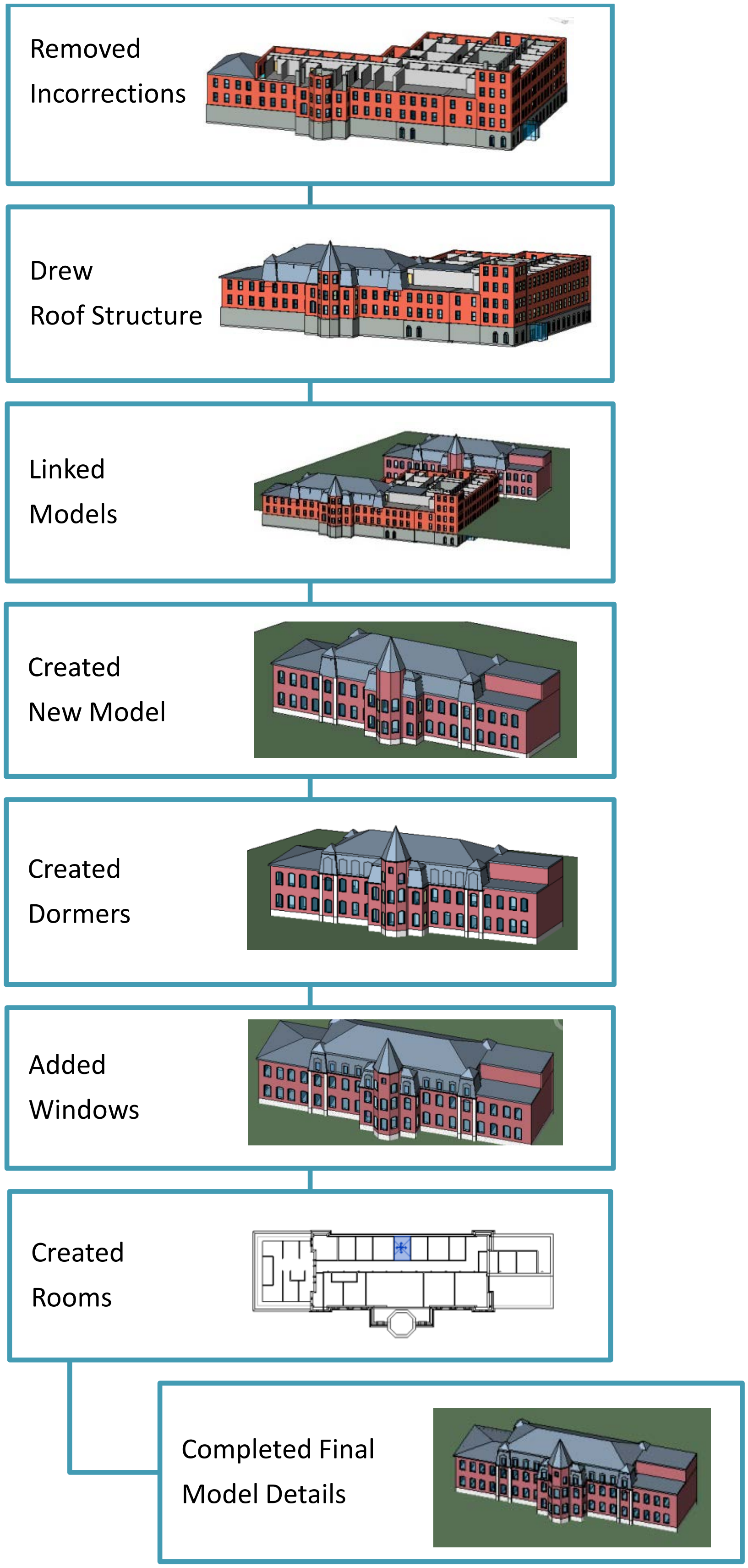


Figure 44: Steps to Completing Model

Gathered Data

In order to bring the 3D model to the level of a BIM model, it was required to gather the necessary data. Through meetings with personnel from Cutler Associates and the review of construction drawings provided by Cutler this data was acquired and then organized. The information was organized in a tabular fashion (Section 3.3.2) by each element of work in the 2011 renovation project.

Attached Data to Model

The renovation data was attached to the model to provide another dimension to the depiction of Washburn. For example the work done to a window, removed and replaced trim, was attached to the window item within the model. This was completed in a likewise manner for all the project work. Schedules were also created to view and organize this data within the model. Figure 45 shows the steps taken to complete the model and transform it into a BIM model.

Figure 45: Final Steps to Complete BIM Model

The completion of these steps created a comprehensive BIM model of Washburn detailing. The resulting model not only contained and presented the three-dimensional and structural elements, but also the information from the most recent renovations.

3.2 Building Code Study Results

The first portion of the building assessment focuses on the application of building codes. The project team concentrated on two areas to investigate the issues in more detail. These areas included a structural analysis and a fire protection system analysis.

3.2.1 Structural Analysis

Washburn was built in the late 1800's and at that time construction materials and methods were different than current technologies. This section focuses on the structural code analysis of Washburn and investigates whether the structure that was built in the 1800's would comply with the codes and standards now in-place. A structural analysis was performed, investigating the performance of Washburn's structure under certain design loads, including wind and seismic loads that must be considered today. A checklist of structural provisions from the *Massachusetts State Building Code* along with the data from the structural analysis was used to assess Washburn's current code compliance.

The wall section shown in Figure 46 depicts the portion of Washburn's wall that is the focus of this structural analysis. It is assumed that the rest of the exterior wall will perform similarly under the loads applied to this wall section.

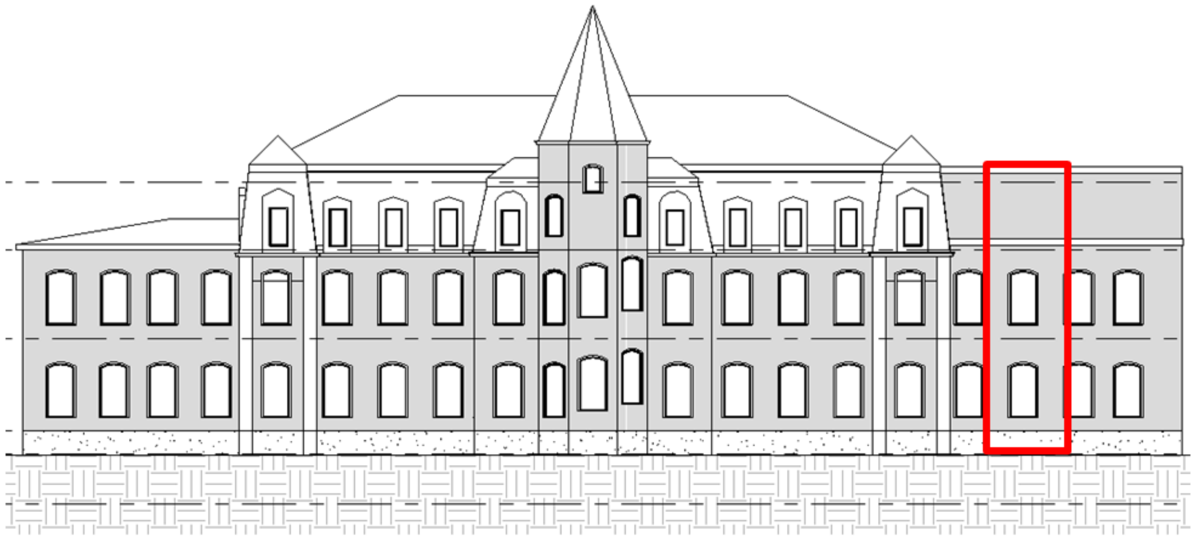


Figure 46: Wall Section Focus

Dead and Live Loading

The dead and live load analysis was compared to the compressive strength of mortar and bricks in order to determine whether they would withstand the loads. Table 20 shows the dead and snow loads acting on the roof. Table 21 depicts the dead loads applied on both the 2nd and 3rd floors, and Table 22 shows the live loads due to two different occupancies. Table 23 has the values for the total gravity loads acting on each of the columns in the wall section. Figure 47 depicts where the point loads are on each column in relation to the values in Table 23.

Table 20: Roof Loading Summary

Roof	
Element	Load (psf)
1” Board	3.0
¼” Slate	10.0
Douglas Fir Timber Frame	34.75
Ceiling System	1.0
MEP System	5.0
Insulation	20.0
Snow	35.0

Table 21: Floor Dead Load Summary

Floor (Dead)	
Element	Load (psf)
Ceiling System	1.0
MEP System	5.0
Insulation	2.0
¼” Linoleum	1.0
Lightweight Concrete	10.0
Brick	38.0

Table 22: Floor Live Load Summary

Floor (Live)	
Element	Load (psf)
Classroom	50.0
Open Plan	100.0

Table 23: Column Gravity Load Summary

Column Loading	
Column	Load (lb)
A	548.45
B	298.53
C	298.53
D	548.45

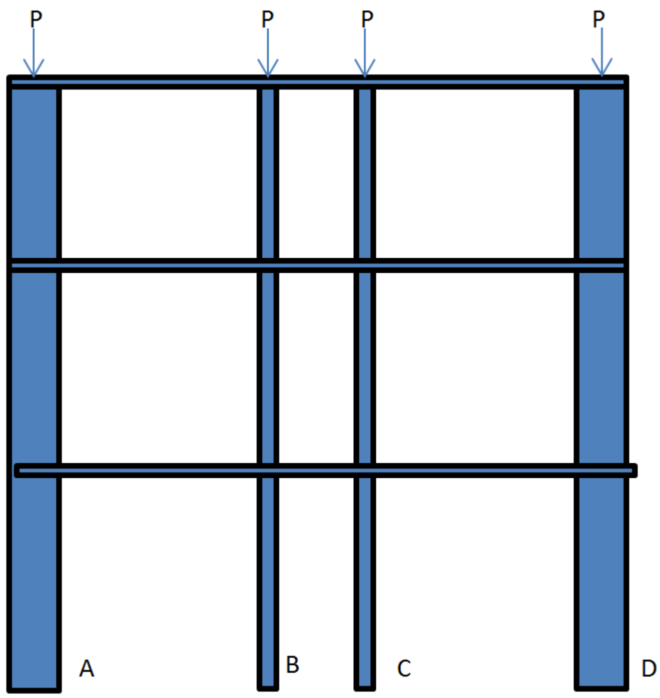


Figure 47: Gravity Loading Diagram

Seismic Loading

The seismic forces acting on the Washburn wall section are shown in Table 24. Note that the forces associated with the seismic loads are in kips and not in pounds. Figure 48 illustrates the story forces on the structure as well as the resulting forces on each column due to the overturning moment.

Table 24: Seismic Loading Values

Seismic Loading		
Column	Force (k)	Force (ksi)
A	212.99	204.80
B	96.26	204.80
C	96.26	204.80
D	212.99	204.80

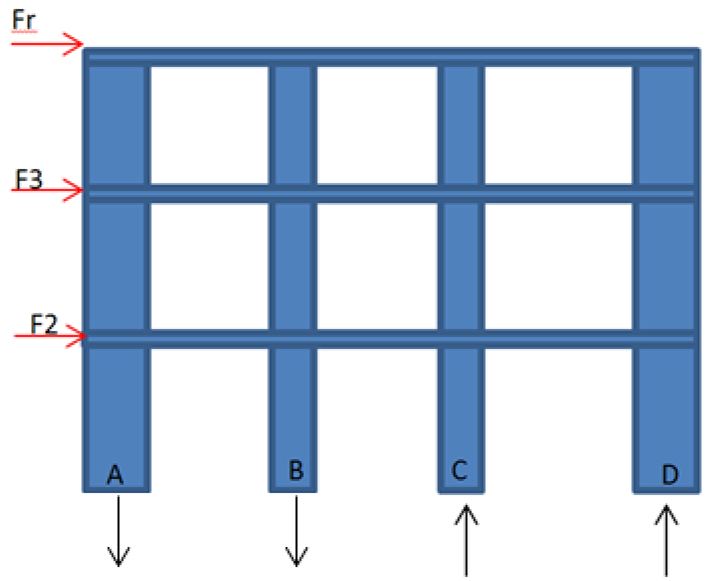


Figure 48: Seismic Loading and Forces

When comparing the seismic loading to the loading due to the gravity loads it is apparent that the seismic uplift forces are much greater than the gravity forces, as seen in Table 25. Therefore there will be resultant tensile forces in the masonry. The f'_m value of masonry was found to be 4060psi from ASTM C150 and the corresponding capacity of the masonry is 0.127 ksi. When comparing the seismic forces to the shear capacity (Table 26) it can be seen that the seismic forces are greater than the shear capacity and the structure will fail under the forces resulting from an Earthquake.

Table 25: Comparison of Gravity and Seismic Forces

Gravity Forces (k)	Seismic Forces (k)
.548	212.99
.298	96.26
.298	96.26
.298	212.99

Table 26: Shear Capacity vs Wall Seismic Shear Force

Shear Capacity (psi)	Seismic Shear Forces (psi)
127.45	1422.22

Wind Loading

Story forces for the equivalent wind load acting at each floor level can be seen in Figure 49, and Figure 50, Figure 51, and Figure 52. The values from the wind load analysis can be found Table 27 in addition to their resulting shear forces. These calculated values for shear due to wind force were compared against the shear capacity of the masonry in order to determine if the wall was in compliance.

The f'_m value of masonry was found to be 4060psi from ASTM C150. Therefore the shear masonry capacity was calculated to be 127.45psi. When comparing this to the shear force resulting from the wind the masonry wall unit meets the code provisions and can bear the wind load calculated from the current standards.

Table 27: Wind Loading Summary

Level	Wind Force (lb)	Shear Force (psf)	Shear Force (psi)
Roof	**1.53**	**0.613**	**.004**
Floor 3	**3.14**	**1.64**	**.004**
Floor 2	**3.31**	**1.73**	**.004**

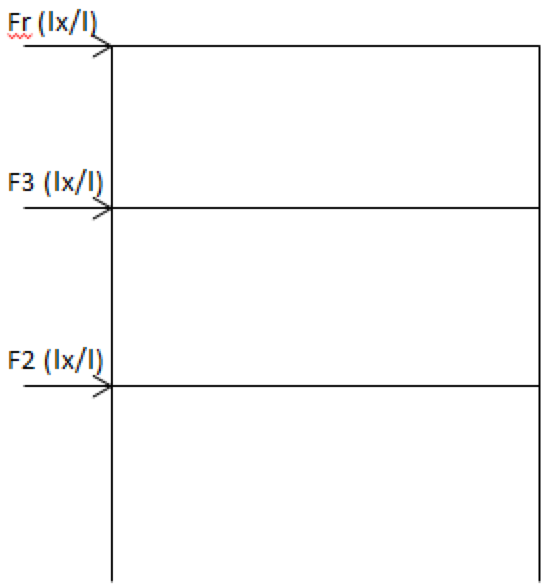


Figure 49: Wind Load Diagram

Figure 50: Roof Shear Force Diagram

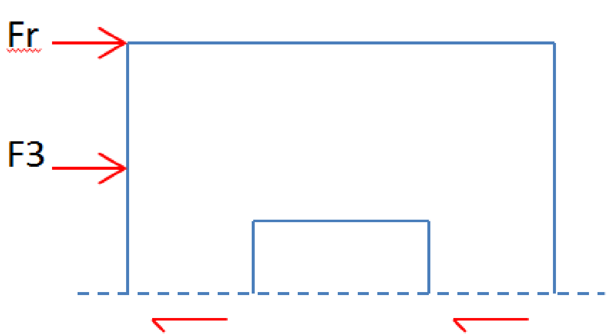


Figure 51: Floor 3 Shear Force Diagram

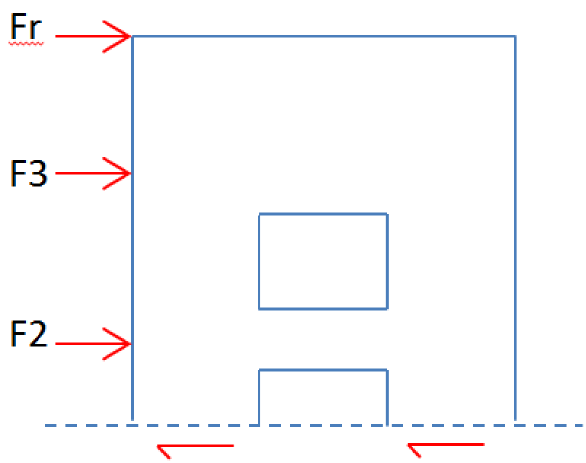


Figure 52: Floor 2 Shear Force Diagram

Areas of Compliance

Through interviews, construction meetings and research, information was gathered about the Washburn renovations and its structural components. This information was then compared against the building code checklist, and it was determined whether or not the building would be in compliance with the codes.

Items 1.a through 1.f, all relating to the element, building materials in existing building structures, are compliant with the *IEBC*. These were determined to be in compliance because the repairs to Washburn were done in accordance to the current standards. The repairs and the standards to which they are in compliance are demonstrated in Table 28. More specifications on the masonry repairs can be found in Appendix 7.3.2. Portions of the wood trim around the windows of Washburn were rotten and in need of repair; the guidelines for the wood repair, in detail, can be found in Appendix 7.3.4. Before Washburn was renovated, there was widespread leaking through the roof and mansard of the building, according to *Hoffman Architects* who were retained to perform a condition assessment of the building enclosure. The roof was completely reroofed; more specifications on the reroofing guidelines can be found in Appendix 7.3.3.

Table 28: Repair Compliance

Area of Construction	Standard in Accordance to	Acronym/reference numbers
Roofing	*National Slate Association*	*NSA*
	National Roofing Contractors Association	*NRCA*
	Roofing Slate	*ASTM* C406
	National Slate Association Slate Roofs	1925 (1997)
	NRCA Roofing and Waterproofing Manual	4th edition
Mansard Replacement	*Architectural Woodwork Institute*	*AWI*
Bricks and Mortar	*Specifications for Aggregate for Masonry Mortar*	*ASTM* C144-99
	Specification for Portland Cement	*ASTM* C150-00
	Specifications for Hydrated Lime for Masonry Purposes	*ASTM* C207-91 (1997)
	Specification for Mortar for Unit Masonry	*ASTM* C270-00
	Brick Color and Size	*ASTM* 216

Item 2.b is in compliance with the *Codes* because the live loads were not changed due to the alterations. Only the exterior of Washburn was altered, and the live load on the roof would not matter if it was altered because the snow load overrides the roof live load and the snow load did not change.

Items 3.c, 5.c, and 6.b, relating to alterations to structural elements carrying lateral load, repairs to vertical elements of lateral force resisting systems and repairs to gravity load carrying components, respectfully, state that Washburn is in compliance with *IEBC* 1301.2.4. This section of the *Code* states that buildings cannot be altered if the alteration will cause a negative change in the level of safety. The level of safety in a building is usually changed when the occupancy level is changed or the purpose of the building changes. Washburn's renovations did not change the level of safety because alterations did not change the occupancy level and the building's purpose stayed the same therefore it is still in compliance with this code. In addition 2.c, 7.a, b, and c discuss change in occupancy and as previously mentioned Washburn's inside was not changed as to allow for a change in occupancy. Therefore Washburn is compliant with *IEBC* 307, *IEBC* Chapter 9 and *IEBC* 1301.2.1.

While repointing the structure, metal bracing was installed in order to improve the performance of the structure against seismic forces. For the purposes of this study the bracing were not included in the structural analysis however 4.b of the checklist is in compliance because of this voluntary update.

Items 5.a, 5.b, and 6.a of the checklist demonstrate that Washburn is in compliance with code sections *IEBC* 304.2, *IEBC* 506.2.3.1 and *IEBC* 506.2.3 because the repairs to Washburn were not done because of substantial damage to Washburn's structure. Substantial damage is defined by *IEBC* as "damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred" (Massachusetts Department of Public Safety, 2011). Washburn's damage, that was repaired, is not characterized as "substantial" because the repairs were summed to less than 50 percent of Washburn's market value, according to *Hoffman Architects*.

9.a, b, c, d, and e of the checklist, having to do with evaluation of the building, are all in compliance with the *Codes*. They are in compliance with the codes because Hoffman Architects evaluated the building prior to renovations.

Element 10 of the checklist, Alterations and Repairs of Unreinforced Masonry bearing wall buildings is in compliance with *the Codes*. It is in compliance because the alterations and repairs were completed in reference to ASTM standards as can be seen in Appendix 7.3. In addition element 11 of the checklist is also in compliance. This element states that if materials are part of the load carrying systems of the structure then they must be repaired or replaced and the masonry was both repaired and replaced in the renovations according to standards. Furthermore, along the same lines as element 11, element 12 is also in compliance because the walls were repaired, even though testing was not performed.

Bracing was installed during renovations and assisted in the connections of the facing and backing of bricks. This was assumed to be in compliance with the codes because the bracing was not part of the project scope, and element 28 was also assumed in compliance because the bracing is out of scope. In addition element 20 was also determined in compliance because according to the renovation specifications the masonry anchors were replaced with new anchors or bracing according to ASTM Standards. Furthermore element 26 and 29 are also in compliance because according to the specification the wall was anchored at every 3 brick courses which exceeded the *Code* specification of the roof and floor. Also, TAPCON was used to secure the wall tie anchors to masonry, in compliance with the *Code* considered in element 27 of the checklist and wall ties of type 304 stainless steel were used and therefore are in compliance with the *Code* (element 30).

Element 13.b states that a running bond pattern must be used for grouted or ungrounted hollow concrete or clay, a running bond is used for a brick pattern in Washburn even though the bricks used are not hollow; therefore Washburn is in compliance with the *Code*. In addition 13.c is also in compliance because the brick pattern is in compliance with *Codes* because a running pattern is used.

The minimum quality of mortar was reached in the Washburn renovations. The mortar specifications can be found in Appendix 7.3.2 and can be seen to be in compliance with the *Codes*. Therefore element 17 of the checklist is in compliance. Furthermore the minimum quality of masonry was also reached due to the specifications outlined in Appendix 7.3.2 as well. This allows element 18 to also be in compliance. Lastly element 19 can be found in compliance when observing the specifications because Washburn was repointed according to ASTM C270 standards.

Finally the maximum masonry compressive strength on a column was calculated to be 548.45lb which is 43.95 psi when applied to a column area. Therefore the dead and live load compression stress does not exceed 300psi and element 22 is in compliance with the *Codes.*

Areas of Non-Compliance

With the assistance of the checklist a few elements pertaining to Washburn's structure were considered in non-compliance with the *Codes*. Although some were determined not in compliance due to the structural analysis, others were assumed to be non-compliant for the purposes of the case study. These elements that were assumed to be non-compliant are elements: 2.a, 3.a, 3.b, 4.a, 8.a, 8.b, 25.a and 25.b.

IEBC A106.3.3.1 states that mortar must be tested by performing an in-place shear test to determine its quality of mortar. However in-place shear tests were not completed therefore element 14.a is non-compliant. Also, 14.b is also non-compliant because no tensile-splitting tests were performed either. Furthermore element 15 and 16 are not in compliance because tests were not completed and these elements specify the test locations and number of tests needed. In addition the masonry shear strength could not be calculated according to the *Code* because these tests were not completed; therefore element 21 is also non-compliant with *Codes*.

Finally element 23 of the checklist was found to be in non-compliance with *Codes*. The seismic forces were calculated to be greater than the gravity forces meaning that there would be tension forces when the *Code* states that unreinforced masonry should be assumed to have no tensile capacity.

3.2.2 Fire Protection System Analysis

This section focuses on the code analysis of the fire protection system. The sprinkler and alarm system was included in this analysis. *NFPA 13*, *NFPA 72* and *NFPA 25* were used as the reference standards according to the *Massachusetts State Building Code.* A Fire Protection Checklist was compiled by the project group and used to inspect Washburn. This checklist and the current conditions, as determined by the project group, are included in Appendix 7.2. This data was used to create new design ideas for updating Washburn to comply with current codes if a renovation was to be completed.

Areas of Non-Compliance

The fire protection system checklist, included in Appendix 7.2, was created based on an inspection done by the project group and is not an official inspection of the building. The project group inspected Washburn based on the assumption that the building would be renovated to an extent (*IEBC* Alternation Level 2 or 3) that would warrant a full upgrade of the system to current codes. The following paragraphs highlight areas of non-compliance throughout Washburn based on this approach. The abbreviated version of the fire system checklist to highlight the non-compliant elements is included as Table 29.

Table 29: Abbreviation Fire System Checklist including Non-Compliant Elements

Item #	Element	Code Reference	Compliant	Current Conditions
10	Sprinkler Obstructions	8.6.5.1.2*	No	Numerous sprinklers were not in compliance. Too close to pipes, beams, and light fixtures.
15	Location of Devices	5.5.2.1	No	Concealed spaces above ceiling are not protected by devices (Horanzy, 2011). Evident from 2011 fire.
17	Smoke-Sensing Detector Location	5.7.1.9*	No	Does not consider ceiling conditions based on the 2011 fire.
20	Smoke-Sensing Detector Location	5.7.3.2.3.3	No	Does not consider ceiling conditions based on the 2011 fire.
		5.7.3.7	No	No detectors are above suspended ceilings (Horanzy, 2011).
21	Manual Fire Alarm Box Location	5.13.6	No	Most exits comply but main entrance does not.

Sprinkler Obstructions

Washburn contains an eclectic group of sprinklers which is most likely due to the fact that the building is used for many different purposes (classrooms, labs, offices, computer areas, etc.) and various interior renovations have occurred to create different spaces. Figure 53 displays the different sprinklers that were found throughout the building.

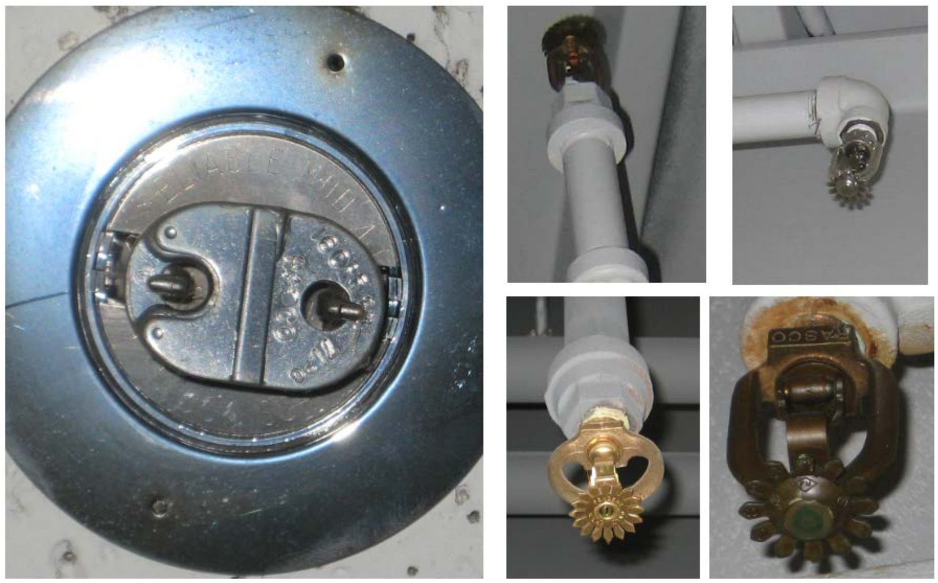


Figure 53: Sprinklers within Washburn

The hallways within the addition of Washburn show very different sprinkler position between floors. On the third floor, sprinklers are included in the suspended ceiling, but in the second floor, the sprinklers are some-what hidden within the pipes and ducts of the overhead area that does not have a suspended ceiling. Figure 54 helps to compare these two situations.

Figure 54: Washburn Ceilings (third floor on left, second floor on right)

The sprinklers on the third floor are visible and no obstruction poses a threat for the sprinklers' spray pattern. However, the sprinklers on the second floor hallway are not even visible in this photo. A closer investigation was done to locate the position of these sprinklers. Figure 55 shows the same sprinkler but at different distances.

Figure 55: Sprinkler Obstruction in Second Floor Hallway Ceiling

Obstructions to the sprinkler are visible, considering the pipe runs directly below the sprinkler by a couple inches. This obstruction placement does not comply with *NFPA 13* 8.6.5.1.2 and 8.6.5.2.1.3 as explained in item 20 of Appendix 7.2 (Fire Protection System Checklist).

Many cases similar to Figure 55 were observed within Washburn, whether the sprinklers are too close to a pipe, beam, or lighting fixture. These cases also violate *NFPA 13* 8.6.5.1.2 and 8.6.5.2.1.3 (item 20 in Appendix 7.2). Examples of sprinklers with obstructions too close to the heads are presented in Figure 56-Figure 58.

Figure 56: Beam Obstruction Room 339

Figure 57: Light Fixture Obstruction Second Floor Hallway

Figure 58: Metal Box Obstruction Room 107

Correcting these obstructions can be difficult because they are primarily caused by fixed objects that cannot be moved (exception being the light fixture). Remediation would then require the sprinkler heads to be moved to a location where they would no longer be obstructed. These solutions are presented later in this report.

The sprinkler system was also examined on the condition of the individual sprinkler heads. Results showed the sprinkler were appropriately temperature rated (the heads in the suspended ceilings); however, some heads were dirty, painted, or damaged. Figure 59 through Figure 62 display these situations.

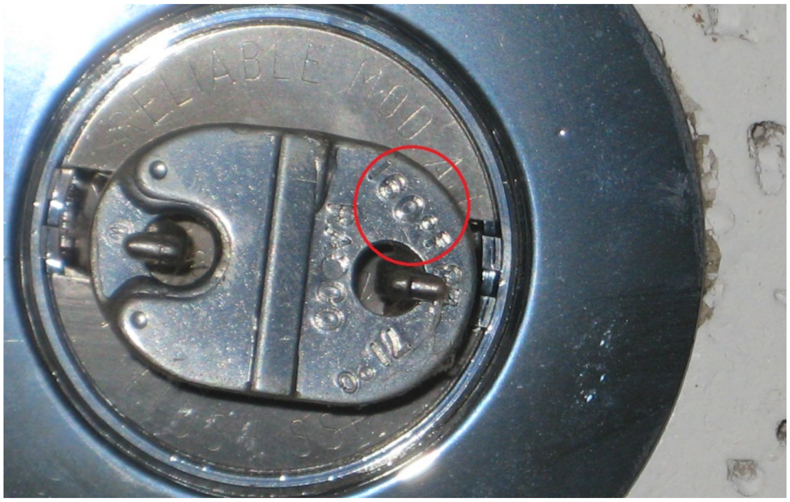


Figure 59: Temperature Rating for Sprinklers in Suspended Ceilings

The sprinklers are rated 160°F and need to be between 135 and 170°F for ordinary rating. This complies with *NFPA 13* 8.3.2.1 and item 5 in Appendix 7.2.

Figure 60: Sprinklers that need to be cleaned

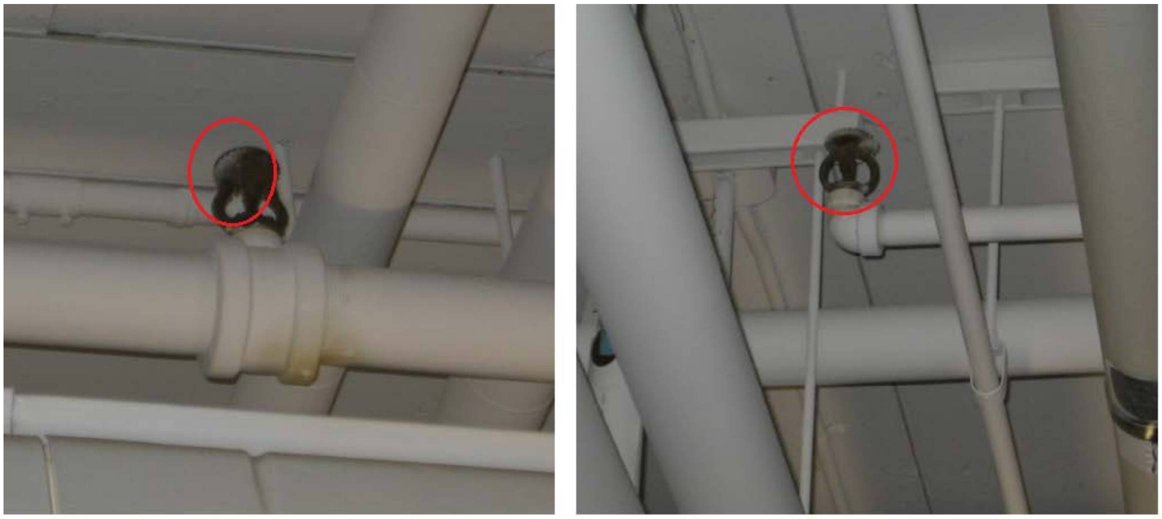


Figure 61: Paint on Sprinkler Deflectors

Figure 60 and Figure 61 show examples of sprinkler heads that need to be cleaned. Proper care was also not taken when painting the pipes around the heads because some of the paint stuck to the deflectors. This paint and dirt can obscure the sprinkler spray pattern and thereby reduce the protection to the floor area below the sprinkler. These situations are out of compliance with *NFPA 13* Table 5.5.1 and item 39 in Appendix 7.2.

Figure 62: Fusable link askew on left sprinkler compared to right

Figure 62 shows that the sprinkler on the left has a fusable link that is at a different angle than the link for the sprinkler on the right. The sprinkler must have been hit, and no one has noticed that the link was misaligned. When the link is not at the angle for which the sprinkler is listed, the sprinkler may not activate in the correct amount of time and may not correctly protect the area below. This condition is also out of compliance with *NFPA 13* Table 5.5.1 and item 39 in Appendix 7.2.

Absent Smoke Detectors

During the roof renovation of Washburn in 2011, a fire started from welding on mansards within an office wall. The office was located on the third floor, room 315. The fire started within the wall area shown in Figure 63 (The wall has since be repaired).

Figure 63: Origin of 2011 Roof Renovation Fire

The smoke from the fire traveled from inside the wall to concealed areas above the ceiling. The smoke then traveled in this concealed area outside the room and above the outside hallway as shown in Figure 64.

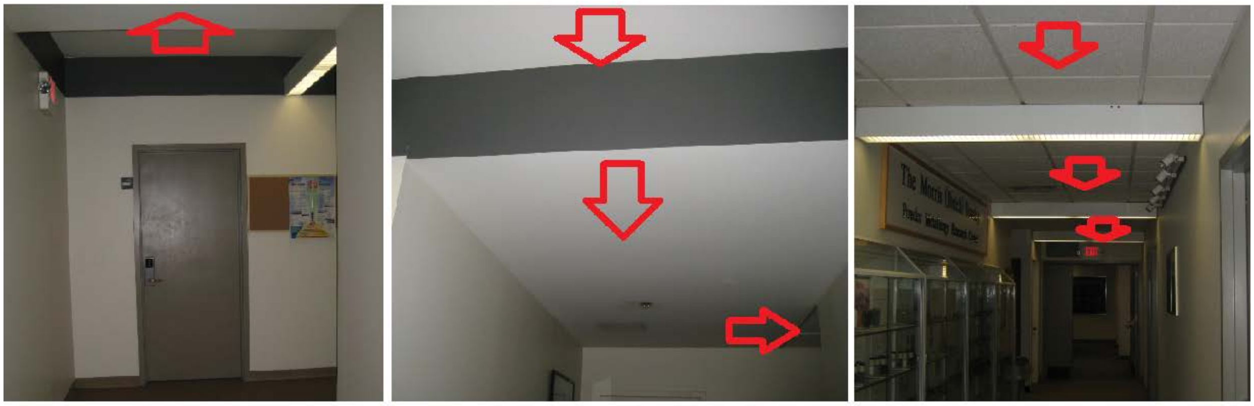


Figure 64: Smoke Pattern of 2011 Roof Renovation Fire

Some smoke was escaping from a hole in the suspended ceiling due to a missing ceiling tile. This smoke was noticed by WPI staff, and a manual pull alarm was used to notify authorities. This pull station is seen in Figure 65. The smoke would have eventually reached a smoke alarm at the end of the hallway shown in the far right picture of Figure 64. This detector is also shown in Figure 65.

Figure 65: Manual Pull Station and Smoke Detector used in 2011 Roof Renovation Fire

If this fire were to occur at night or the ceiling tile was not missing, no one would have noticed the smoke. The smoke would eventually reach the smoke alarm at the end of the hall but it may not have gone off in time to stop the fire from causing serious damage to the building.

Since there were no detectors within the concealed space above the ceiling, there is a violation of *NFPA 13* 5.5.2.1 and 5.7.1.9 (items 15 and 16 in Appendix 7.2). The distance from the smoke detector located in the hall that did not activate to the door of the room in which the fire originated is depicted in Figure 66. This distance to the door is 46 feet but according to *NFPA 13* 5.7.3.2.3.1 (item 19 in Appendix 7.2) the detectors are allowed to be a maximum of 30 feet apart.

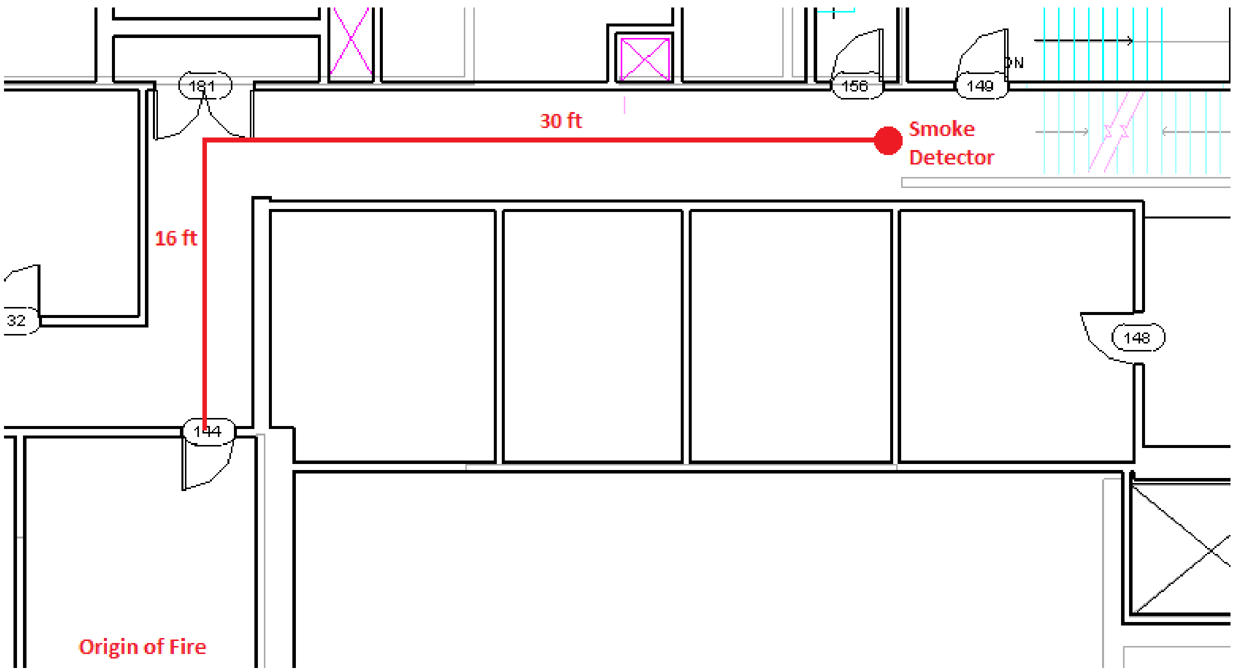


Figure 66: Distance to Nearest Smoke Detector in 2011 Roof Renovation Fire

The manual pull station alarm was located in the correct spot on this floor; however, on the main floor, the alarm is too far away from the entrance, item 21 in Appendix 7.2. This fire had the potential to cause damage to Washburn and luckily the right people were present to notice the danger and stop the situation from permanently damaging the building.

3.3 Current Drawings and Model

With the data received from WPI Department of Facilities, Cutler, and past student work, a 3D computer model representing the current conditions of Washburn was created. This model details the structure and general architectural layout of the building.

3.3.1 Washburn 3D Model

The final model created resulted from the combination and correction of the model from WPI Department of Facilities that was developed by Hoffman Associates (Figure 67) and a model developed by WPI students from two-dimensional *dwg* files (Figure 68).

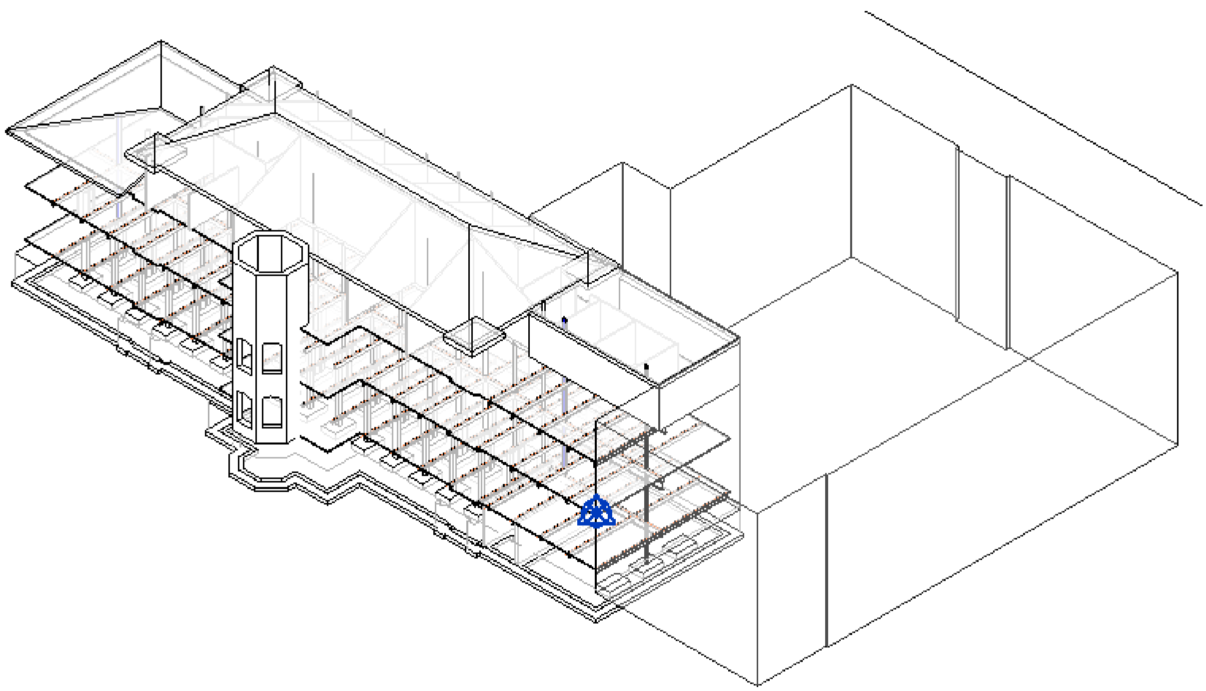


Figure 67: Model from WPI Facilities Developed by Hoffman Associates

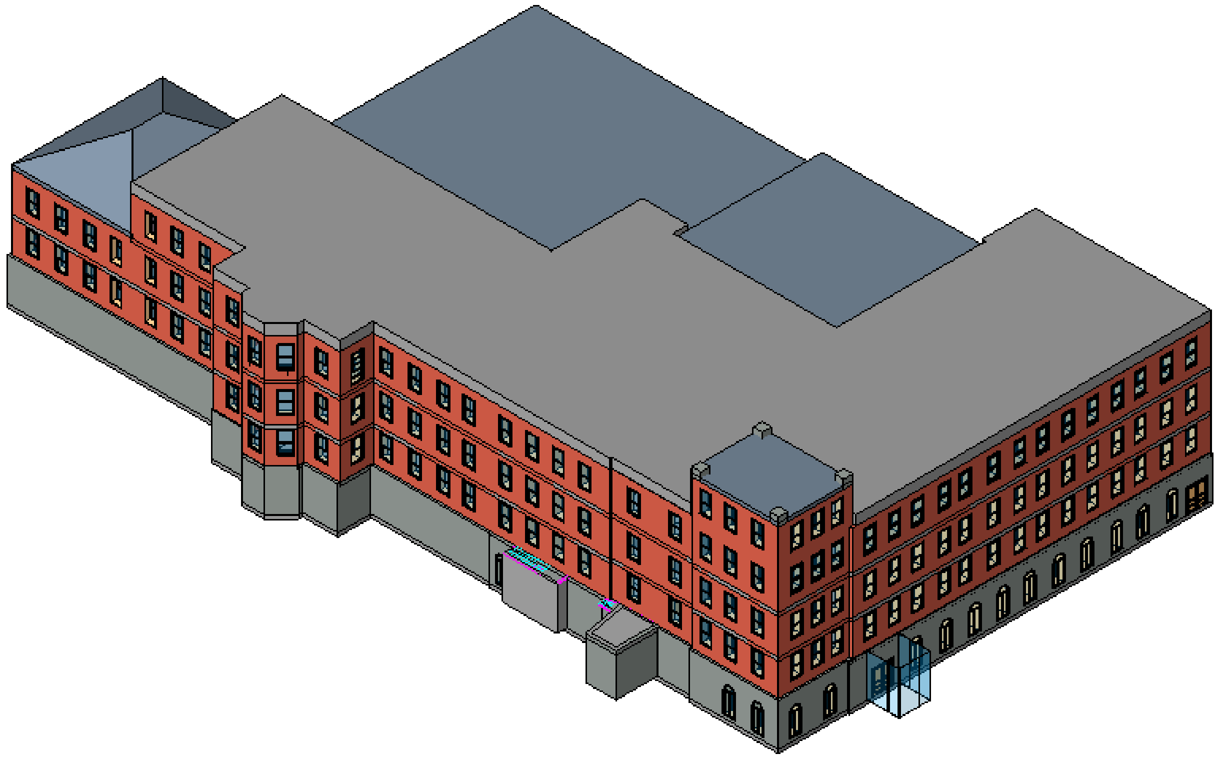


Figure 68: Model from WPI Students

The two models had some inconsistencies that needed to be confirmed and corrected. By taking elements and data from the models, a third model developed by our project team was created. When comparing the models many differences were outlined and it was discovered that the dimensions and detail of the WPI Department of Facilities' model more accurately represented the building. This model was developed more recently and with more data than was used in the WPI student model. The model created by WPI students, Mengling Wang and Holian Qu (2010), was created from floor plans of the building and focuses on space distribution. Some of this space and room data was incorporated into the final model but the majority of the building data was retrieved from the WPI Department of Facilities' model. Table 30 compares the attributes of the two original models given to the project team.

Table 30: Comparison of Original Models

WPI Students' Model	WPI Department of Facilities' Model
• Created by Mengling Wang & Holian Qu • Focus on room and space distribution • Created Spring 2010 • Details from WPI floorplans	• Created by Hoffman • Focus on building shell and structure • Created Fall 2011 • Details from Hoffman resources

The problems and discrepancies with the WPI students' model are highlighted in Figure 69. The windows are of different type and the third floor begins the roof structure. The floor heights also vary from the WPI Department of Facilities' model.

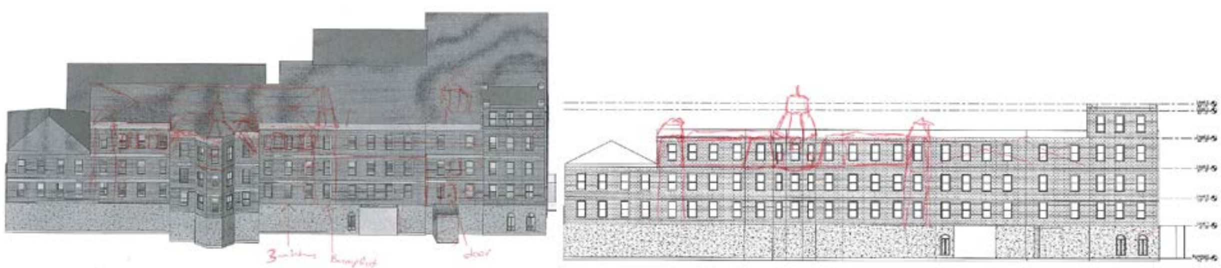


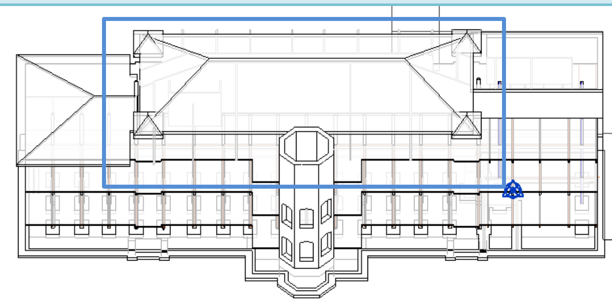
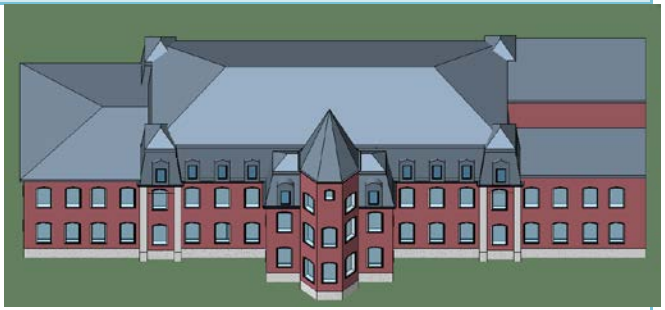
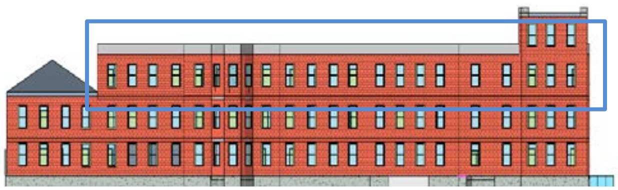
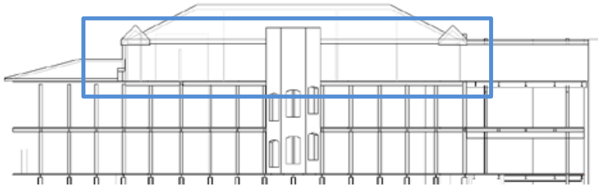
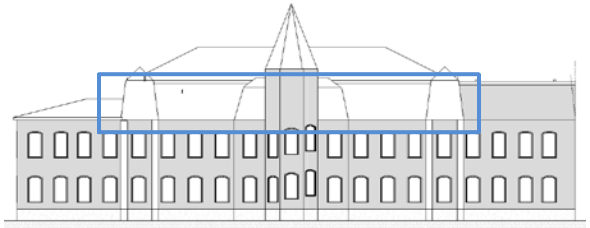
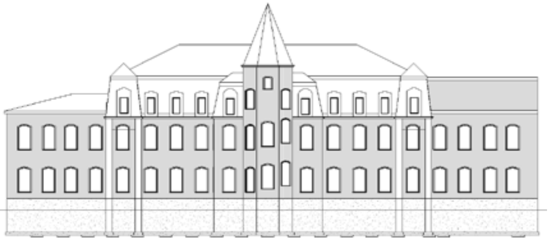
Figure 69: Notes on WPI Students' Model Discrepancies

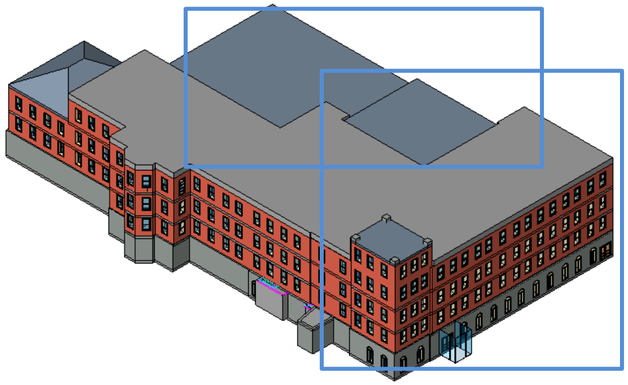
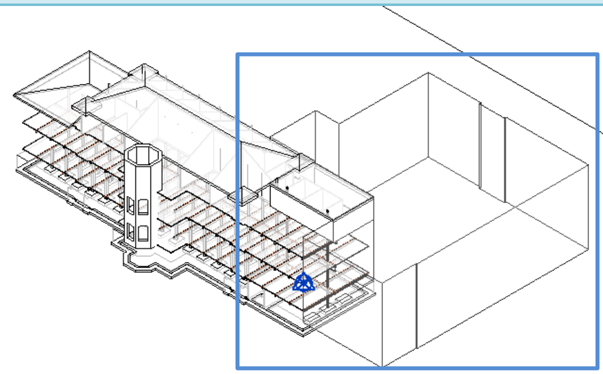
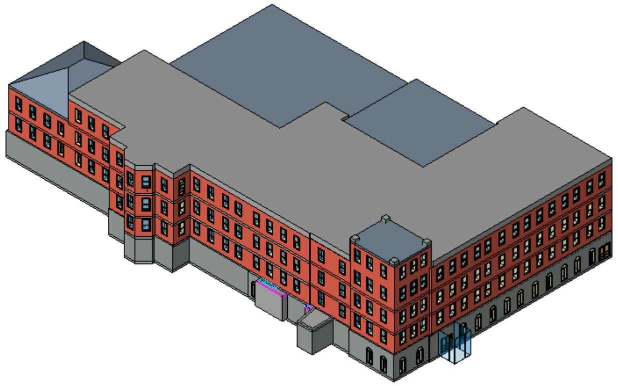
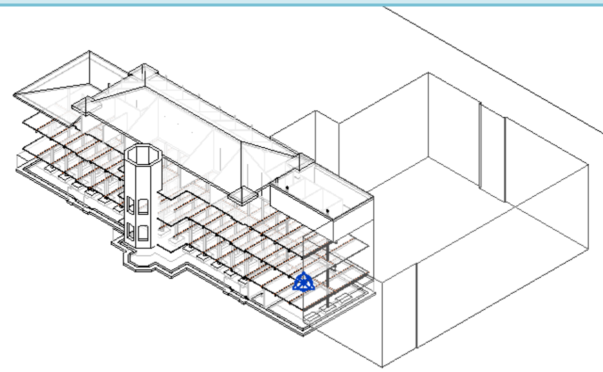
As the models were compared to each other and to the existing building these issues were discovered. It was first thought that the project team would work off of the WPI student model but after discovering the discrepancies, it was determined to be more beneficial to develop our own model.

The project team's model was based mainly on the WPI Department of Facilities' model. This model included the core and structural layout of the original Washburn building. Some detailing was missing and additional elements were included in the final model but the dimensions and building shell were taken from this model.

Table 31 displays the original models compared to the final project team model. The elements in need of correction in both the WPI Student and WPI Department of Facilities' Models are shown in detail and then compared to the finished image of the project team's model.

Table 31: Corrections to Models

WPI Students' Model	WPI Department of Facilities' Model	Final Project Model
Added Roof		
 Model missing entire roof structure	 Model missing sloped roof and tower	
Corrected Third Floor/Added Dormers		
 Third floor does not have brick walls	 Third floor missing dormers	
Updated/Added Windows		
 Incorrect size and number of windows	 Model missing third floor windows	

WPI Students' Model	WPI Department of Facilities' Model	Final Project Model
Removed Other Sections		
 Model includes power house and new section	 Model includes outline of new section	
Added/Corrected View Details		
 Details differ from actual building	 Model missing rendering and site	

The final model incorporates the roof structure of Washburn along with the addition of the dormers and windows on the third level which neither of the other models displayed. For the final model the project team focused on the core of Washburn, only showing the original building. This section of the building is the highlight of our project and of the most recent renovation work. There is also the most accurate data for this section. The project team did not have the proper documentation to accurately model and display the rest of the building.

3.3.2 Washburn BIM Model

Washburn recently went through an exterior renovation project in which Hoffman was the architect and Cutler Associates was the construction manager. In creating a complete picture of the building and fully documenting the structure, the details of this project have been included in the project team's model. The elements that were replaced or fixed have been tagged within the model along with the details of the renovation effort. In the future when other renovation takes place, the architects and construction team will be able to see the previous work in relation to the building model. Adding this data allows for a complete model of the building, helping the project team to better study and analyze Washburn. The use of BIM better helps visualization of the building greater than that of a simple 3D model

The data added to the model was received from Cutler and through various meetings with Dave Guertin. Cutler provided the team with a set of as-built drawings from their work on the project (Appendix 7.5). Figure 70 shows a sample section from of these drawings. The drawings consist of building elevation with the work noted and detailed descriptions of elements.

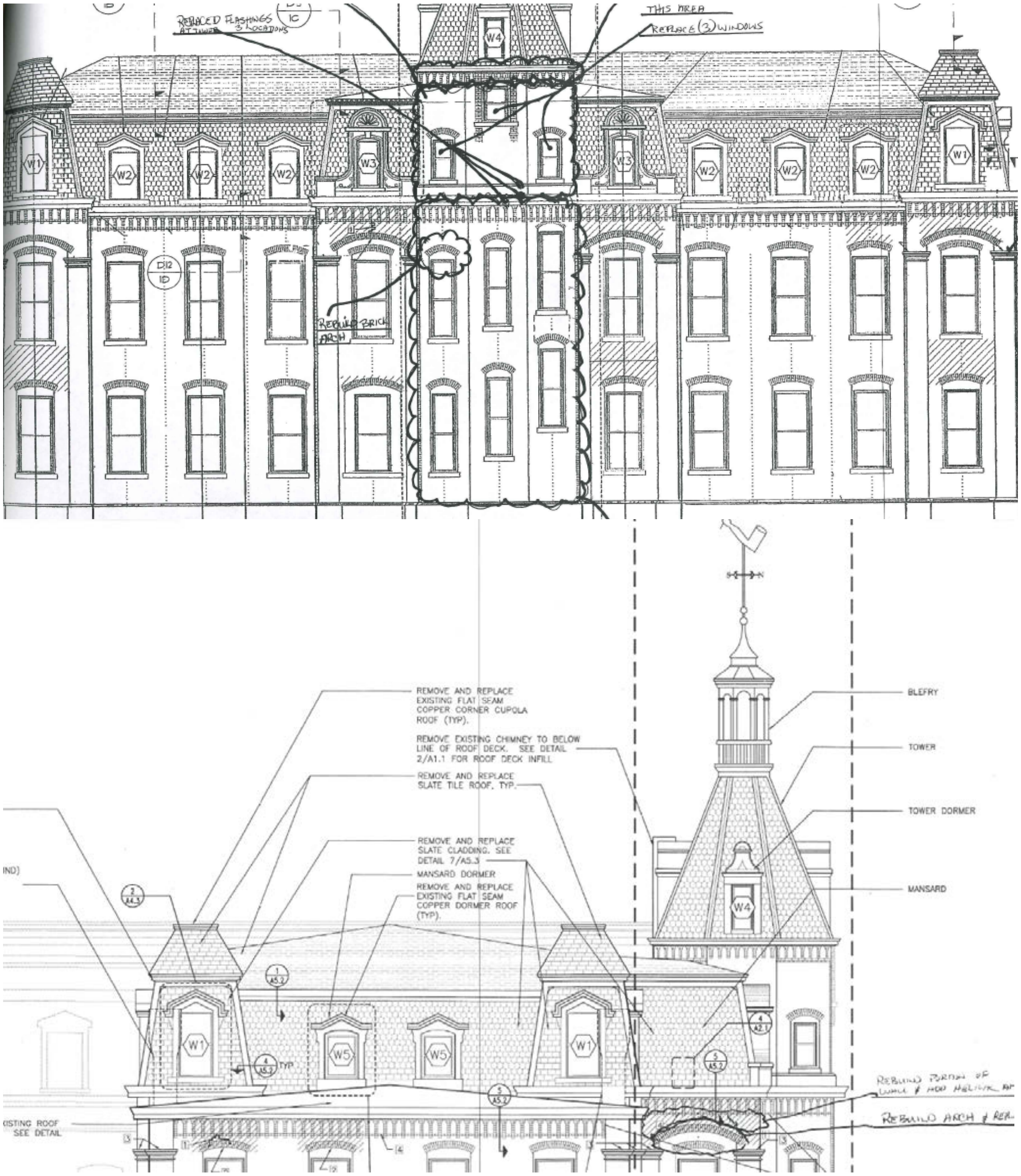
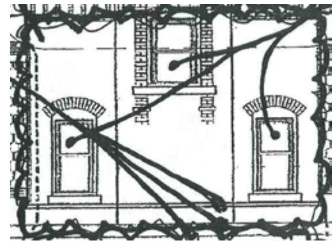
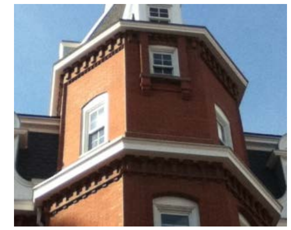
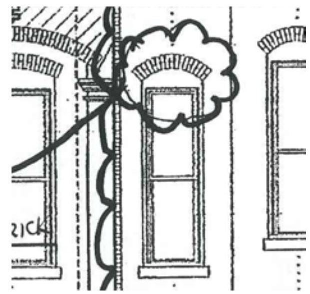
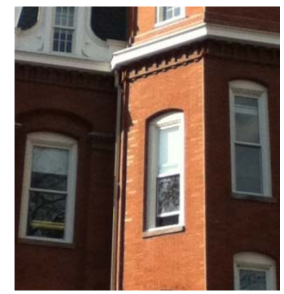
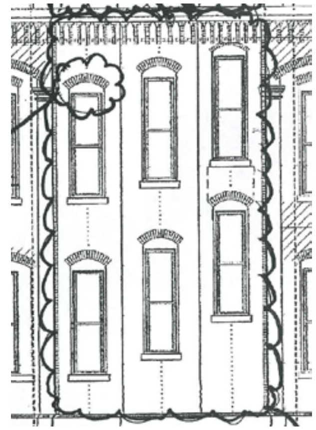
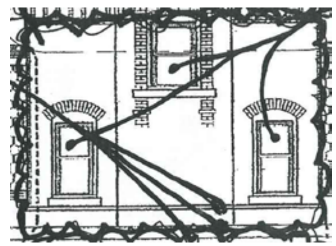
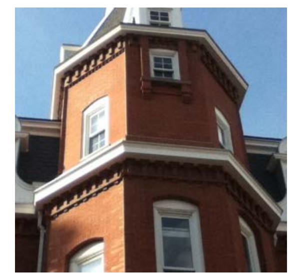
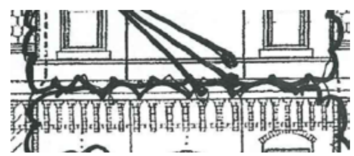
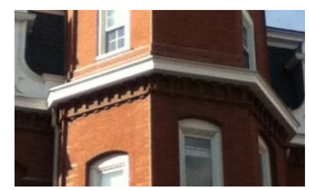
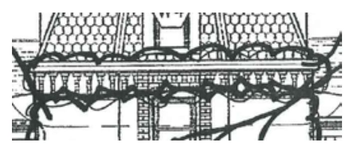
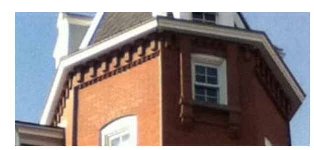


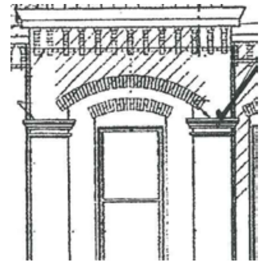
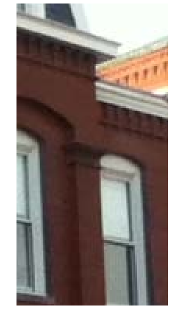
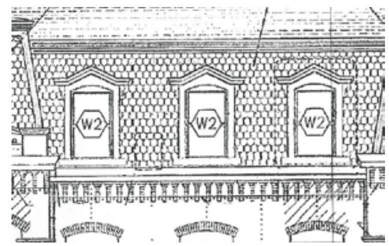
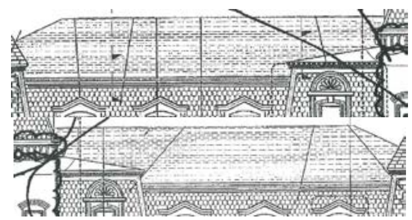
Figure 70: Sections of Cutler As-Builts

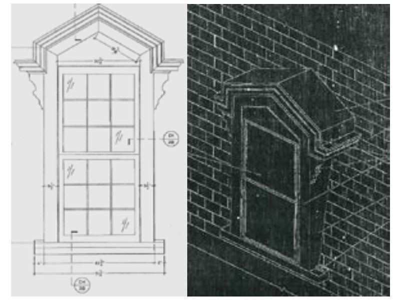
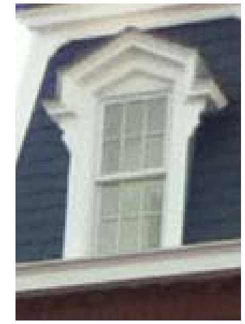
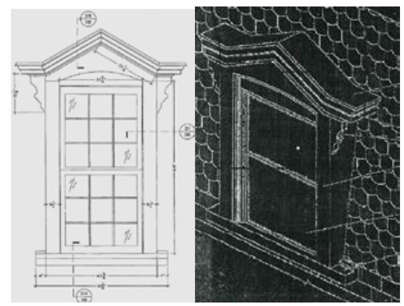
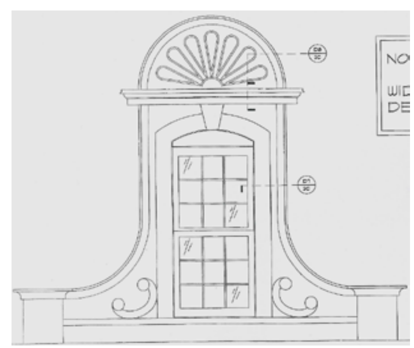
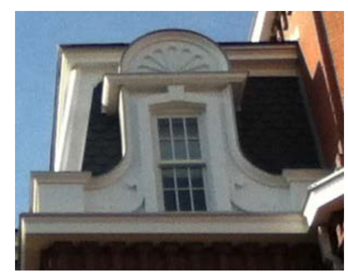
This information was taken from the drawings and then organized in tabular form below. Table 32 characterizes the renovation project by element each with its appropriate description, section from the as-built drawings, and photograph.

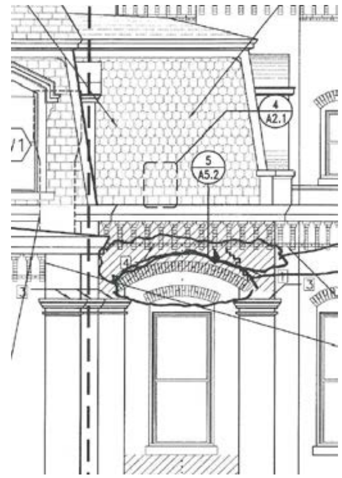
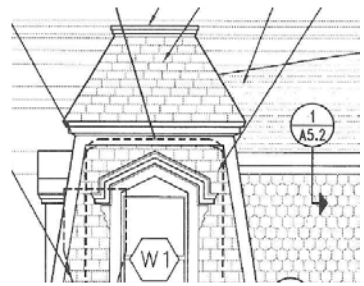
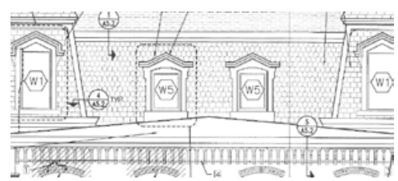
Table 32: Washburn Renovation Data for BIM

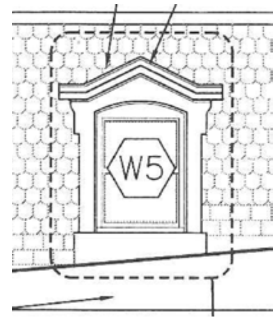
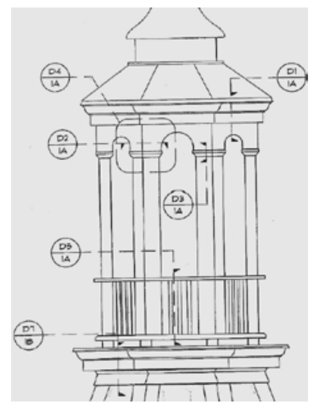
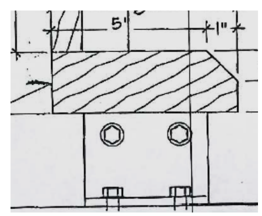
Element	Location	Renovation Details	Plan Drawing	Images
East Elevation				
Windows	3rd Floor Tower	Replaced 3 windows on level	 Sheet 1	
Arch	2nd Floor Tower above left window	Rebuilt brick arch	 Sheet 1	

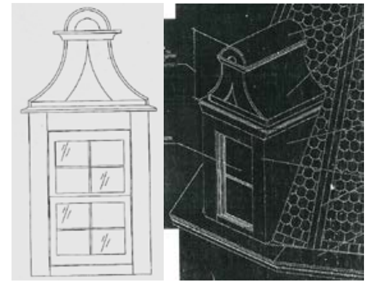
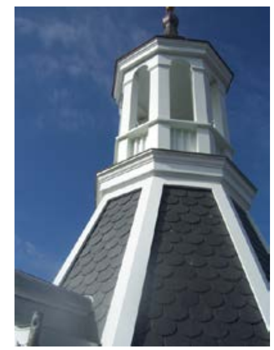
Element	Location	Renovation Details	Plan Drawing	Images
Brick Walls	1st and 2nd Floor of Tower	Corrugated masonry anchors every 3rd coarse	 Sheet 1	
Brick Walls	3rd Floor of Tower	Repointed and added helical anchors every other coarse	 Sheet 1	
Flashing	Between 2nd and 3rd Floors of Tower	Replaced flashings at tower	 Sheet 1	
Brick Details	Base of Tower Roof, Top of 3rd Floor	Replaced bricks	 Sheet 1	

Element	Location	Renovation Details	Plan Drawing	Images
Column	Top of Right Column at 2nd Floor, Rightmost	Replaced column washes	 Sheet 1	
Mansard Roof	3rd Floor Sloped Mansard	Slate cladding removed and replaced	 Sheet 1	
Roofing	Entire Roof Area of Original Building	Removed and replaced slate tile roof	 Sheet 1	
Window Roofs	3rd Floor Windows	All window roofs rebuilt with PT. frame and plywood sheathing	 Sheet 2	

Element	Location	Renovation Details	Plan Drawing	Images
Windows (Type W1)	3rd Floor Windows (2) on bumped out portions far left and right	Removed and replaced existing sill; Deteriorated wood trim removed and replaced; Dormer window removed and replaced; Sheet metal dormer removed and replaced	 Sheet 2	
Windows (Type W2)	3rd Floor Windows (6) on flat face of building	Removed and replaced existing sill; Deteriorated wood trim removed and replaced; Dormer window removed and replaced; Sheet metal dormer removed and replaced	 Sheet 2	
Windows (Type W3)	3rd Floor Windows (2) left and right of Tower	Removed and replaced deteriorated wood trim, moldings and cresting; Sheet metal dormer removed and replaced	 Sheet 2A	

Element	Location	Renovation Details	Plan Drawing	Images
South Elevation				
Arch	2nd Floor Rightmost Window bump out of front façade	Rebuilt arch and replaced flashing above window		
Dormer Roofs	3rd Floor both Dormers	Remove and replace slate tile roof		
Mansard Roof	3rd Floor Sloped Roof	Removed and replaced slate cladding		

Element	Location	Renovation Details	Plan Drawing	Images
Window	3rd Floor 2nd Window from left	Removed and replaced flat seam copper dormer roof		
Tower				
Belfry	Throughout Belfry at Top of Tower	Replaced Spanish cedar woodwork	 Sheet 1A	
Reinforcement	Belfry Columns in Tower	Reinforced column support with brackets and bolts	 Sheet 1B	

Element	Location	Renovation Details	Plan Drawing	Images
Window (Type W4)	Tower Roof	Removed and replaced window in dormer; Cresting removed and replaced; Wood trim removed and replaced; Metal window framing removed and replaced	 Sheet 2A	
Roofing	Tower Roof	Slate roofing removed and replaced	 Sheet 2A	

Once categorized, these elements were incorporated into the project team's BIM model of Washburn. The information on the renovations was tagged to the corresponding element in the model, so when an element in the model is selected the associated data on the renovation work can be viewed. Figure 71, for example, shows that when a window is selected, then the renovation information can be seen in the Properties window under Identity Data.

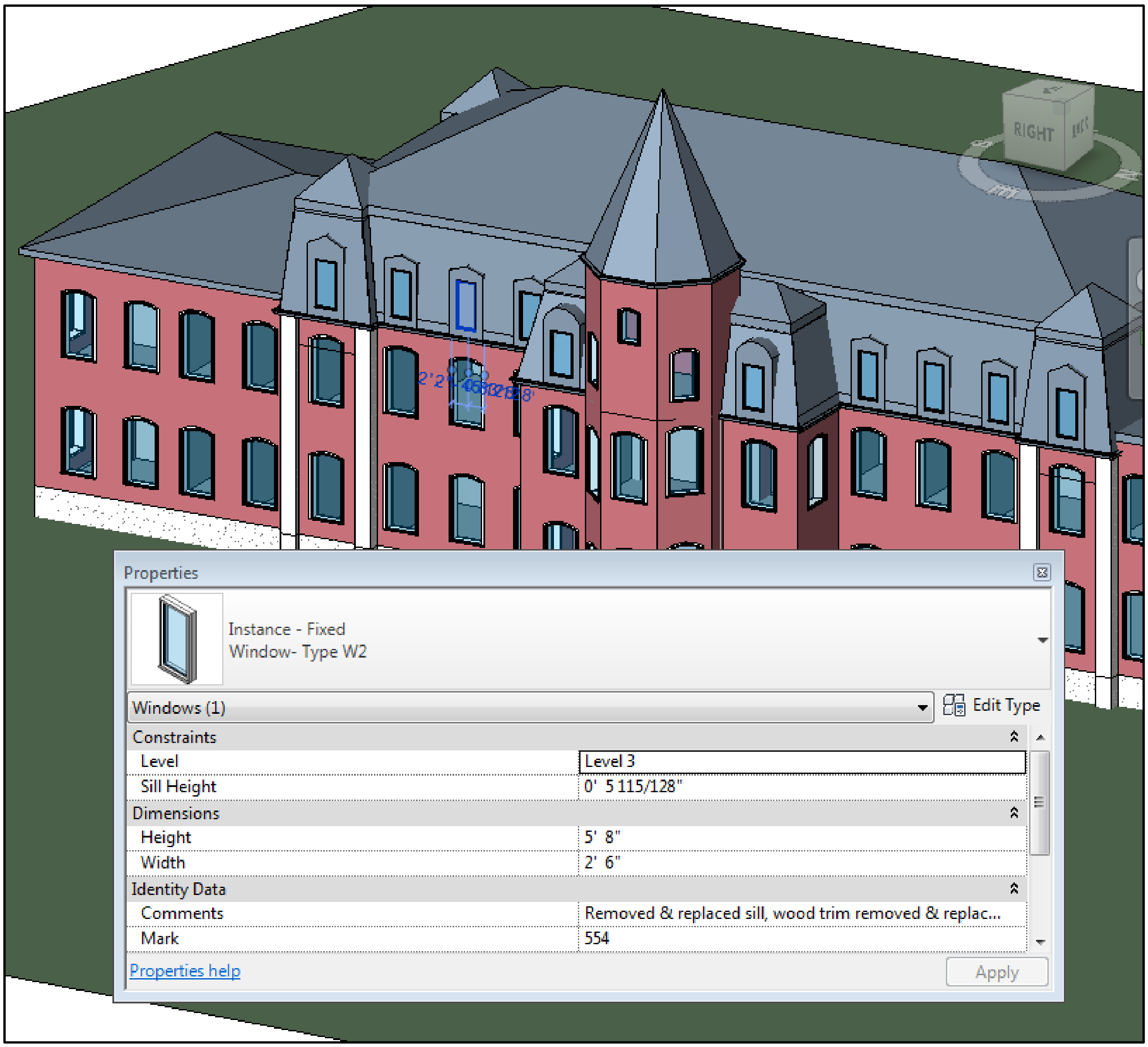


Figure 71: Example of Data Tagged in BIM Model

The building information can also be reviewed in the model through the item schedules. The current version contains schedules for three major groups of work: windows, walls, and roof. Each schedule lists all of the associated elements and their descriptive information such as type, location, or size. A section of each of these schedules are shown in Figure 72-Figure 74. These schedule tables give all the relevant information for each of the elements. If the user selects an item from the table it will also be highlighted in the model to view its location three-dimensionally.

Adding this element data brings the 3D model to another level allowing it to enter the BIM category. This information adds another dimension to the representation of the building. A viewer can not only gain insight into the geometry of the building, but also the specific attributes of the elements that compromise the whole. The model captures the building in its entirety including the most recent renovation project.

Window Schedule				
Type	Level	Comments	Height	Width
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Tower	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Tower	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Tower	2	Rebuilt brick arch- 2011 Renovations	8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	1		8' - 0"	4' - 0"
Window- Typical	1		8' - 0"	4' - 0"
Window- Typical	1		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Typical	2		8' - 0"	4' - 0"
Window- Type W	3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 9"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 6"
Window- Type W	Level 3	Removed & replaced deteriorated wood trim, moldings and cresting, sheet metal dormer removed and replaced- 2011 Renovations	5' - 3"	2' - 9"
Window- Type W	3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 9"
Window- Type W	Level 3	Removed & replaced deteriorated wood trim, moldings and cresting, sheet metal dormer removed and replaced- 2011 Renovations	5' - 3"	2' - 9"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 6"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 8 3/4"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 6"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 6"
Window- Type W	Level 3	Removed & replaced sill, wood trim removed & replaced, dormer window removed & replaced, sheet metal dormer removed & replaced- 2011 Renovations	5' - 8"	2' - 6"
Window- Tower	3	Replaced- 2011 Renovation	6' - 0"	3' - 0"
Window- Tower	3	Replaced- 2011 Renovation	6' - 0"	3' - 0"
Window- Tower	3	Replaced- 2011 Renovation	4' - 0"	2' - 6"

Figure 72: Section of Window Schedule with Data

Wall Schedule		
Structural Usage	Type	Comments
Non-bearing	Generic - 24"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 24"	
Non-bearing	Generic - 24"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 24"	
Non-bearing	Generic - 24"	Replaced column washes- 2011 Renovations
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	Repointed & added helical anchors every other coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	Repointed & added helical anchors every other coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	
Bearing	Generic - 24"	

Figure 73: Section of Wall Schedule with Data

Roof Schedule			
Type	Base Level	Comments	Area
Generic - 9"	3		1611 SF
Generic - 12"	3	Removed & replaced slate tile roof- 2011 Renovations	4444 SF
Generic - 12"	3		117 SF
Generic - 12"	3		117 SF
Generic - 12"	3		117 SF
Generic - 12"	3		117 SF
Generic - 12"	3		313 SF
Generic - 12"	3	Reinforced & replaced belfry elements, tower window removed & replaced, slate roofing removed & replaced- 2011 Renovation	574 SF
Generic - 12"			23 SF
Generic - 12"			120 SF
Generic - 12"		Slate cladding removed and replaced- 2011 Renovations	1289 SF
Generic - 12"			90 SF
Generic - 12"			93 SF
Generic - 12"			129 SF
Generic - 12"			17 SF
Generic - 12"			23 SF
Generic - 12"			120 SF
Generic - 12"			17 SF
Generic - 12"			126 SF
Generic - 12"			117 SF
Generic - 12"			18 SF
Generic - 12"			23 SF
Generic - 12"			128 SF
Generic - 12"			129 SF
Generic - 12"			25 SF
Generic - 12"			23 SF

Figure 74: Section of Roof Schedule with Data

3.3.3 LOD (Level of Detail)

Building information models are characterized by the AIA (American Institute of Architects) according to the amount of detail incorporated. The project team's model also falls into this classification system. According to the guidelines set by AIA (Bedrick, 2011), the BIM model created falls into LOD 300 because it incorporates the elements of traditional construction drawings. It has the specific 3D geometry of the facility and there are also some detailed elements and systems such as the structural system. The model is not categorized as LOD 400 or LOD 500. LOD 400 is a model for fabrication or assembly that can be detailed by a subcontractor; LOD 500 incorporates the mechanical, electrical or plumbing of the building. The model is an as-built in terms of structures and layout, but does not qualify as a complete as-built of the building.

3.3.4 Current Building Representations

The final product created by the project team to document Washburn is a BIM model in *Autodesk Revit* that has also been converted to a file format *dwf* that is compatible with *Autodesk Design Review*. This format gives access to non-Revit users to the model and its stored information, having a greater ease of use and is a more user friendly program that can be easily downloaded from the Autodesk website. The following are sheets from the model to display the groups work in representing the building (Figure 75-Figure 80).

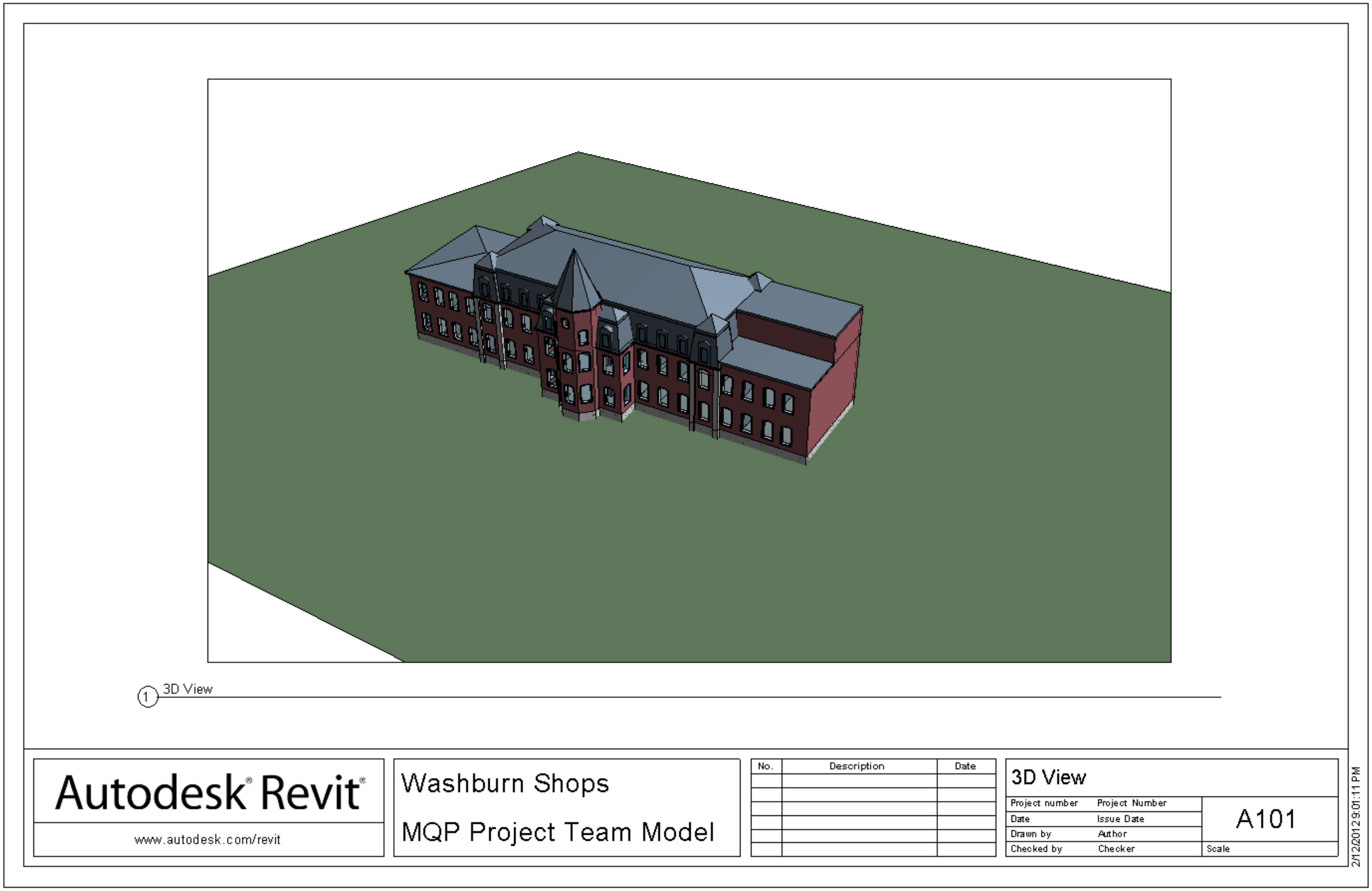


Figure 75: Sheet A101- 3D View

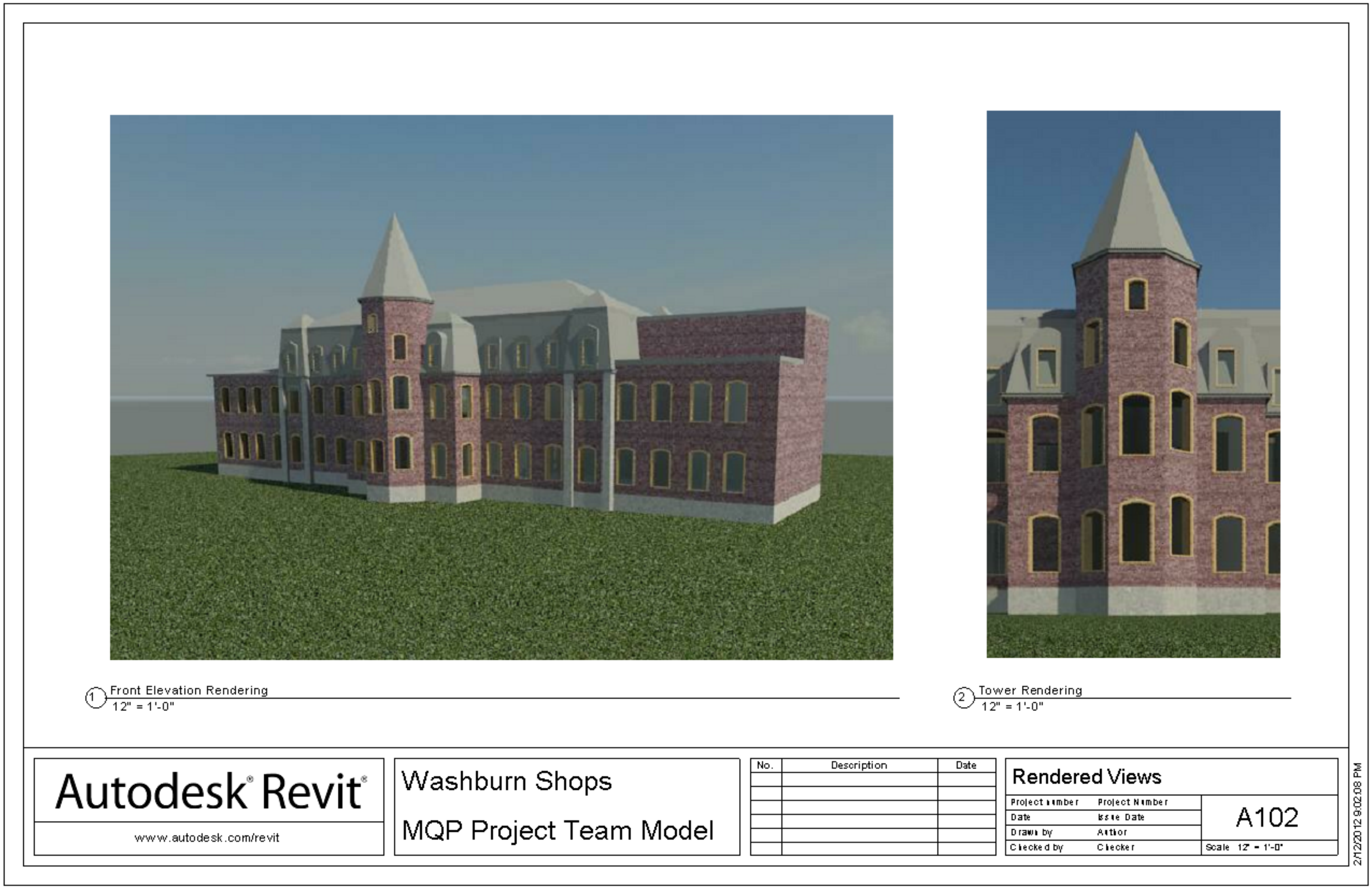


Figure 76: Sheet A102- Rendered Views

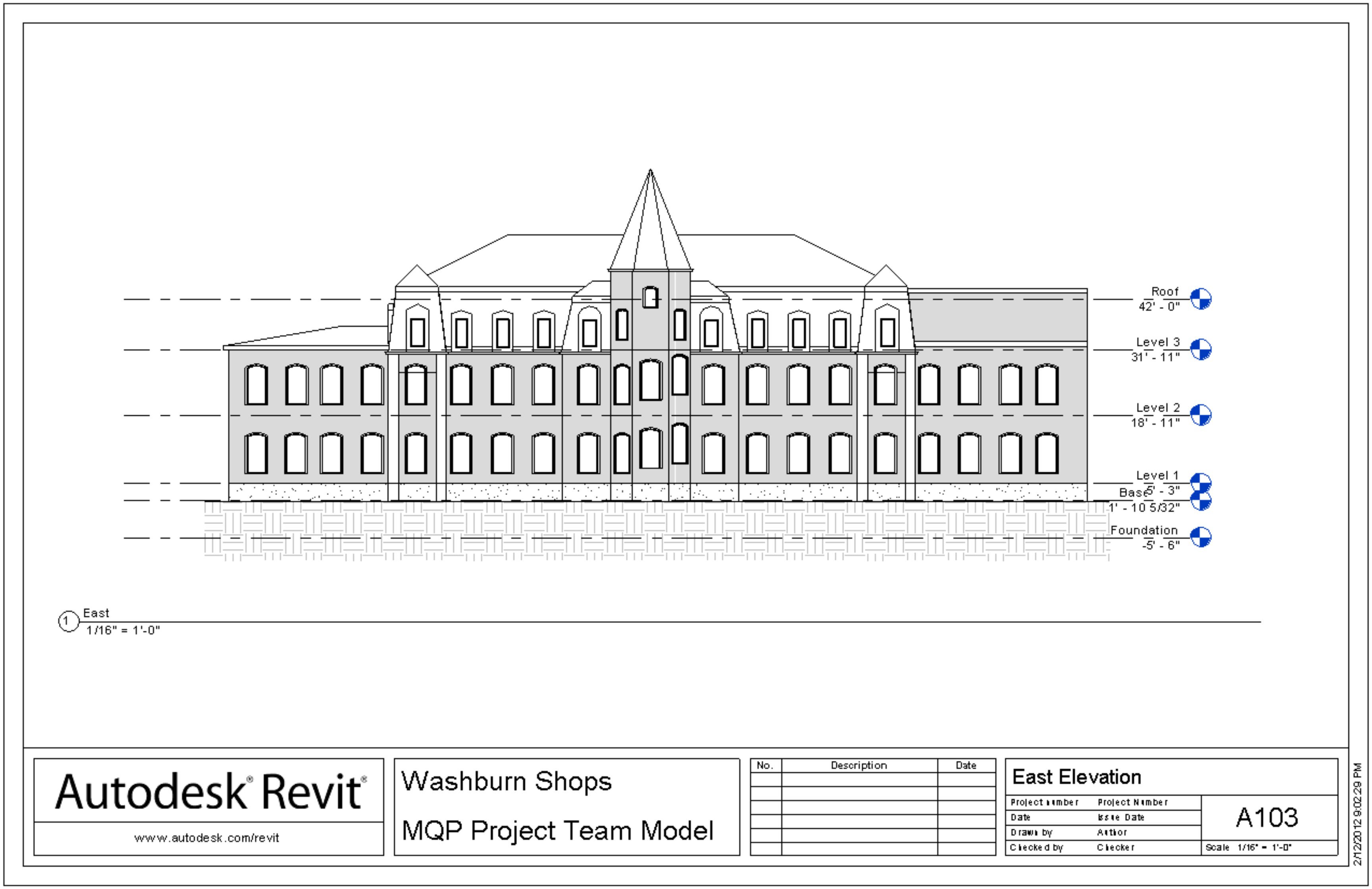


Figure 77: Sheet A103- East Elevation

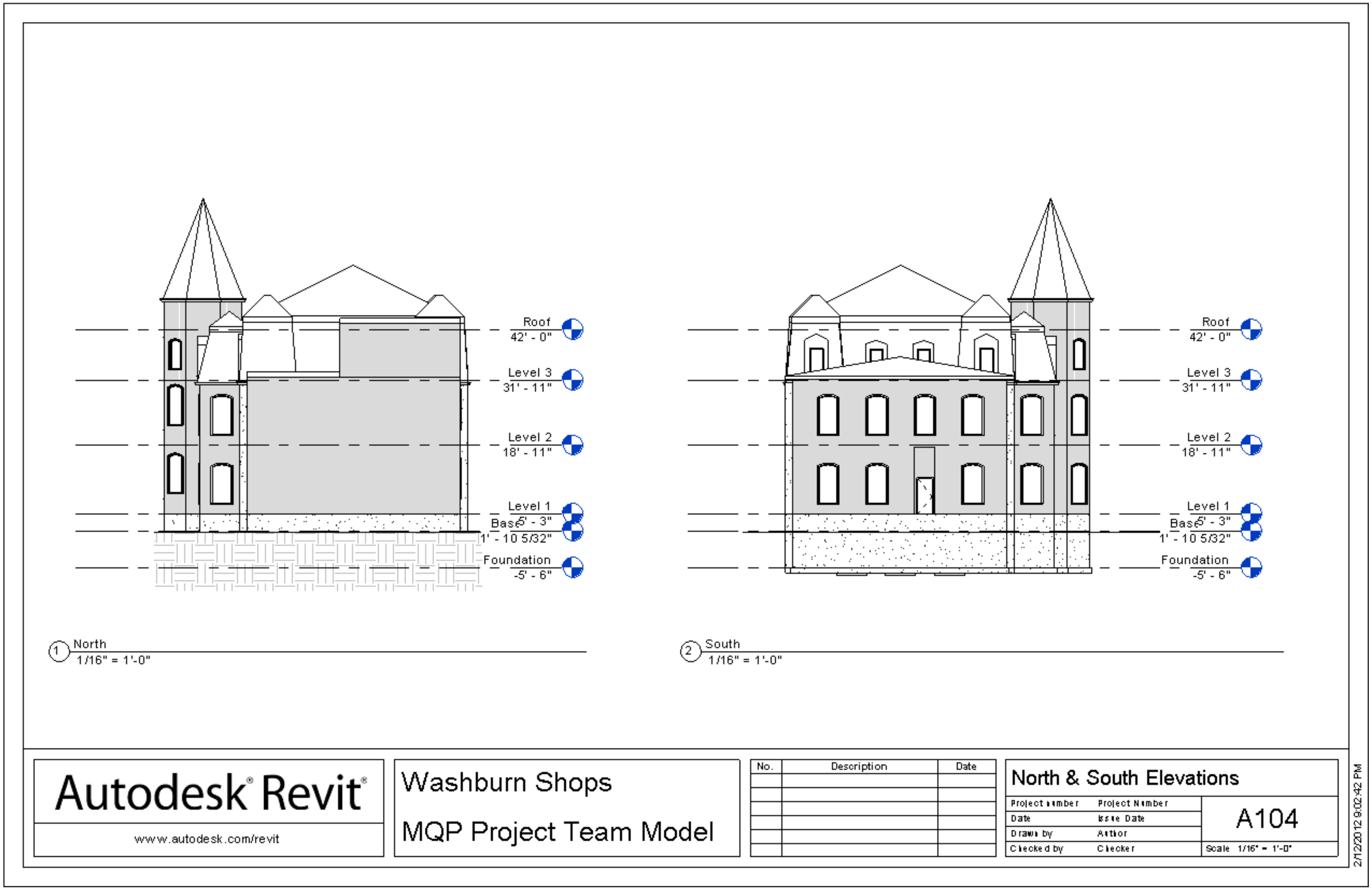


Figure 78: Sheet A104- North & South Elevations

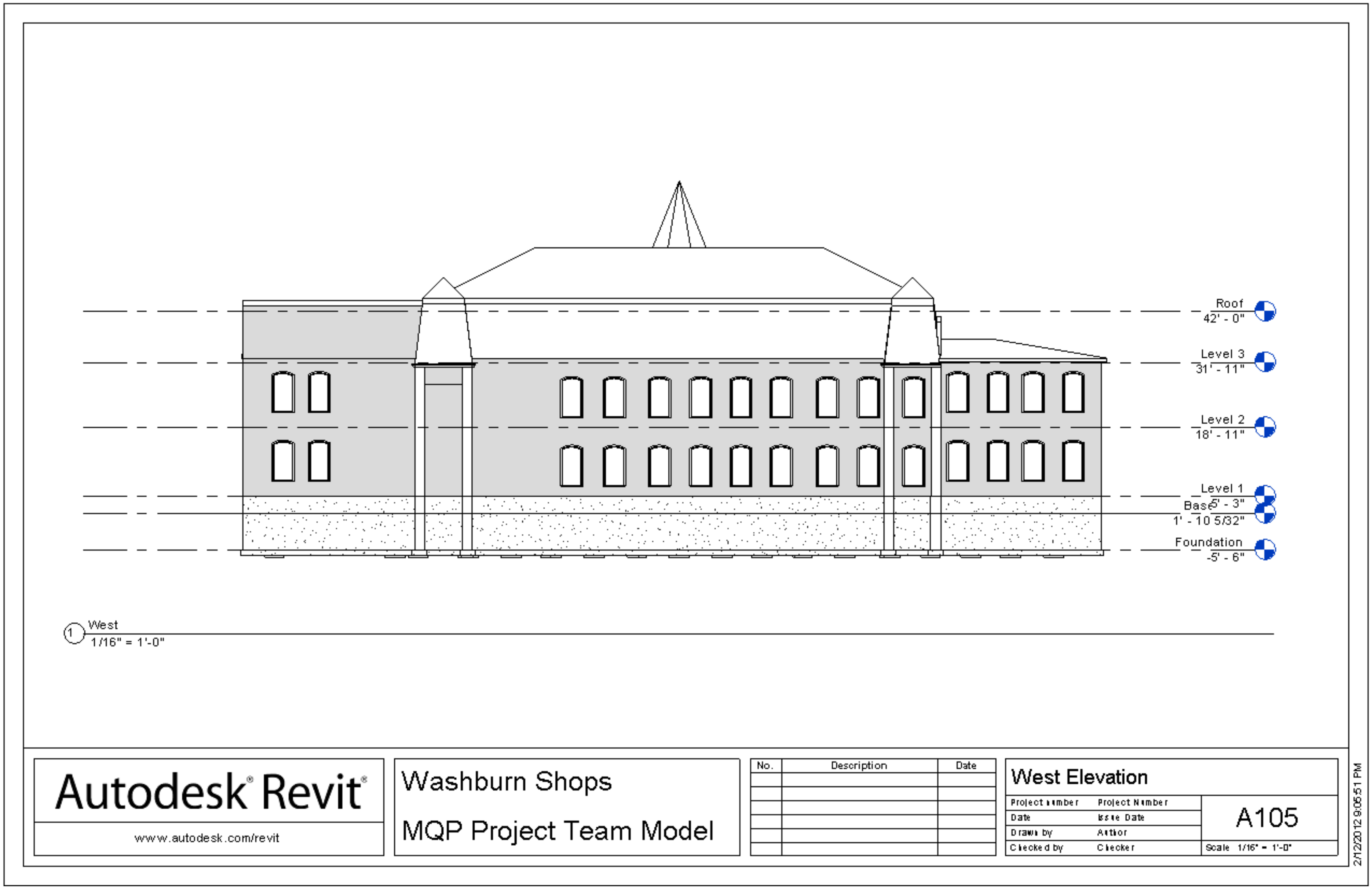


Figure 79: Sheet A105- West Elevation

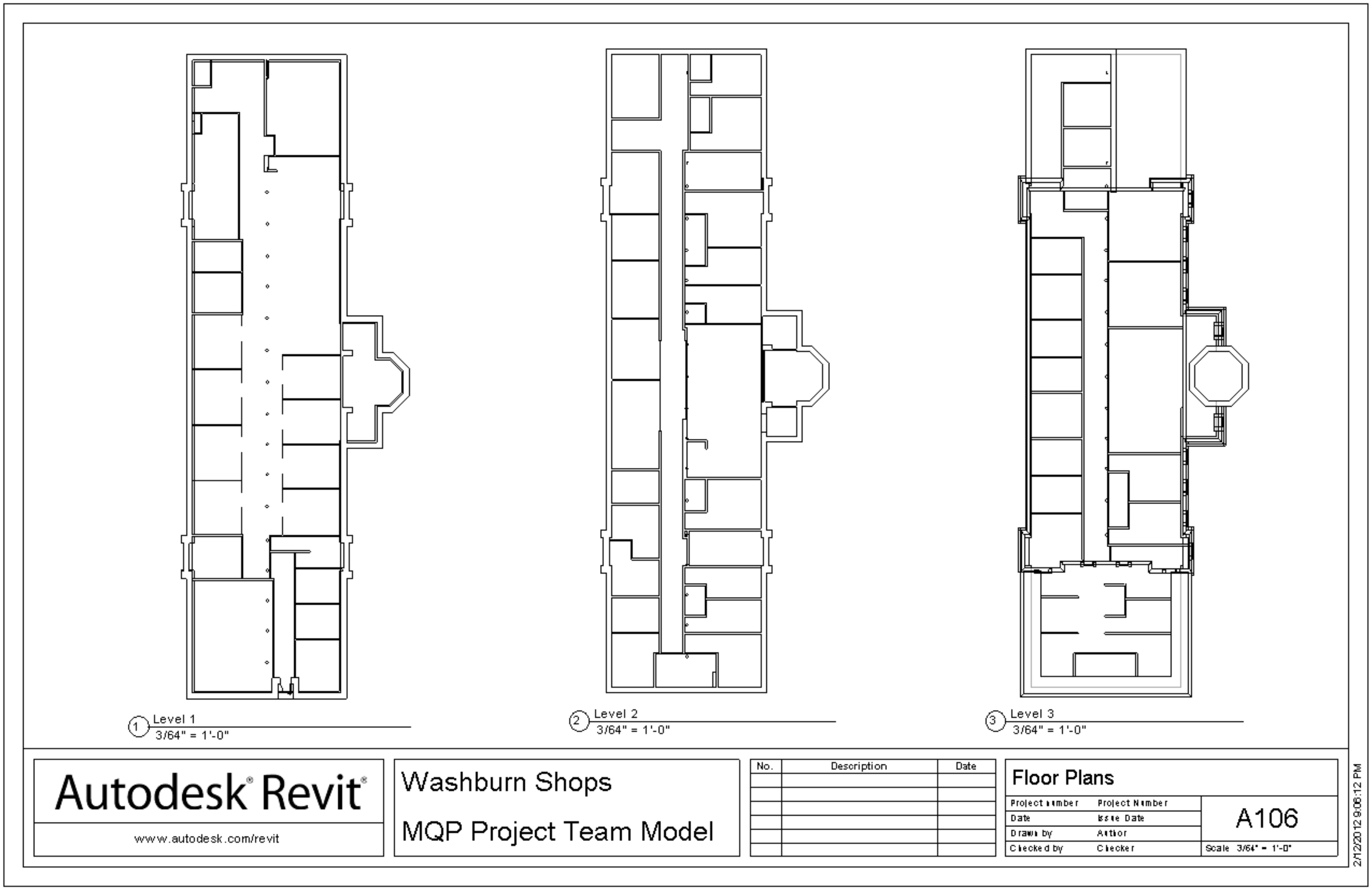


Figure 80: Sheet A106- Floor Plans

4.0 Future Options

The second section of the study of Washburn proposes future options for the building and the BIM model created. The project team evaluated possible solutions to correct the areas of non-compliance and designed appropriate solutions based on cost and functionality.

4.1 Methodology

The following methodology details the steps taken to complete the future options section of the project. Figure 81 outlines the process on the next page.

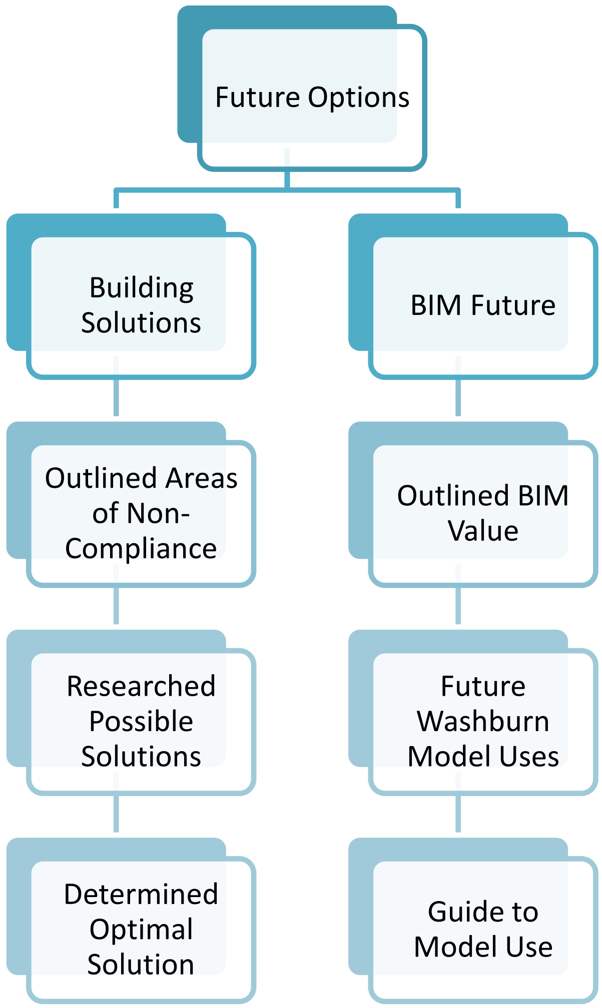


Figure 81: Future Options Methodology

4.1.1 Building Solutions

The checklist from the building code analysis identified elements that were not compliant with *the Code*. From this checklist, the team developed steps to follow to create solutions for these elements. These steps are outlined below.

Outlined Areas of Non-Compliance

First, the checklist was cut down to only the items that had a "no" in the compliant column. These elements were then grouped together to form areas of non-compliance. This was possible because usually an element could be grouped with other similar non-compliant elements into one large, non-compliant issue.

Researched Possible Solutions

Once the areas of non-compliance were determined, the team researched possible solutions. In some cases this was a simple process but for others it was more complicated. For example, changing the spacing of elements may simply solve the problem but in other cases a whole new design was deemed necessary. The team also used research on case studies to brainstorm ideas on how to satisfy code compliance issues from past building renovations.

Determined Appropriate Solution

When different design solutions were proposed, the team had to choose a design to recommend. The team recommended the final solutions based on cost-efficiency and functionality. This was because the team wanted to recommend solutions that would not force WPI to invest more finances that necessary and to provide solutions that would be realistic so that the space can still be used for the same purpose without disruption.

4.1.2 BIM Future

To highlight and detail the future of the created BIM model several steps detailed below were accomplished.

Outlined BIM Value & Determined Future Model Uses

The areas of value provided by the BIM model were investigated and outlined to display the significance and implications of using such a model. The possible future uses were researched and highlighted to provide the WPI Department of Facilities with recommendations in order to gain the most value from the project team’s model.

Created Guide to Model

For those who may not have technical background or are not familiar with the Revit software, a guide to viewing the model has been created. The major tasks required to view and use the model were determined. These tasks were then broken down into easy to follow steps with images making it easy for anyone to gain value from the project team's model.

4.2 Future Building Solutions

From the areas discovered that do not comply with current codes, future solutions have been designed for Washburn. The following section details these proposed designs.

4.2.1 Structural Solutions

This section proposes solutions for the elements from the checklist that are non-compliant with the *Codes*. Table 33 summarizes the non-compliant elements as determined from the checklist. Most of the non-compliant elements were assumed to be non-compliant for the case study because they had to be assumed non-compliant so that the structural analysis' could be performed to determine a solution. Through the structural analysis calculations it was found that the seismic forces would cause the building to become unsafe, therefore causing the most significant area of non-compliance to be related to the seismic forces. For this reason the solutions for reinforcing against the seismic forces of the structure were the focus of the structural solutions described in this section.

Table 33: Non-compliant elements

Item #	Element	Code Reference	Compliant	Current Conditions
2.a	Alterations to Structural elements carrying gravity load	*IEBC* 303.3	No	Assumed that the alterations caused increase in loads. (For purposes of project)
3.a	Alterations to structural elements carrying lateral load	*IEBC* 303.4	No	Assumed that lateral loads were increased with alterations for the purposes of the project
14.a	Mortar Tests	*IEBC* A106.3.3.1	No	No in-place shear tests were performed on the structure
14.b	Masonry Tests	*IEBC* A106.3.3.2	No	No tests were performed to determine the tensile-splitting strength of the masonry
15	Test location	*IEBC* A106.3.3.3	No	No tests were completed
16	Number of Tests	*IEBC* A106.3.3.4	No	No tests were completed
21	Masonry Shear Strength	*IEBC* A108.2	No	Mortar tests were not completed to could not calculate masonry shear strength according to the *Codes*
23	Masonry Tension	*IEBC* A108.4	No	Calculated tensile strength due to seismic forces
25.a & 25.b	Lateral Forces on elements of structures	*IEBC* A110.2	No	Assumed not to be in compliance

Seismic Reinforcement Solutions

There are numerous ways to rehabilitate masonry walls and reinforce them. A few ways are outlined in the table below. Table 34 summarized the advantages and disadvantages of each type of masonry reinforcement as well as the average costs associated with these reinforcement methods. The costs are based off of *RS Means* and include cost of labor as well as material costs however they do not include scaffolding costs and the costs associated with working at elevated levels. When considering costs versus the different advantages and disadvantages of each reinforcement type in relation to Washburn's reinforcement a couple of solutions stand out. Steel reinforcement would probably be the best cost option for the amount of tensile strength reinforcement required; however, there are a couple of disadvantages to installing the steel reinforcement. The main disadvantage to this is that Washburn would probably have to be closed for renovations. Usually steel reinforcement is installed by drilling holes through the masonry and placing the steel bars and then grouting the holes. This would cause vibrations of the building hindering building occupants and could make the building unsafe. In addition Washburn's brick exterior was just recently renovated and this would have to be altered to include the steel reinforcement making the recent renovations unproductive. Surface treatment and jacketing would be easiest to apply to the building while keeping it mostly open to the public, as is necessary on a college campus. However with jacketing or surface treatments, the thickness of the wall could increase greatly. Therefore Fiber Reinforced Polymers (FRP) would be the best jacketing solution. There are four types: glass bar, glass sheet, carbon strap and carbon sheet fiber reinforced polymer. The carbon sheet FRP is considered to be moderately priced and moderately strengthened while glass FRP has the lowest strength and cost; carbon strap has the highest strength and cost. For Washburn a carbon sheet is suggested to be used because when considering the unit costs in relation to square footage of coverage area as well as the installation process this method and material would best fit Washburn's retrofit.

In addition to reinforcing the masonry the *Code* states that is it necessary to install ties to connect the floor slab at each level to the exterior wall in order to properly transfer the forces in the floor plane to the wall. These brick ties were not fully assessed for a solution for Washburn because they were just added in the recent renovations their specifications can be found in Appendix 7.3.2(were not part of the structural analysis).

Table 34: Masonry Reinforcement Solutions

Reinforcement Type	Advantages	Disadvantages	Cost
Injection Grouting	• Strengthen masonry • Increase resistance to moisture penetration • Does not alter building's appearance	• Requires skilled labor to implement • Disrupts everyday function of the building to install	Epoxy injection (1/8" wide 12" deep) =$33.39 per foot
			Latex injection (1/8" wide 12" deep)=$23.59 per foot
Insertion of Reinforcing Steel	• Strengthen masonry • High tensile strength	• Requires skilled labor to implement • Disrupts everyday function of the building to install	Masonry Reinforcing Bars (#3 and #$ placed horizontally)=$1.57 per lb.
			Masonry Reinforcing bars (#3 and #4 placed vertically)=$1.87
Jacketing -shotcrete and ferrocement jacketing	• Strengthen masonry	• Requires skilled labor to implement • Disrupts everyday function of the building to install • Can add 30-100mm of additional thickness to existing wall	$44.25 per V.L.F
			Shotcrete=$3.14 per S.F
Surface treatments	• Strengthen masonry	• Requires skilled labor to implement • Disrupts everyday function of the building to install • Can add 30-100mm of additional thickness to existing wall	Sprayed membrane compound=$13.15 per C.S.F
Jacketing -Fiber Reinforced Polymers (FRPs)	• Small added thickness • High strength to weight ratio • High stiffness • Ease in application • Low axial coefficient of thermal expansion • Corrosions resistance	• Lower elastic modulus • Lack of ductility • High raw material cost • Glass FRP has stress corrosion	Glass bar fiber reinforcing polymer=$0.53 per foot
			Carbon strap fiber reinforcing polymer=$56/SF
			Carbon sheet fiber reinforcing polymer=$52/SF
			Glass sheet fiber reinforcing polymer=$48/SF

Table 35:Rehabilitation Cost

Wall Elevation	Area	Cost	Cost/Square Foot
East	6672.237SF	$346956.32	$51.99
West	6672.237SF	$346956.32	$51.99
North	1930.5SF	$100386	$52.00
South	1336.5	$69498	$52.00
Tower (North)	273SF	$14196	$52.00
Tower (South)	273SF	$14196	$52.00
TOTAL	17157.47SF	$892188.44	$52.00

4.2.2 Fire Solutions

This section will propose options for the items identified in section 3.2.2 that do not comply with current building code provisions. The list of items was summarized from Appendix 7.2 and is repeated below in Table 36:

Table 36: Abbreviated Fire System Checklist including Non-Compliant Elements

Item #	Element	Code Reference	Compliant	Current Conditions
10	Sprinkler Obstructions	8.6.5.1.2*	No	Numerous sprinklers were not in compliance. Observations included sprinkler heads positioned too close to pipes, beams, and light fixtures.
15	Location of Devices	5.5.2.1	No	Concealed spaces above ceiling are not protected by detection devices (Horanzy, 2011) based on the 2011 fire.
17	Smoke-Sensing Detector Location	5.7.1.9*	No	Does not consider ceiling conditions based on the 2011 fire.
20	Smoke-Sensing Detector Location	5.7.3.2.3.3	No	Does not consider ceiling conditions based on the 2011 fire.
		5.7.3.7	No	No detectors are above suspended ceilings (Horanzy, 2011).
21	Manual Fire Alarm Box Location	5.13.6	No	Most exits comply but main entrance does not.

The main concerns arising from these non-compliant items are the obstructed sprinklers and missing smoke detectors. In the event of a fire, the few smoke detectors may be located too far from the fire to alarm. In addition, activated sprinklers may not suppress or even control the fire if obstructions are in the sprinkler spray pattern.

Sprinkler Obstructions: Second Floor Hallway of Washburn

Numerous sprinkler obstructions were identified in section 3.2.2 but the second floor hallway was the most concerning area because almost every sprinkler is obstructed by the network of pipes and vents below the sprinkler heads. Figure 55 is repeated as Figure 50 below to show an obstructed sprinkler within this hallway.

Figure 82: Sprinkler Obstruction in Second Floor Hallway Ceiling

As Figure 82 shows, a pipe almost directly below the sprinkler head would obstruct the spray pattern. *NFPA 13* Section 8.6.5.1.2 states that an obstruction less than 1 foot from a sprinkler head must be at the same height as the deflector or above. In order to alleviate the obstruction problem in this hallway, the goal would be to create a ceiling similar to the one on the third floor hallway as seen in Figure 83.

Figure 83: Washburn Ceilings (third floor on left, second floor on right)

To create a ceiling equivalent to the third floor, the second floor requires a suspended ceiling. Along with this ceiling, sprinklers that drop down to the new ceiling level would have to be added to the system. This would allow for the concealed space above the ceiling to be protected with the current sprinklers and the floor space to have protection from the new, unobstructed sprinklers in the suspended ceiling. The suspended ceiling is necessary because without it, the new, dropped sprinklers would not perform properly. If a fire occurred, smoke would rise to the top of the ceiling setting off the current, obstructed sprinklers. The dropped sprinklers would not activate from the heat of the fire because there is no space for the heat to collect around the sprinkler, causing the heat to collect around the current, obstructed sprinklers. The current sprinklers cannot fully protect the area below because they are obstructed. Also, these obstructed sprinklers will cause an activation delay of the dropped sprinklers by cooling down the area around these sprinklers. Thus, the suspended ceiling would create a barrier for the smoke to remain only near the new drop sprinklers which can fully protect the floor area.

Seven new sprinklers would be added to account for the seven sprinklers that are obstructed by the current construction conditions. Figure 84 shows where the current sprinklers are located within this hallway. The full floor plan with the fire protection system is included as Appendix 7.6.

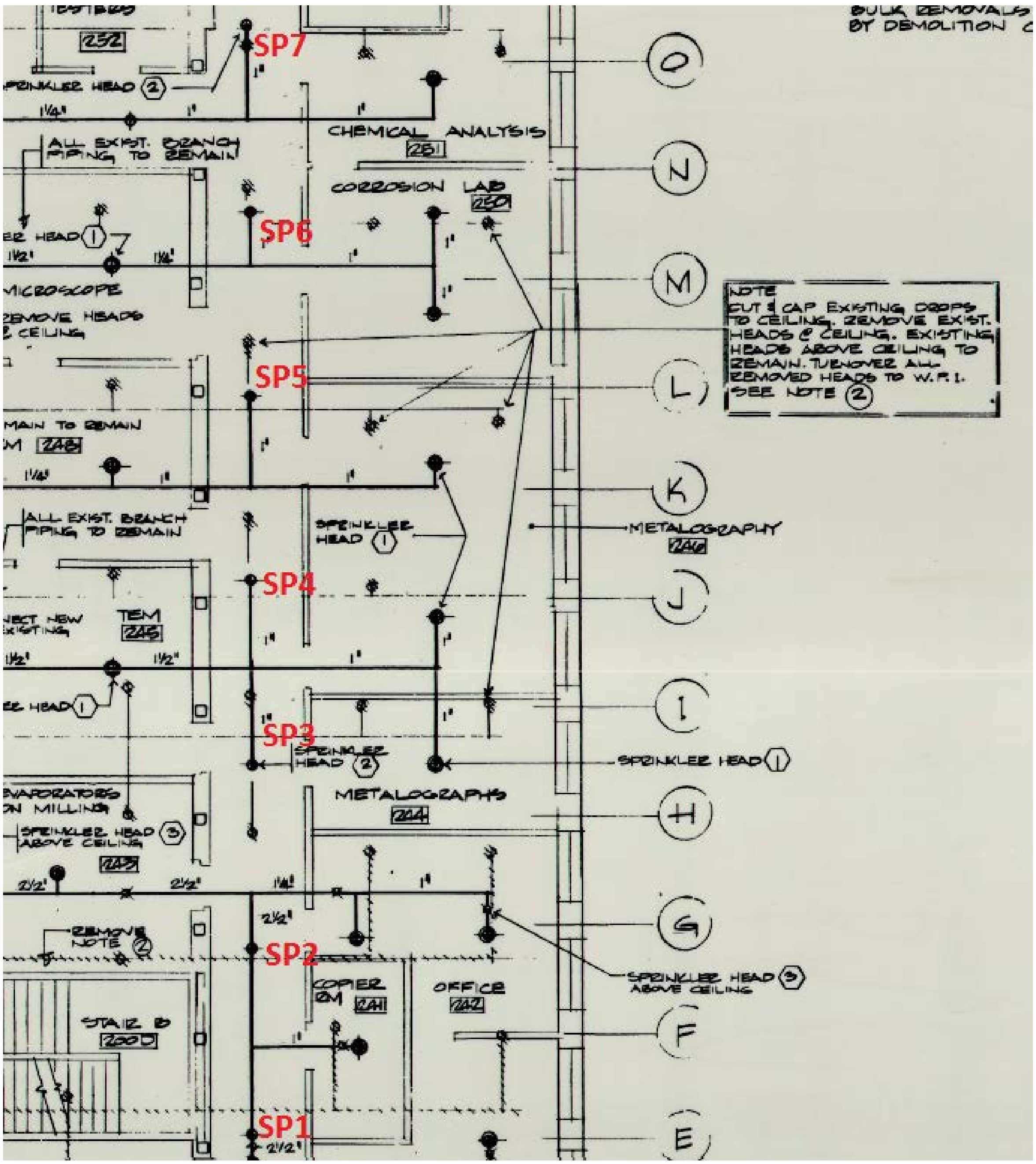


Figure 84: Current Sprinklers in Second Floor Hallway of Washburn

The sprinklers to be added can be installed to the side of where the current sprinklers are located. A potential problem for this installation would be that the number of pipes and conduit may not allow for a straight pipe vertically down. In this case, pipe elbows would be installed to redirect the water supply around the obstruction. The sprinklers would have to be at least 3 feet vertically from the current horizontal piping to be located below the existing network of pipes and ducts. The sprinklers that are currently installed in the third floor drop out ceiling would be used here. Figure 85 shows the plans of the selected sprinklers for this hallway.

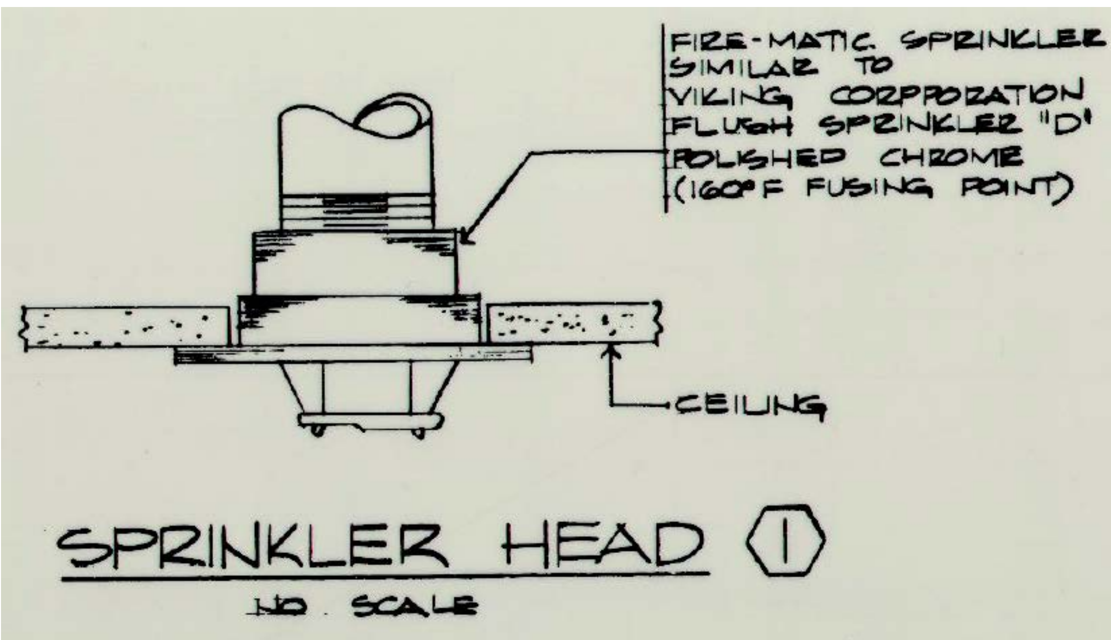


Figure 85: Sprinkler Head used in Third Floor Drop Out Ceiling

Since piping is being added to the system, it may be a concern that the sprinkler system will not supply an adequate flow of water at a certain pressure. However, because this piping is so short and fire protection systems are only designed for one fire event to occur at a time, the additional 3 feet of piping will have minimal impact on the expected water flow and pressure. Also, the installation of an additional set of sprinklers below the current sprinklers will not cause a water flow problem because both sets will not be activated during a fire because the sprinklers in the suspended ceiling would respond to a fire on the floor level while the sprinklers above the suspended ceiling would respond to a fire within the concealed space above this suspended ceiling. This small additional water flow and pressure only becomes a concern if this hallway is the area with the most remote sprinkler. Since this hallway is on the second floor and there is a floor above it to which water must flow, this area can be ruled out as the most remote even with the small additional water flow and pressure requirements incurred by the drop-down piping.

Smoke Detector Placement: Third Floor Hallway of Washburn

The placement of smoke detectors were obviously an issue in the roof renovation fire and raised concerns of the protection the existing detectors are offering the building. According to *NFPA 13* Sections 5.5.2.1 and 5.7.3.2.3.1, smoke detectors can be at most 30 feet from each other and concealed spaces above the ceiling should be protected with detectors. Figure 86 repeats Figure 66 and shows the distance the smoke had to travel in the hallway during the fire (this does not consider the distance between detectors).

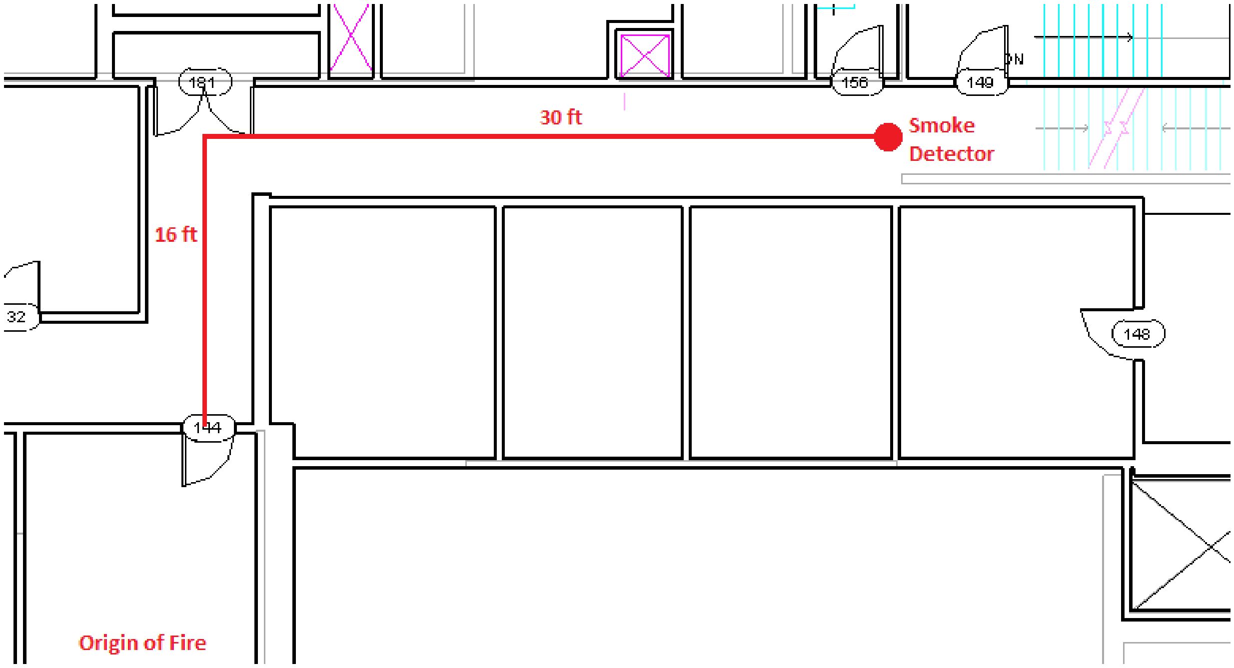


Figure 86: Distance to Nearest Smoke Detectors in 2011 Rood Renovation Fire

Although the current spacing between detectors exceeds the permissible value, Washburn does comply with other detector placement codes just as having smoke detectors placed on either side of fire doors. For the new design, it is proposed that the detectors at the fire doors remain in place and additional detectors be installed with an appropriate spacing along the hallway to meet the code requirements. Figure 87 illustrates sufficient placement of detectors on the third floor. The other floors of Washburn have a similar layout to this one and thus the detectors can be placed almost identically to Figure 87.

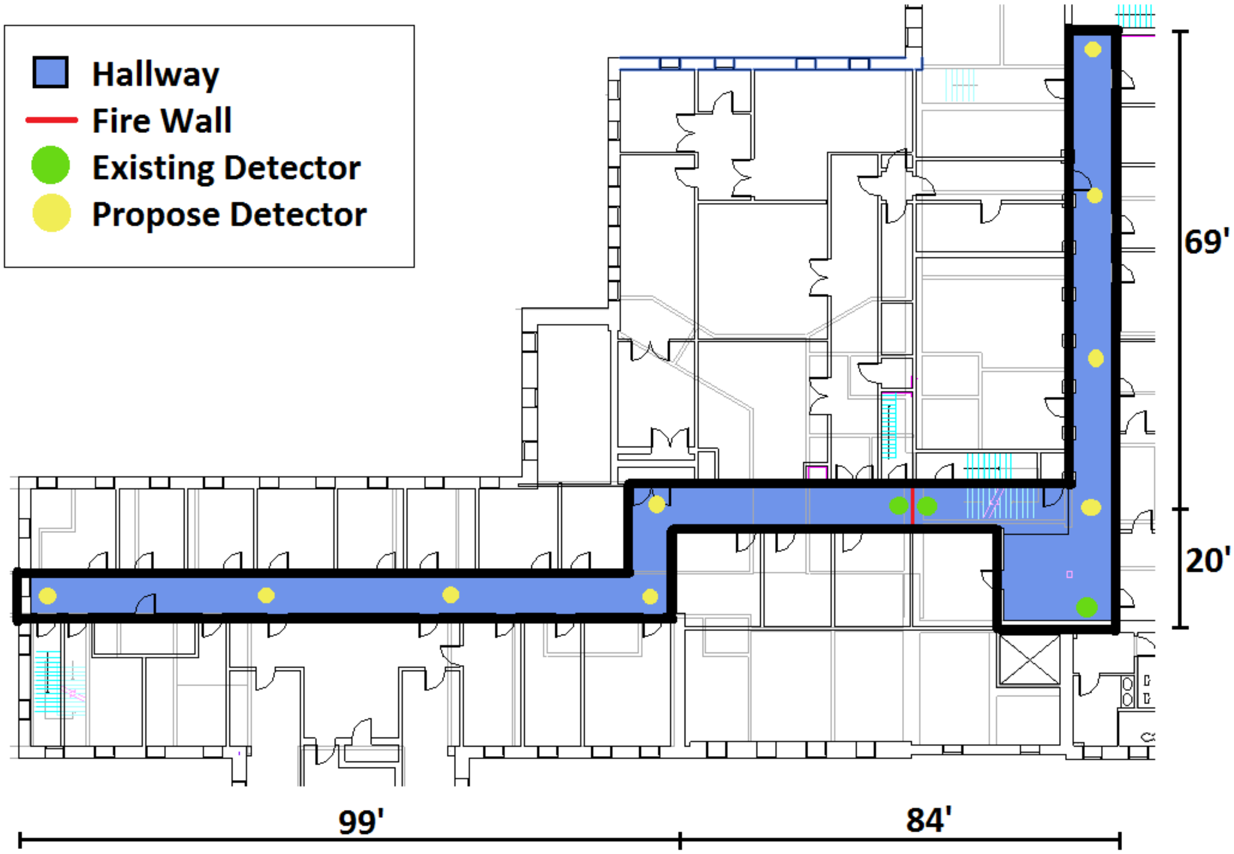


Figure 87: Proposed Placement of Smoke Detectors on Third Floor

The required number and placement of detectors should also account for the fact that detectors are needed below and above the suspended ceilings that were proposed above as part of the correction for the obstructed sprinkler heads. Therefore 18 new detectors are needed per floor hallway.

In order for the new detectors to synchronize effectively with the existing alarm system, Simplex products were chosen to keep the same manufacturer; this should also make maintenance simpler. Although the same manufacturer is used, there still may be difficulties in synchronizing the new detectors with the alarm system because the panel does not have addressable capabilities which the detectors do.

4.2.3 Cost of Solutions

The costs for the solutions from the previous two sections are presented below. The cost estimates were based on the materials specified in the various solutions.

Cost of Structural Solutions

The Carbon sheet total cost of material and labor is around $52 per square foot. The material cost is about $26 per square foot and the labor cost is about $26 per square foot as well. The total estimated cost for the rehabilitation of Washburn is $892188.44.

Cost of Fire Protection Solutions

Table 37 summarizes the cost for each fire protection solution design. These costs are based off of a design for one floor of Washburn. The total cost of all solutions is $3,489.60 for materials and labor.

Table 37: Cost of Fire Protection Solutions

Solution	Material Cost		Labor Cost		Total Cost
	Unit Cost	Total Cost	Unit Cost	Total Cost	
Suspended Ceiling	$1.49/ft^2	$666	$0.42/ft^2	$188	$854
Sprinklers	$57.67/head	$403.67	$25/head	$175	$578.67
Sprinkler Piping	$3.76/ft	$78.96	$13.45/3ft. sprig	$94.15	$173.11
Detectors	$112.99/head	$2,033.82	$25/head	$450	$2,483.82
Total		$3,182.45		$907.15	$4,089.60

Installing a suspended ceiling below the piping would be very simple. The lighting units would be below the ceiling, similar to the current third floor construction, thus making the only necessary cuts in the ceiling for the sprinkler heads. The average cost for materials of a suspended ceiling is $1.49 per square foot (Ceilume, 2012). With 447 ft^2 this ceiling would cost approximately $666. The cost of labor would be approximately $188 for a ceiling with 2’ by 4’ grid panels (RS Means, 2010).

Currently, the Horizon Standard Response Flush Pendent Sprinkler CK400 with a 165°F is most similar to the Viking Flush Sprinkler "D" polished chrome with a 160°F fusing point in 1983. The Horizon sprinkler has a thread size of ½" and a K-Factor of 5.8. The current cost is $57.67 per sprinkler (Viking Group, Inc., 2011), bringing the total material cost for sprinklers to $403.69. The cost of labor to install the sprinklers is $175 based on a $25 per sprinkler cost (RS Means, 2010).

The needed piping is 3 feet of ½" galvanized steel piping for each of the 7 sprinklers. This steel piping can be quoted at approximately $78.96 (Kessler Sales and Distribution, 2011). The cost of labor for installing the steel piping is $94.15 (RS Means, 2010).

Simplex offers a photoelectric addressable sensor head for $112.99 (SimplexGrinnell, 2012). With 18 detectors needed, the total cost for the detectors would be approximately $2,033.82. The cost of labor for these detectors would be $450 (RS Means, 2010).

4.3 BIM Future

The model created by the project team has many useful applications that can be vital to WPI and the Department of Facilities. This section details the possible future uses and a guide to make the model user friendly.

4.3.1 Future Uses and Value of Model

BIM models are growing in use and in practical applications. The opportunities for this new technology are endless. The BIM model of Washburn holds great value for many parties and can aid in facilities management operations at WPI. Currently the WPI Department of Facilities does not possess a complete set of drawings for the building and many unknowns exist. The model produced in this project creates a comprehensive picture of Washburn detailing the building in its entirety.

Reference & Organization

The staff within the Department of Facilities can reference this model when searching for information or to find the specifics of the most recent renovation work. The project team's BIM model organizes the information related to the building in an easy to view format. Users can visualize Washburn as a whole and easily reference elements or sections of the structure. Two-dimensional and three-dimensional images can be extracted for various purposes.

Model Additions

Much value is added by transforming the available documentation for Washburn into digital and three-dimensional media. This model can be used as is or extended. With the addition of the fire protection or mechanical systems, the model's use can be expanded and possibly used for operation and maintenance activities. The model can be used throughout the buildings lifecycle to document the changes and renovation efforts. It can also be consulted in order to make decisions about space management or the placement for example of future fire projection systems, taking advantage of the comprehensive data.

The project team has created a model that can expand and grow with the growth of the building. The model has value currently but its value will only continue to increase. The level of detail can be increased by adding different building systems. Drawings and documentation can be produced from the model. Numerical, text and two-dimensional graphics can be taken out of the model.

Further Software

Additional software can be used with the project team's model in order to retrieve information and investigate building performance. One particular software that is applicable to this project is *Solibri*, which is a model checking technology for BIM (Solibri, 2012). It can analyze a model for integrity, quality and safety. This system reveals potential flaws and weaknesses in the design, including clashing components and building code compliance. Software of this type can be used to further check the compliance of Washburn in other areas. Navis Works can also be used to integrate with other 3D CAD software. As shown in this project the model can be viewed by those who do not use *Revit* with *Autodesk Design Review*.

Future Contractors

Washburn is an aging building and will need further renovations in the future, perhaps incorporating some of the recommended designs that were presented above for the building structure and fire safety systems. When this project work is planned, estimated, and then executed, the responsible parties will need to know the existing condition to inform and guide their decisions. The BIM model will provide a complete picture of Washburn along with the previous work from 2011. The contractor can use the model to access and view floor plans and elevations as well as to identify the windows, walls, etc. that have been repaired or restored. With the increased use of BIM technology in the civil engineering field, WPI can better work with contractors that already implement this software more easily.

Computer software and building information modeling is taking a bigger role in the construction and civil engineering industry. WPI can benefit from being on the cutting edge and transferring their documentation into BIM. Washburn can more readily be explored and understood with the application of this model.

4.3.2 User Guide to Washburn BIM Model

User's guides were created to add ease to using and implementing the project team's generated BIM model (Appendix 7.7). These guides detail the steps to needed perform certain tasks that are beneficial to WPI Department of Facilities. These tasks cover the basic functions to view the 3D model and BIM data. Appendix 7.7.1 is a guide to using the model in *Autodesk Revit* and Appendix 7.7.2 is a guide to using the model in *Autodesk Design Review*. The first guide details how to use the model in its original form as created by the project team. Alternatively the model can be transferred into a *dwf* format that could be read by *Design Review* to simplify its use and ease of viewing. *Design Review* is a more user friendly program than *Revit* and can be downloaded free from the *Autodesk* website. The second guide provides instructions on how the user can take advantage of this program.

5.0 Conclusions and Recommendations

One of the largest facilities management issues institutions like Worcester Polytechnic Institute (WPI) face is keeping their historic buildings well-maintained and safe while satisfying the functional needs of the occupants. This is a never-ending battle because once one building has been renovated; another is in dire need of reconditioning. This cycle of ongoing renovation and rehabilitation is particularly hard to sustain because of the financial investment that must be made for repairs that are often not noticeable from the exterior of the building. It can be hard for institutions to convince a benefactor to invest in a project that won't aesthetically change a building when other potential projects involve constructing a state-of-the-art new building that may also bring the prestige of naming rights. In addition institutions often do not have the proper documentation to maintain their buildings, and studies must be performed in order to allow for these buildings to be preserved properly.

The Washburn Shops Case Study concentrated on the building's structural aspects, elements of its fire protection system, and documentation. Through code review and analysis, the building's structural and fire systems were examined, and it was found that, if deemed necessary by a local building official, some aspects of these two systems would not be in compliance and would need to be updated. Washburn's unique reliance on built-up brick column sections within its exterior masonry walls was important in the study of structural compliance and structural performance. Documentation on these composite columns was not available before the renovations of the building in the summer of 2011. Therefore the case study deemed it necessary to perform a structural analysis to determine the structural integrity of the building.

Through the structural analysis of Washburn's wall section it was found that some wall strengths are sufficient to sustain forces in order to comply with *Codes* however others did not and the structure may fail due to these load combinations. The gravity forces due to dead and live load produced unit stresses in the masonry that were less than the 300psi capacity of the masonry, therefore complying with the *Codes.* In addition the unit shear stresses due to the wind loading were less than the shear capacity of the masonry wall. However the investigation of seismic forces indicated that these forces are significantly greater than both the gravity loading and the shear masonry capacity of the wall. The uplift effect of these forces is greater than the gravity loading. The shear effect is also greater than the shear capacity. Consequently, the potential failure modes for the wall under seismic forces may involve both tensile cracking of the built-up column sections due to uplift and shear failure of the bricks and mortar through the thickness of the wall. It is concluded that a more in depth study of the seismic loading on Washburn must be performed.

Solutions for reinforcing Washburn's wall against seismic forces were found, and it was concluded that carbon fiber polymer reinforcement sheet would be the best solution for Washburn providing the needed tensile strength and short renovation period. The estimated cost for the rehabilitation of Washburn's wall with carbon fiber polymer reinforcement sheet without including the scaffolding and other costs associated with working at elevated levels is about $892,000.

Through analysis the fire protection system, it was determined that if the building was found to be unsafe and in need of renovations to reach code compliance, then the smoke detectors and sprinklers would need to be reassessed and updated. It was found that there was an insufficient amount of smoke detectors in the hallways. Furthermore it was concluded that although there were enough sprinklers in the hallways to comply with *Codes* many of these sprinklers were obstructed and therefore would not provide adequate protection. To upgrade the sprinkler and detector protection, the total cost would be approximately $4,090, which also includes the installation of a suspended ceiling.

The previously existing documentation of Washburn's layout was outdated and in some instances incorrect. Through comparing the existing documentation to documentation produced by Hoffman Architects and Cutler Associates after the renovations new accurate documentation was created. Produced in *Revit,* this 3D BIM model provides a comprehensive digital representation of the building including all data from the 2011 renovation work. The BIM model allows users to view many aspects of Washburn in the same document allowing for easy access and updates if needed. The team also provided user's guides to make this use easier. The created model can be used in many applications including extracting two-dimensional drawings.

The three topics of structural integrity, fire safety and BIM were the focus of the study and allowed for Washburn to be better understood and provide a base for identifying building updates to comply with current building code provisions, if desired.

5.1 Recommendations for Washburn

The case study of Washburn encompassed structural and fire code analyses, a wall section structural analysis, and development of a Building Information Model. Although this project sets a foundation for the study of Washburn, offering strategies to update its structural integrity and fire safety and a new medium for storing and retrieving the available documentation, there are still more elements that can be analyzed and updated.

The structural analysis performed only focused on a specific section of Washburn's wall. In order to fully understand Washburn's unique structure, perhaps a 3D analysis of the exterior wall could be conducted to investigate its overall behavior as a system and to identify possible sections subject to stress concentrations. In addition the timber frame structure of the roof was not considered in the project scope and only an assumed dead load for roof was considered in the structural analysis. A model of the roof could be used to observe the load transfer into the wall, which would be best dealt with by a detailed model of the load transfer area. Furthermore this model of the roof truss would provide insight into the internal load paths of this complex structure.

The analysis of the fire protection system focused on the building code provisions associated with the fire alarm systems as well as the sprinkler systems. A way to further the protection system analysis would be to analyze the risks associated with the building. For example the documentation of the protection systems outdate renovations that have been completed on the building to add new labs and equipment. These projects could be assessed in order to bring the documentation up to date. In addition there are no records available for the upgrades that have been done to the fire protection systems. A potential risk analysis could be based off this fact and study what would happen if a fire were to occur, finding where and at what speed the fire would spread.

In addition to fire safety and structural integrity, energy efficiency is also of rising importance in studies of historical buildings and assessing their fitness for purpose. An energy audit inspects and analyzes how energy flows throughout a building and how this affects the energy conservation of the building. An audit also includes solutions detailing how to reduce the energy input while maintaining the same output. The main issues addressed in an audit are: analyze building and utility data (energy bills); survey operating conditions; assess the building behavior as a whole and interactions between the building, weather, occupancy and operating schedules; select and evaluate measures of conservation; estimate the potential to save energy; and identify the concerns and needs of the customer in association to energy (Energy Audit Input Procedures and Forms, 1983). Based on the amount of information wanted from the analysis audits can range from a preliminary audit to an investment-grade audit. Examples of the information needed to perform an energy audit on Washburn would be determining the thermal properties of the brick and cavity wall (Types of Energy Audits, 2007).

In relation to the project documentation of Washburn, the BIM model created could also be expanded. The current BIM model only focuses on the original Washburn building. More information could be gathered on the additions to the original building and included in the current model. The LOD (Level of Detail) of the model can also be expanded to include other building systems such as MEP or fire protection systems. This model and other BIM models can be of great use for the documentation of aging historic buildings. The model can be used for facilities management to track all changes in the building and monitor any issues that arise. WPI Department of Facilities can use the model to view the building three-dimensionally or from extracted 2D drawings. Furthermore, the structural and fire codes regulations that were considered in this study could be added to the BIM model in the areas where they apply. With this information the areas of compliance and noncompliance with building code criteria could be outlined in the model along with their possible solutions and costs. This case study on Washburn provides a foundation for more in-depth and explicit studies of building performance and code compliance.

A large amount of information was gathered on Washburn through this project; however, as with any aged building with limited documentation, there are still many unknowns and areas of further study.

5.2 General Recommendations

The study that was conducted relates specifically to Washburn; however, the fundamental methods and results that were obtained can be applied to similar studies of other historical buildings. Historical buildings that were built with outdated technologies or adhere to less stringent building regulations are often protected from modern building code requirements by 'grandfather clauses.' In many cases building owners lack the project documentation and knowledge of the structural aspects of their buildings. Certain building components may remain unknown until they are uncovered during the investigation of a building failure or execution of a planned renovation. In order to avoid or mitigate the adverse impact of these discoveries, studies similar to the one completed on Washburn can be undertaken. For instance, Worcester Polytechnic Institute can perform studies on all of its aging buildings. If building documentation is continuously updated and complete then building owners will not have to pay construction companies to fully analyze the structure after renovations have already begun, which would contribute to controlling renovation costs and ultimately assisting to prioritize renovation and rehabilitation work.

Washburn Shops, WPI's second constructed building, is an integral part of the Worcester Polytechnic Institute community. The two towers, Washburn and Boynton, have set the foundation for WPI's curriculum; much like this Case Study on Washburn has set the foundation for future examinations of historical and aged buildings.

6.0 References

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7.0 Appendixes

7.1 Structural Checklist

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
	Existing Building Structures					Yes/No	
1.a	Building Materials	IEBC 301.2.1	Existing Materials already in use in a building in compliance with requirements or approvals in effect at the time of their erection or installation shall be permitted to remain in use unless determined by the code official to be dangerous to life, health or safety. Where such conditions are determined to be dangerous to life, health or safety, they shall be mitigated or made safe.	Building materials that were in compliance at the time of construction may remain	Unless determined unsafe or dangerous by the code official	Yes	The existing materials that were not altered were in compliance with the codes at the time of construction.
1.b		IEBC 301.2.2	Except otherwise required or permitted by this code, materials permitted by the applicable code for new construction shall be used. Like materials shall be permitted for repairs and alterations, provided no hazard to life, health or property is created. Hazardous materials shall not be used where the code for new construction would not permit their use in buildings of similar occupancy, purpose and location.	In new construction or repairs to structures materials similar to the existing structure may be used		Yes	The masonry repairs were done in compliance with ASTM standards
1.c						Yes	The exterior finish repairs were done in compliance with AWI (architectural woodwork institute) standards

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
1.d						Yes	The roof repairs were done in compliance with ASTM, National Slate Association and NRCA Standards
1.e		IEBC 502.1	Materials already in use in a building in conformance with requirements or approvals in effect at the time of their erection or installation shall be permitted to remain in use	Building materials that were in compliance at the time of construction may remain		Yes	The existing materials that were not altered were in compliance with the codes at the time of construction.
1.f		IEBC 502.2	Materials permitted by the applicable code for new construction shall be used. Like materials shall be permitted for repairs and alterations	Building materials that were in compliance at the time of construction may remain		Yes	The existing materials that were not altered were in compliance with the codes at the time of construction.
2.a	Alterations to Structural elements carrying gravity load	IEBC 303.3	Any existing gravity load-carrying structural element for which an alteration causes an increase in design gravity load of more than 5% shall be strengthened, supplemented, replaced or otherwise altered as needed to	If alteration causes more than 5% increase in loads than the structure must be strengthened or replaced to comply with the new load	N/A	No	Assumed that the structure needed to be strengthened

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			carry the increased gravity load required by the IBC for new structures. Any existing gravity load-carrying structural element whose gravity load-carrying capacity is decreased as part of the alteration shall be shown to have the capacity to resist the applicable design gravity loads required by the IBC for new structures.	and IBC			
2.b		IEBC 303.3.1	Where alteration does not result in increased design live load, existing gravity load-carrying structural elements hall be permitted to be evaluated and designed for live loads approved prior to the alteration. If the approved live load is less than that required by section 1607 of IBC, the area designed for the nonconforming live load shall be posted with placards of approved design indicating the approved live load. Where the alteration does result in increased design live load, the live load required by section 1607 of IBC shall be used.	If does not alter design live load than new structure can be designed for the design live load pre-alteration		Yes	Live load not changed with alterations
2.c		IEBC 1301.2.4	An existing building or portion thereof that does not comply with the requirements of this code for new construction shall not be altered or repaired in such a	The building cannot be altered if it will cause the building to change the level of safety if so it must be		Yes	Level of Safety not changed

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			manner that results in the building being less safe or sanitary than such building is currently. If, in the alteration or repair, the current level of safety or sanitation is to be reduced, the portion altered or repaired shall conform to the requirements of Chapters 2 through 12 and chapters 14 through 33 of IBC.	in compliance with IBC			
3.a	Alterations to structural elements carrying lateral load	IEBC 303.4	The alteration increases design lateral loads in accordance with Section 1609 or 1613 of the IBC, or where the alteration results in a structural irregularity as defined in ASCE 7, or where the alteration decreases the capacity of any existing lateral load-carrying structural element, the structure of the altered building or structure shall be shown to meet the requirements of section 1609 and 1613 of IBC	If alteration changes design lateral loads than must be in compliance with Section 1609 or 1613 of IBC	If permitted by 303.5	No	Assumed that the lateral loads were changed and so they were not in compliance. A structural analysis was performed and solutions were found for this.
3.b					If demand-capacity ration isn't more than 10% of the demand-capacity ration without alteration than remain unaltered		
3.c		IEBC 1301.2.4	An existing building or portion thereof that does not comply with the requirements of this code for new construction shall not be altered or repaired in such a manner that results in the building	Building cannot be altered if it will cause the building to change the level of safety, if so it must be in compliance with	N/A	Yes	Washburn was not altered to change the level of safety

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			being less safe or sanitary than such building is currently. If, in the alteration or repair, the current level of safety or sanitation is to be reduced, the portion altered or repaired shall conform to the requirements of Chapters 2 through 12 and chapters 14 through 33 of IBC.	IBC			
4.a	Seismic	IEBC 303.4.1	Seismic requirements for alteration shall be in accordance with this section. Where the existing seismic force-resisting system is a type that can be designated ordinary, values of R, Ω_0, and C_d, for the existing seismic force-resisting system shall be those specified by this code for an ordinary system unless it is demonstrated that the existing system will provide performance equivalent to that of a detailed, intermediate or special system.	Alteration must have the same performance as the force resisting system now or must be updated	N/A	Yes but assumed no for purposes of project	Alterations increased the seismic performance however for the project it was assumed that it did not so that an analysis and solutions could be produced.
4.b		IEBC 303.5	Alterations to existing structural elements or additions of new structural elements that are not otherwise required by this chapter and are initiated for the purpose of improving the performance of the seismic force-resisting system of an existing structure or the performance of seismic bracing or anchorage of existing nonstructural	Can voluntarily update seismic bracing or anchorage if an engineering analysis is submitted showing compliance with IBC Chapter 16 and ASCE 7	N/A	Yes	Voluntarily updated while performing alterations (installed bracing)

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			elements shall be permitted, provided that an engineering analysis is submitted demonstrating all of the following: 1. The altered structure and the altered nonstructural elements are no less conforming to the provisions of the IBC with respect to earthquake design than they were prior to the alteration 2. New structural elements are detailed and connected to the existing structural elements as required by Chapter 16 IBC 3. New or relocated nonstructural elements are detailed and connected to existing or new structural elements as required by Chapter 16 of IBC 4. The alteration do not create a structural irregularity as defined in ASCE 7 or make an existing structural irregularity more severe				
5.a	Repairs to vertical element of lateral force resisting systems	IEBC 304.2	A building that has sustained substantial structural damage to the vertical elements of its lateral-force-resisting system shall be evaluated and repaired in accordance with the applicable	If substantial structural damage then the structure must be evaluated and repaired to comply with IEBC	N/A	Yes	There was not substantial damage to Washburn's structure

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			provisions of sections 304.2.1 through 304.2.3	304.2.1 through 304.2.3			
5.b		IEBC 506.2.3.1	Regardless of the level of damage to gravity elements of the lateral-force-resisting system. If substantial structural damage gravity load-carrying components was caused primarily by wind or seismic effects, then the building shall be evaluated in accordance with section 506.2.2.1 and, if noncompliant, rehabilitated in accordance with section 506.2.2.3	If damage was caused by wind or seismic then the structure must be assessed and if not compliant must be rehabilitated to comply with 506.2.23	N/A	Yes	There was no damage to Washburn by wind or seismic effects
5.c		IEBC 1301.2.4	An existing building or portion thereof that does not comply with the requirements of this code for new construction shall not be altered or repaired in such a manner that results in the building being less safe or sanitary than such building is currently. If, in the alteration or repair, the current level of safety or sanitation is to be reduced, the portion altered or repaired shall conform to the requirements of Chapters 2 through 12 and chapters 14 through 33 of IBC.	Building cannot be altered if it will cause the building to change the level of safety, if so it must be in compliance with IBC	N/A	Yes	Washburn was not altered to change the level of safety

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
6.a	Repairs to gravity load carrying components	IEBC 506.2.3	Gravity load-carrying components that have sustained substantial structural damage shall be rehabilitated to comply with the applicable provisions for dead and live loads in the IBC. Snow loads shall be considered if the substantial structural damage was caused by or related to snow load effects. Undamaged gravity load-carrying components that receive dead, live or snow loads from rehabilitated components shall also be rehabilitated if required to comply with the design loads of the rehabilitation design.	Shall be rehabilitated to comply with the applicable provisions for dead and live loads in IBC	N/A	Yes	There was no substantial damage to Washburn's structure
6.b		IEBC 1301.2.4	An existing building or portion thereof that does not comply with the requirements of this code for new construction shall not be altered or repaired in such a manner that results in the building being less safe or sanitary than such building is currently. If, in the alteration or repair, the current level of safety or sanitation is to be reduced, the portion altered or repaired shall conform to the requirements of Chapters 2 through 12 and chapters 14 through 33 of IBC.	Building cannot be altered if it will cause the building to change the level of safety, if so it must be in compliance with IBC	N/A	Yes	The repairs did not alter the level of safety

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
7.a	Change of Occupancy	IEBC 307	No change shall be made in the use or occupancy of any building that would place the building in a different division of the same group of occupancy or in a different group of occupancies, unless such building is made to comply with the requirements of the IBC for such division or group of occupancy. Subject to the approval of the building official, or use or occupancy of existing buildings shall be permitted to be changed and the building is allowed to be occupied for purposes in other groups without conforming to all the requirements of this code for those groups, provided the new or proposed use is less hazardous, based on life and fire risk, than the existing use.	Where an existing building is changed to a new occupancy classification the provisions of this section for the new occupancy shall be used to determine code compliance	N/A	Yes	The occupancy of Washburn was not changed during renovations
7.b		IEBC Chapter 9	A change in occupancy, as defined in section 202, with no change of occupancy classification shall not be made to any structure that will subject the structure to any special provisions of the applicable international codes, includeing the provisions of sections 902 through 911, without the approval of the code official. A certificate of occupancy shall be issued where it				

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			has been determined that the requirements for the change in occupancy have been met.				
7.c		IEBC 1301.2.1	Where an existing building is changed to a new occupancy classification and this section is applicable, the provisions of this section for the new occupancy shall be used to determine compliance with this code.				
8.a	Historic Buildings	IEBC 308	The provisions of this code relating to the construction, repair, alteration, addition, restoration and movement of structures, and change of occupancy shall not be mandatory for historic buildings where such buildings are judged by the building official to not constitute a distinct life safety hazard	Alteration, repair etc of historic building are not mandatory if they are judged by a building official and determined safe	N/A	No	Assumed it was unsafe for the purposes of the project
8.b		IEBC Chapter 11	A historic building undergoing repair, alteration or change of occupancy shall be investigated and evaluated, if it is intended that the building meet the requirements of this chapter, a written report shall be prepared and filed with the code official by a registered design professional when such a report is necessary in the opinion of the code official. Such report shall be in accordance	Historic building shall comply with the applicable structural provisions for work as classified in chapter 4	Unless determined safe by a building official	No	Assumed it was unsafe for the purposes of the project

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			with chapter 1 and shall identify each required safety feature that is in compliance with this chapter and where compliance with other chapters of these provisions would be damaging to the contributing historic features. For buildings assigned to Seismic Design category D, E o F, a structural evaluation describing, at minimum, a complete load path and other earthquake-resistant features shall be prepared. Additionally, the report shall describe each feature that is not in compliance with these provisions and shall demonstrate how the intent of these provisions is complied with in providing an equivalent level of safety.				
9.a	Evaluations	IEBC 304.2.1	The building shall be evaluated by a registered design professional, and the evaluation findings shall be submitted to the code official. The evaluation shall establish whether the damaged building, if repaired to its pre-damage state, would comply with the provisions of the IBC for wind and earthquake loads. Evaluation for earthquake loads shall be required if the substantial structural damage was caused by or related to earthquake effects or	Buildings must be evaluated by a registered design professional and these evaluations must be submitted to the code official	N/A	Yes	Building was evaluated by Hoffman Architects prior to renovations

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			if the building is in Seismic Design Category C, D, E or F				
9.b		IEBC 506.2.2.1	The building shall be evaluated by a registered design professional, and the evaluations findings shall be submitted to the code official. The evaluation shall establish whether the damaged building, if repaired to its predamaged state, would comply with the provisions of the IBC, except that the seismic design criteria shall be the reduced IBC level seismic forces specified in section 101.5.4.2.				
9.c		IEBC 1301.4	For proposed work covered by this chapter, the building owner shall cause the existing building to be investigated and evaluated in accordance with the provisions of section 1301.4 through 1301.9				
9.d		IEBC 1301.5	The evaluation shall be compromised of three categories: fire safety, means of egress, and general safety, as defined in sections 1301.5.1 through 1301.5.3				
9.e		IEBC 1301.6	The evaluation process specified herein shall be followed in its entirety to evaluate existing buildings. Table 1301.7 shall be utilized for tabulating the results of the evaluation. References to other sections of this code indicate that				

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			compliance with those sections is required in order to gain credit in the evaluation herein outlined. In applying this section to a building with mixed occupancies, there the separation between the mixed occupancies does not qualify for any category indicated in section 1301.6.16, the score for each occupancy shall be determined, and the lower score determined for each section of the evaluation process shall apply to the entire building.				
	Unreinforced Masonry Bearing Wall Buildings						
10	Alterations and Repairs	IEBC A105.2	Alterations and repairs required to meet the provisions of this chapter shall comply with applicable structural requirements of the building code unless specifically provided for in this chapter	Unless specified in this appendix, alteration and repairs should comply with IEBC	N/A	Yes	See masonry Specifications
11	Materials	IEBC A106.2	Existing materials used as part of the required vertical-load-carrying or lateral-force-resisting system shall be in sound condition, or shall be repaired or removed and replaced with new materials. All other unreinforced masonry materials shall comply with the following requirements: 1. The lay-up of the masonry units shall comply with section	Materials that are part of the load carrying systems shall be in good condition or need to be replaced or repaired	N/A	Yes	The masonry components were repointed

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			A106.3.2, and the quality of bond between units has been verified to the satisfaction of the building official 2. Concrete masonry units are verified to be load-bearing units complying with UBC Standard 21-4 or such other standard as is acceptable to the building official 3. The compressive strength of plain concrete walls shall be determined based on cores taken from each class of concrete wall. The location and number of tests shall be the same as those prescribed for tensile-splitting strength tests in Sections A106.3.3.3 and A106.3.3.4 or in Section A108.1				
12	Existing Unreinforced Masonry	IEBC A106.3.1	Unreinforced masonry walls used to carry vertical loads or seismic forces parallel and perpendicular to the wall plane shall be tested as specified in this section. All masonry that does not meet the minimum standards established by this chapter shall be removed and replaced with new materials, or alternatively, shall have its structural functions replaced with new materials and shall be	Unreinforced masonry walls that carry load shall be tested and if they do not meet the standards must be removed and replaced or have the structural functions replaced	N/A	Yes	Testing was not performed however walls were repaired in compliance with ASTM standards

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			anchored to supporting elements.				
13.a	Lay-up of Walls	IEBC A106.3.2.1	The facing and backing shall be bonded so that not less than 10% of the exposed face area is composed of solid headers extending not less than 4inches into the backing. The clear distance between adjacent full-length headers shall not exceed 24inches vertically or horizontally. Where the backing consists of two or more wythes, the headers shall extend not less than 4 inches into the most distant wythe, or the backing wythes shall be bonded together with separate headers with their area and spacing conforming to the foregoing. Wythes of walls not bonded as described above shall be considered veneer. Veneer wythes shall not be included in the effective thickness used in calculating the height-to-thickness ratio and the shear capacity of the wall	The facing and backing of bricks should be connected so that not less than 10% of the exposed face is composed of solid headers.	Veneer wythes anchored as specified in the building code and made composite with backup masonry may be used for calculation of the effective thickness, where S_{D1} exceeds 0.3.	Yes	Bracing was installed in order to connect the facing and backing of bricks. (Assumed compliant because bracing out of project scope)
13.b		IEBC A106.3.2.2	Grouted or ungrouted hollow concrete or clay block and structural hollow clay tile shall be laid in a running bond pattern.	Use a running bond pattern for grouted or ungrouted hollow concrete or clay	N/A	Yes	They bricks were not hollow so in compliance
13.c		IEBC A106.3.2.3	Lay-up patterns other than those specified in sections A106.3.2.1 and A106.3.2.2 above are allowed if	Other patterns can be used if their performance is	N/A	Yes	Lay-up pattern complies with the *Codes*

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			their performance can be justified	justified			
14.a	Mortar Tests	IEBC A106.3.3.1	The quality of mortar in all masonry walls shall be determined by performing in-place shear tests in accordance with the following: 1. The bed joints of the outer wythe of the masonry should be tested in shear by laterally displacing a single brick relative to the adjacent bricks in the same wythe. The head joint opposite the load end of the test brick should be carefully excavated and cleared. The brick adjacent to the loaded end of the test brick should be carefully removed by sawing or drilling and excavating to provide space for a hydraulic ram and steel loading blocks. Steel blocks. The size of the end of the brick, should be used on each end of the ram to distribute te load to the brick. The blocks should not contact the mortar joints. The load should be applied horizontally, in the plane of the wythe. The load recorded at first movement of the test brick as indicated by spalling of the face of the mortar bed joints is	The quality of mortar shall be determined by performing in-place shear tests	N/A	No	The in-place shear tests were not performed to determine the quality of mortar. The quality of quality of mortar was assumed to be the minimum.

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			V_{test} in equation A1-3 2. Alternative procedures for testing shall be used where in-place testing is not practical because of crushing or other failure mode of the masonry unit				
14.b		IEBC A106.3.3.2	The tensile-splitting strength of existing masonry, f_{sp}, or the prism strength of existing masonry, f'_m, may be determined in accordance with one of the following procedures: 1. Wythes of solid masonry units shall be tested by sampling the masonry by drilled cores of not less than 8inches in diameter. A bed joint intersection with a head joint shall be in the center of the core. The tensile splitting strength of these cores should be determined by the standard test method of ASTM C496. The core should be placed in the test apparatus with the bed joint 45 degrees from the horizontal. The tensile-splitting strength should be determined by the following equations $f_{sp}=2P/\pi a_n$ 2. Hollow unit masonry constructed of through-the-	The tensile-spliting strength of masonry, f_{sp}, or the prism strength of existing masonry, f'_m, can be found through 1. Masonry core test and equation $f_{sp}=2P/\pi a_n$ 2. Sawn square prism test and equation $f_{sp}=0.494P/a_n$ 3. Estimate f'_m	N/A	No	No tests were performed to find the tensile splitting strength of the masonry.

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			wall units shall be tested by sampling the masonry by a sawn square prism of not less than 18inches square. The tensile-splitting strength should be determined by the standardtest method of ASTM E519. The diagonal of the prism should be placed in a vertical position. The tensile-splitting strength should be determined by the following equation f_{sp}=0.494P/a_n 3. An alternative to material testing is estimation of the f'_m of the existing masonry. This alternative should be limited to recent constructed masonry. The determination of f'_m requires that the unit correspond to a specification of the unit by an ASTM standard and classification of the mortar by type.				
15	Test location	IEBC A106.3.3.3	The shear test shall be taken at locations representative of the mortar conditions throughout the entire buildings, taking into account variations in workmanship at different building height levels, variations in weathering or the exterior surfaces, and variations in	Shear tests shall be taken at various locations that account for variations in workmanship, weathering, deterioration and deleterious effects.	N/A	No	No tests were completed

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			the conditions of the interior surfaces due to deterioration caused by leaks and condensation of weather and/or by the deleterious effects of other substances contained within the building. The exact test locations shall be determined at the building site by the engineer or architect in responsible charge of the structural design work. An accurate record of all such tests and their locations in the building shall be recorded, and these results shall be submitted to the building department for approval as part of the structural analysis				
16	Number of Test	IEBC A106.3.3.4	The minimum number of tests per class shall be as follows: 1. At each of both the first and top stories, not less than two tests per wall or line of wall elements providing a common line of resistance to lateral forces 2. At each of all other stories, not less than one test per wall or wall element providing a common line of resistance to lateral forces 3. In any case, not less than one test per 1,500 SF of wall	The minimum number of tests: 1. Atleast two tests per wall at the top and floor stories 2. At all stories not less than one test per wall 3. Not less than one test per 1,500SF of wall and not less than eight total	N/A	No	No tests were completed

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			surface and not less than a total of eight tests				
17	Minimum Quality of Mortar	IEBC A106.3.3.5	1. Mortar shear test values, v_{to}, in pounds per square inch (kPa) shall be obtained for each in-place shear test in accordance with the following equation $v_{to}=(V_{test}/A_b)-p_{D+L}$ 2. Individual unreinforced masonry walls with v_{to} consistently less than 30pounds per square inch (207kPa) shall be entirely pointed prior to retesting 3. The mortar shear strength, $v_{t'}$ is the value in pounds per square inch that is exceeded by 80% of the mortar shear test values, v_{to} 4. Unreinforced masonry with mortar shear strength, $v_{t'}$ less than 30 pounds per square inch shall be removed, pointed and retested or shall have its structural function replaced, and shall be anchored to supporting elements in accordance with sections A106.3.1 and A113.8. When existing mortar in any wythe is pointed to increase its shear strength and is retested, the	1. Mortar shear test values, v_{to} from in-place shear test and equation: $v_{to}=(V_{test}/A_b)-p_{D+L}$ 2. If v_{to} is consistently less than 30 pounds per square inch then entirely repointed 3. $v_{t'}$ is exceeded by 80% of v_{to} 4. if $v_{t'}$ is less than 30 pounds per square inch then it shall be repointed and retested or have its structural function replaced	N/A	Yes	Mortar was made with Portland cement (type 1: ASTM C150), Hydrated Lime (Type S: ASTM C207) and aggregate according to ASTM C144. The water was from municipal water supply and was mixed by a SPEC-MIX licensee. Type O mortar according to ASTM C270

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			condition of the mortar in the adjacent bed joints of the inner wythe or wythes and the opposite outer wythe shall be examined for extent of deterioration. The shear strength of any wall class shall be no greater than that of the weakest wythe of that class				
18	Minimum Quality of Masonry	IEBC A106.3.3.6	1. The minimum average value of tensile-splitting strength shall be 50 pounds per square inch (344.7kPa). The minimum value of f'_m determined by categorization of the masonry units and mortar should be 1,000 pounds per square inch (6895kPa). 2. Individual unreinforced masonry walls with average tensile-splitting strength of less than 50 pounds per square inch shall be entirely repointed 3. Hollow unit unreinforced masonry walls with estimated prism compressive strength of less than 1,000 pounds per square inch shall be grouted to increase the average net area compressive strength	1. Minimum tensile-splitting strength= 50 pounds per square inch. Minimum f'_m= 1000 pounds per square inch 2. Masonry walls with less than 50 pounds per square inch in tensile-splitting strength shall be repointed 3. Masonry walls with prism compressive strength less than 1,000 pounds per square inch needs to be	N/A	Yes	Masonry was replaced to comply with ASTM 216: Grade SW and Type FBX

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
				regrouted			
19	Pointing	IEBC A106.3.3.9	Deteriorated mortar joints in unreinforced masonry walls shall be pointed according to UBC Standard 2 1-8.	Joints must be repointed according to UBC Standards 2 1-8	At the discretion of the building official, incidental pointing may be performed without special inspection	Yes	Washburn was repointed according to ASTM C270 standards
20	Existing Wall Anchors	IEBC A107.3	Existing wall anchors used as all or part of the required tension anchors shall be tested in pullout according to UBC Standard 2 1-7. The minimum number of anchors tested shall be four per floor, with two tests at walls with joist framing into the wall and two tests at walls with joists parallel to the wall, but not less than 10% of the total number of existing tension anchors at each level.	Existing wall anchors shall be tested according to UBC Standard 2 1-7. Minimum of 10% of total number of anchors must be tested at each level	N/A	Yes	The old wall anchors were not tested by they were corroded and so replaced by new wall anchors according to ASTM Standards
21	Masonry Shear Strength	IEBC A108.2	The unreinforced masonry shear strength, v_m, shall be determined for each masonry class from one of the following equations: 1. The unreinforced masonry shear strength, v_m, shall be determined by the equation	Unreinforced masonry shear strength shall be determined by: 1. V_m=0.56v_t +(0.75P_D/A) when use A106.3.3.1	N/A	No	The masonry shear strength was not calculated because mortar testing was not

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			$v_m=0.56v_t+(0.75P_D/A)$ when the mortar shear strength has been determined by section A106.3.3.1. The mortar shear strength values, v_t, shall be determined in accordance with section A106.3.3.5 and shall not exceed 100 pounds per square inch for the determination of v_m 2. The unreinforced masonry shear, v_m, shall be determined by the equation $v_m=0.8f_{sp}+0.5P_D/A$ when tensile-splitting strength has been determined in accordance with section A106.3.3.2 3. When f'_m has been estimated by categorization of the units and mortar in accordance with section 2105.2.2.1 of IBC, the unreinforced masonry shear strength, v_m, shall not exceed 200 pounds per square inch or the less of the following: 2.5sqrt(f'_m) 200 psi $v+0.75P_D/A$ where v=62.5psi for running bond masonry not grouted solid	2. $V_m=0.8f_{sp}+0.5P_D/A$ when use A106.3.3.2 3. 2.5sqrt(f'_m) or 200psi or $v+0.75P_D/A$ where v=62.5psi for running bond not grouted, v=100psi for running bond grouted, v=25psi for stack bond grouted, when use 2105.2.2.1 IBC			completed.

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			v=100psi for running bond masonry grouted solid v=25psi for stack bond grouted solid				
22	Masonry Compression	IEBC A108.3	Where any increase in dead plus live compression stress occurs, the compression stress in unreinforced masonry shall not exceed 300psi	The dead plus live compression stress can't exceed 300psi	N/A	Yes	Calculated dead and live compression stresses do not exceed 300psi
23	Masonry Tension	IEBC A108.4	Unreinforced masonry shall be assumed to have no tensile capacity	No tensile capacity	N/A	No	Calculated Seismic forces are greater than gravity loads causing tensile stresses
24	Foundations	IEBC 108.6	For existing foundations, new total dead loads may be increased over the existing dead load by 25%. New total dead load plus live load plus seismic forces may be increased over the existing dead load plus live load by 50%. Higher values may be justified only in conjunction with a geotechnical investigation.	New dead loads may increase existing dead loads by 25% and new dead plus live load may be 50% more than existing.	N/A	Out of Scope	Was not determined because foundations were not in structural analysis project scope
25.a	Lateral Forces on elements of Structures	IEBC A110.2	Parts and portions of a structure not covered in sections A110.3 shall be analyzed and designed per the current building code, using force levels defined in section	Parts of the structure must be designed and analyzed to comply with current codes	If height to thickness ratios do not exceed table A1-B	No	Assumed not to be in compliance and analyzed for the project

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
			A110.1		then don't need to be analyzed		
					Parapets complying with Section A113.6 don't need to be analyzed		
25.b					Walls shall be anchored to the floor and roof diaphragms according to Section A113.1		
26	Wall Anchorage Locations	IEBC A113.1.1	Unreinforced masonry walls shall be anchored at the roof and floor levels as required in Section A110.2. Ceilings of plaster or similar materials, when not attached directly to roof or floor framing and where abutting masonry walls, shall either be anchored to the walls at a maximum spacing of 6ft, or be removed	Unreinforced masonry walls shall be anchored at the roof and floor	N/A	Yes	Anchored at every 3 brick courses

Item #	Element	Code Reference	Code Text	Interpretation	Exceptions	Compliant	Current Conditions
27	Wall Anchorage Requirement	IEBC A113.1.2	Anchors shall consist of bolts installed through the wall as specified in table A1-E, or an approved equivalent at a maximum anchor spacing of 6ft. All wall anchors shall be secured to the joists to develop the required forces	Anchors must have bolts in compliance with table A1-E	N/A	Yes	TAPCON was used for securement of wall tie anchors to existing masonry.
28	Minimum Wall Anchorage	IEBC A113.1.3	Anchorage of masonry walls to each floor or roof shall resist a minimum force determined as $0.9S_{DS}$ times the tributary weight or 200 pounds per linear foot, whichever is greater, acting normal to the wall at the level of the floor or roof. Existing wall anchors, if used, must meet the requirements of this chapter or must be upgraded	Anchorage at each floor or roof must resist a minimum force of $0.9S_{DS}$ times the tributary weight	N/A	Out of Project Scope	The project did not assess the bracing that was installed in the renovation
29	Wall Anchorage at corners	IEBC A113.1.4	At the roof and floor levels, both shear and tension anchors shall be provided within 2ft horizontally from the inside of the corners of the walls	At roof and floor levels shear and tension anchors are needed 2ft from wall corners	N/A	Yes	Joint reinforcements were installed at every 3 brick courses
30	Ties and continuity	IEBC A113.4	Ties and continuity shall conform to the requirements of the building code	Ties must comply to IBC	N/A	Yes	Wall ties of type 304 stainless steel were used

7.2 Fire Checklist

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
	NFPA 13: Standard for the Installation of Sprinkler Systems					
1	Accessibility	8.1.2*	System valves and gauges shall be accessible for operation, inspection, tests, and maintenance	All equipment must be accessible	Yes	Yearly tests are completed and therefore all valves and gauges are accessible (Horanzy, 2011)
2	Sprinkler System Area Coverage	8.2.1	Maximum floor area on any one floor to be protected by sprinklers supplied by any one or combined sprinkler system riser: Light Hazard: 52,000ft^2 Ordinary Hazard: 52,000ft^2 Extra Hazard: 25,000ft^2 or 40,000ft^2 Storage: 40,000ft^2	In NFPA, offices and educational buildings are considered Light Hazard Occupancy (A.5.2) and therefore can have one riser supplying 59,000 ft^2 on one floor.	Yes	Riser in every exit stairway
3	Sprinkler Installation	8.3.1.1	Sprinklers shall be installed in accordance with their listing	Follow instruction for installation on listing	N/A	No available documentation on sprinkler installation
4	Sprinkler Frame Arms	8.3.1.3*	Upright sprinklers shall be installed with the frame arms parallel to the branch line, unless specifically listed for other orientation	Frame arms must be parallel to branch line.	Yes	All upright sprinklers inspected complied. See Figure 88.
5	Temperature Ratings	8.3.2.1*	Unless [other requirements]	Sprinklers near heating	Yes	All sprinklers in

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			are met, ordinary- and intermediate-temperature sprinklers shall be used throughout buildings	ducts may need a higher temperature rating but other should be ordinary or intermediate.		suspended ceiling complied. See Figure 89.
6	Area of Coverage	8.5.2.2.2	The maximum area of coverage of any sprinkler shall not exceed 400ft^2	A sprinkler can protect a maximum of 400 ft^2	Yes	Inspected sprinklers were closer than necessary
7	Deflector Orientation	8.5.4.2	Deflectors of sprinklers shall be aligned parallel to ceilings, rods, or the incline of stairs.	Deflectors are parallel to surface above sprinklers	Yes	All deflectors inspected were parallel. See Figure 88.
8	Distance from Walls	8.6.3.2.1	The distance from sprinklers to walls shall not exceed one-half of the allowable distance between sprinklers	Sprinklers must be between 4 inches and half of maximum allowable distance	Yes	All sprinklers inspected followed this spacing from wall.
		8.6.3.3	Sprinklers shall be located a minimum of 4 in. from a wall		Yes	
9	Sprinkler Spacing	8.6.3.4.1	Unless [other requirements] are met, sprinklers shall be spaced not less than 6 ft on center	Sprinkler spacing must be more than 6 ft	Yes	All sprinklers inspected followed this spacing.
10	Sprinkler Obstructions	8.6.5.1.2*	Sprinklers shall be arranged to comply with one of the following arrangements: (1) Subsection 8.5.5.3, Table 8.6.5.1.2 and Figure 8.6.5.1.2(a) (2) Obstructions less than 4 ft with sprinklers on either side	If sprinklers are less than 1 ft from an obstruction, the deflector must be at the same height as the bottom of the obstruction	No	Numerous sprinklers were not in compliance. Observations included sprinkler heads positioned too close to pipes,

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			(3) Obstructions on wall less than 30 in wide and in accordance with Figure 8.6.5.1.2(b)			beams, and light fixtures.
		8.6.5.2.1.3*	Sprinklers shall be positioned away from obstructions a minimum distance of three times the maximum dimension of the obstruction. The maximum clear distance required shall be 24 in. in accordance with Figure 8.6.5.2.1.3	Sprinkler must be a distance 3 times largest dimension of bottom truss member or greater than 24”		
12	Sprinkler Distance to Ceiling	8.6.4.1.1.1 8.6.4.1.2	Under unobstructed construction, the distance between the sprinkler deflector and the ceiling shall be a minimum of 1 in. and a maximum of 12 in. throughout the area of coverage of the sprinkler. Under obstructed construction, the distance between the sprinkler deflector and the ceiling shall be a maximum of 22 in.	Unobstructed Construction: 1” < x < 12” Obstructed Construction: 1” < x <22”	Yes	Suspended ceiling sprinklers compile. Unable to measure distance between other sprinklers and ceiling but by visual inspection, sprinklers compile.
	NFPA 72: National Fire Alarm and Signaling Code					
13	Location of Devices	5.4.2	Initiating devices shall not be installed in inaccessible areas.	All equipment should be accessible	Yes	Yearly tests are completed and therefore all valves and

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
						gauges are accessible (Horanzy, 2011)
14	Installation of Devices	5.4.4	Initiating devices shall be supported independently of their attachment to the circuit conductors.	Devices need to be installed with proper support, accessibility, distance from ceiling	Yes	Proper mounting support for detectors was determined. See Figure 91.
		5.4.5	Initiating devices shall be installed in a manner that provides accessibility for periodic maintenance.		Yes	Devices were accessible and not block by any temporarily placed objects.
		5.5.1	Unless tested and listed for recessed mounting, detectors shall not be recessed into the mounting surface.		Yes	All detectors inspection were flush with surface. See Figure 90.
15	Location of Devices	5.5.2.1	When inaccessible areas contain combustible materials, unless specified in 5.5.2.1.2, they shall be made accessible and shall be protected by a detector(s).	Combustible materials in concealed spaces need to be protected by detectors.	No	Concealed spaces above ceiling are not protected by detection devices (Horanzy, 2011) based on the 2011 fire.
17	Smoke-Sensing Detector Location	5.7.1.9*	The location of smoke detectors shall be based on an evaluation of potential ambient sources of smoke, moisture, dust, or	Smoke detector location is based on evaluation of environmental conditions.	No	Does not consider ceiling conditions based on the 2011 fire.

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			fumes, and electrical or mechanical influences to minimize nuisance alarms.			
18	Smoke-Sensing Detector Specification	5.7.2.1*	Smoke detectors shall be marked with their nominal production sensitivity and tolerance (percent per foot obscuration), as required by the listing.	Smoke detectors must be marked with sensitivity and tolerance.	N/A	Could not read detectors from floor visual inspection. See Figure 91.
19	Smoke-Sensing Detector Spacing	5.7.3.2.3.1*	In the absence of specific performance-based design criteria, smoke detectors shall be permitted to be located using 30 ft spacing.	Smoke detectors shall be spaced 30 ft apart	No	Smoke detectors are spaced over 30 ft apart
		5.7.3.2.3.5*	For smooth ceilings, all points on the ceiling shall have a detector within a distance equal to 0.7 times the selected spacing.	Smoke detectors will be located 0.7 times the selected spacing on smooth ceilings	N/A	Ceiling are not all smooth
20	Smoke-Sensing Detector Location	5.7.3.2.3.3	Other spacing shall be permitted to be used depending on ceiling height, different conditions, or response requirements.	Spacing also should consider ceiling conditions and response conditions	No	Does not consider ceiling conditions based on the 2011 fire.
		5.7.3.7	Spaces beneath raised floors and above suspended ceilings shall be treated as separate rooms for smoke detector spacing purposes. Detectors installed beneath raised floors or above suspended ceilings, or both,	The space above suspended ceilings must be treated as a separate room then the one below it and be protected by detectors.	No	No detectors are above suspended ceilings (Horanzy, 2011).

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			shall not be used in lieu of providing detection within the room.			
21	Manual Fire Alarm Box Location	5.13.4	The operable part of each manual fire alarm box shall be not less than 3.5 ft and not more than 4.5 ft above the floor.	Manual pull stations must be ≥ 3.5 ft and ≤ 4.5 ft from the floor	Yes	Inspected manual pull stations comply. See Figure 92.
		5.13.6	Manual fire alarm boxes shall be located within 5 ft of the exit doorway opening at each exit on each floor.	Manual pull stations must be at each exit on each floor and ≤ 5 ft from the exit.	No	Most exits comply but main entrance does not. See Figure 92.
		5.13.8*	Additional manual fire alarm boxes shall be provided so that the travel distance to the nearest fire alarm box will not be in excess of 200 ft measured horizontally on the same floor.	Manual pull stations will be ≤ 200 ft apart on each floor.	Yes	Pull stations were located near each exit which also fulfilled this requirement.
22	Manual Fire Alarm Box Specifications	5.13.5*	Manual fire alarm boxes shall be installed so that they are conspicuous, unobstructed, and accessible.	Manual pull stations must be accessible and distinguishable	Yes	Inspected manual pull stations comply. See Figure 93.
23	Smoke-Sensing Detector Specifications	5.16.6.4	Smoke detectors shall be of the photoelectric, ionization, or other approved type.	Smoke detectors must be an approved type	N/A	Could not read detectors from floor visual inspection. See Figure 91.
24	Smoke-Sensing Detector Location	5.16.6.5.1.1	If the depth of wall section above the door is 24 in or	1 ceiling-mounted detector or 2 wall-	Yes	Smoke detector placement

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			less, one ceiling-mounted smoke detector shall be required on one side of the doorway only, or two wall-mounted detectors on each side of the doorway.	mounted detectors when depth of wall above a door is ≤ 24 inches.		complies. See Figure 94.
		5.16.6.5.1.2	If the depth of wall section above the door is greater than 24 in on both sides, two ceiling-mounted or wall-mounted detector shall be required, one on each side of the doorway.	2 ceiling-mounted detectors or 2 wall-mounted detectors when depth of wall above a door is > 24 inches.		
25	Alarm Notification	6.8.1.1*	Actuation of alarm notification appliances or emergency voice communications, fire safety functions, and annunciation at the protected premises shall occur within 10 seconds after the activation of an initiating device.	Alarm notification will started within 10 seconds after initiating device activation.	N/A	Not enough data from available testing records.
26	Access to Alarm Controls	6.9.6.2	Controls shall be located or secured to allow access by only trained and authorized personnel.	Only Authorized personnel shall have access to alarm controls.	Yes	On tour, all rooms with controls were locked
27	Alarm Zoning	4.4.6.6.1	For the purpose of alarm annunciation, each floor of the building shall be considered as a separate zone. If a floor is subdivided by fire or smoke barriers and	Each floor must be a separate zone for the fire alarm	Yes	Each floor has a separate zone (Horanzy, 2011)

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			the fire plan for the protected premises allows relocation of occupants from the zone of origin to another zone on the same floor, each zone on the floor shall be annunciated separately for purposes of alarm location.			
		A.4.4.6.6	Fire alarm system annunciation should, as a minimum, be sufficiently specific to identify a fire alarm in accordance with the following (A.4.4.6.6(1-5))			
28	Responsibility	10.2.2.1*	The property or building owner or the owner's designated representative shall be responsible for inspection, testing, and maintenance of the system and for alterations or additions to this system.	The owner is responsible for keeping the system compliant over the lifetime of the building.	Yes	WPI has passed their inspections every year or fixed the violations pointed out by the contractor.
29	Visual Inspection	10.3.1*	Visual inspections shall be performed in accordance with the schedules in Table 10.3.1 or more often if required by the authority having jurisdiction.	This table is a checklist for the inspections of the system and how often certain tasks need to be completed	N/A	Not enough data from available testing records.
30	Testing	10.4.4*	Testing shall be performed in accordance with the schedules in Table 10.4.4, except as modified in other	This table is a checklist for the testing of the system and how often certain tasks need to be	N/A	Not enough data from available testing records.

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			paragraphs of 10.4.4, or more often if required by the authority having jurisdiction.	completed		
31	Maintenance	10.5.2	The frequency of maintenance of fire alarm system equipment shall depend on the type of equipment and the local ambient conditions.	Maintenance depends on equipment and environment. This table is a checklist for the inspections of the system and how often certain tasks need to be completed	N/A	Not enough data from available testing records.
32	Records	10.6.2.1	Records shall be retained until the next test and for 1 year thereafter.	These records must be kept for 1 year after the next set of data	Yes	Data from previous tests has been kept on record.
	NFPA 25: Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems					
33	Responsibility	4.1.2*	The responsibility for properly maintaining a water-based fire protection system shall be that of the owner of the property	The owner is responsible for upkeep of the system	Yes	WPI has passed their inspections every year or fixed the violations pointed out by the contractor.
34	Records	4.4.4	As-built system installation drawings, hydraulic calculations, original acceptance test records, and device manufacturer's data sheets shall be retained for life of the system.	These particular system records must be kept for the lifetime of the system	N/A	Not enough data from available testing records.
		4.4.5	Subsequent records shall be	These particular data	Yes	Data from

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			retained for a period of 1 year after the next inspection, test, or maintenance of that type required by the standard.	records must be kept for 1 year after the next set of data		previous tests has been kept on record.
35	Summary Table	Table 5.1	Summary of Sprinkler System Inspection, testing, and Maintenance	This table is a checklist for the upkeep of the system and how often certain tasks need to be completed	N/A	Not enough data from available testing records.
36	Sprinkler Inspection	5.2.1.1.4*	Sprinklers installed in concealed spaces such as above suspended ceilings shall not require inspection	Sprinklers in concealed spaces do not need inspection.	Yes	Compliant but how are these sprinklers maintained if they don't need to be inspected?
37	Sprinkler Inspection	5.2.1.2*	The minimum clearance required by the installation standard shall be maintained below all sprinklers. Stock, furnishings, or equipment closer to the sprinkler than the clearance rules allow shall be corrected.	Obstruction rules from NFPA 13 must be followed throughout lifetime of system	Yes	No temporary items obstructed any inspected sprinklers
38	Sprinkler Maintenance	5.3.1.1.1	Where sprinklers have been in service for 50 years, they shall be replaced or representative samples from one or more sample areas shall be tested. Test procedures shall be repeated at 10-year	Samples must be taken from system older than 50 years to test integrity of sprinklers	Yes	Washburn's system was installed in the 1980's (Salter, 2011)

Item #	Element	Code Reference	Code Text	Interpretation	Compliant	Current Conditions
			intervals.			
39	Summary Table	Table 5.5.1	Summary of Component Replacement Action Requirements	This table is a checklist for the replacing items in the system when the AHJ deems it necessary	N/A	Not enough data from available testing records.

Figure 88: Frame arms parallel to branch line (item 4) Deflector parallel to ceiling (item 7)

Figure 89: Temperature Rating (item 5)

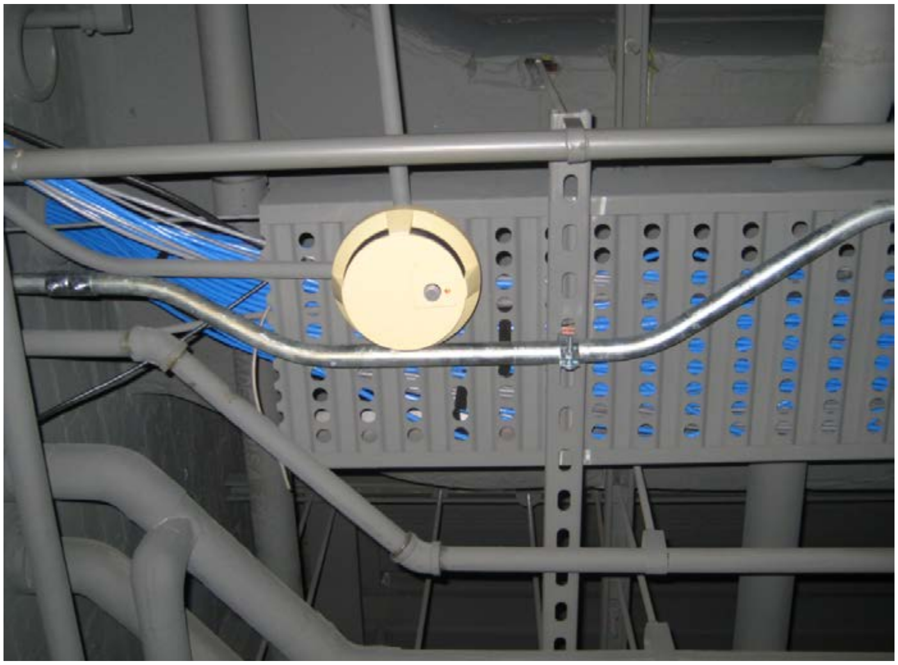

Figure 90: Smoke detector mounted and not recessed (item 14)

Figure 91: Marked Smoke Detectors (items 18 and 23)

Figure 92: Pull station more than 5 ft from entrance (item 21)

Figure 93: Pull station correct height and distinguishable (items 21 and 22)

Figure 94: Smoke detectors on either side of fire door (item 24)

7.3 Renovation Guidelines

7.3.1 Brick Column Specifications

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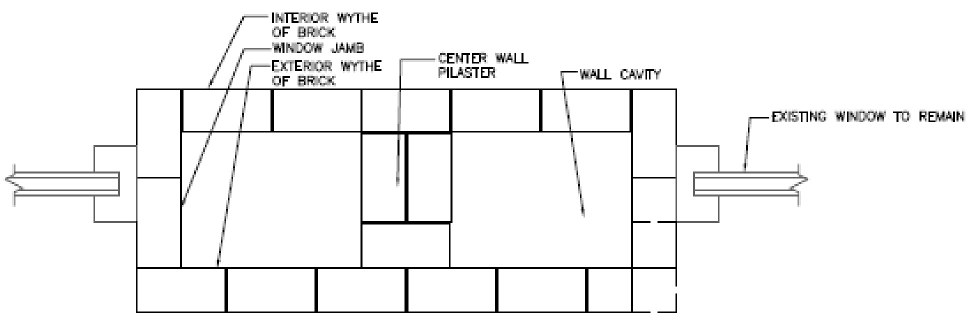
BY MSP DATE 12/05/11 CHECKED BY SJS SCALE AS NOTED ADDENDUM NO. ____ DATE ____



1 SECTION—BRICK COLUMN
SCALE: 1"=1'-0"

Notice: Do not scale drawings. Contractor is responsible for verifying dimensions and details in the field. Report any discrepancies to architect for resolution.

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7.3.2 Masonry Guidelines

Division 4 - Masonry

Section 04 01 20 - Brick Restoration

Part 1 - General

1.01 Description

A. The principal items of work are related to:

1. Repointing of the entire brick facade;
2. Replacement of face brick at select areas;
3. Restoration of the brick dentils at the top of the brick masonry walls;
4. Replacement of cracked brick (to be eliminated if Alternate 2 is chosen);
5. Reconstruction of the corners of the brick tower from the base of the wall up to the level of the gutter, and
6. Work called for the Drawings, and other work necessitated by these operations.

Alternate 2:

8. Reconstruction of select areas of the exterior wythe of brick masonry

1.02 Related Sections

A. 04 91 20 – Helical Restoration Anchors

1.03 Submittals

A. Submit list of all materials proposed for use. Submit technical data sheet for each manufactured product.

B. Submit drawings and written description of shoring procedures, including extent of removals and method of support, to the Architect. This is an information submittal and not subject to the Architect's review.

C. Submit written description of removal procedures and operations sequencing to the Architect prior to commencement of the Work. This is an information submittal and not subject to the Architect's review.

D. Submit certification that aggregate for masonry mortar complies with specified requirements including grading requirements.

E. Submit confirmation of mortar mix design.

F. Submit brick samples: two units

G. Submit brick test results from independent testing laboratory (ASTM C67):

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1. compressive strength

2. absorption: 24-hour cold water test

3. absorption: 5-hour boiling water test

4. initial rate of absorption

1.04 Quality Assurance

A. Ensure that all personnel engaged in the Work of this Section are qualified masonry journeymen, who may be assisted by masonry apprentices qualifying for their journeyman status.

1. Common labor may be used for tasks not requiring journeyman skills.

2. Ensure that the foreman of the crew has had at least 5 years experience in work of similar nature and scope.

1.05 Reference Standards

A. ASTMC144-99 Specification for Aggregate for Masonry Mortar

B. ASTM C150-00 Specification for Portland Cement

C. ASTM C207-91(1997) Specification for Hydrated Lime for Masonry Purposes

D. ASTM C270-00 Specification for Mortar for Unit Masonry

E. ASTM C67-00 Test Methods of Sampling and Testing Brick and Structural Clay Tile

F. ASTM C114-00 Test Methods for Chemical Analysis of Hydraulic Cement

G. ASTM C62-01 Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)

H. BIA (Brick Industry Association) Technical Note 1, Revised: All-Weather Construction (1992)

1.06 Delivery, Handling and Storage

A. Prevent segregation and contamination of aggregates by effective containment on a flat, hard surface and covering with a secured tarpaulin.

B. Store bagged material with bags intact and undamaged until needed for use.

C. Store masonry units elevated and covered to prevent contamination with salts that cause efflorescence.

1.07 Job Conditions

A. Cold Weather: Do not perform masonry work when temperatures may drop below 40 degrees F within 24 hours.

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B. Hot Weather: When ambient air temperature exceeds 90 degrees F with wind velocity greater than 8 mph (or when ambient air temperature exceeds 100 degrees F regardless of wind velocity), protect mortar from moisture loss as specified in Part 3 below.

1.08 Protection

A. Immediately remove excess mortar, stains, or other elements that would mar the surface appearance. Follow procedures outlined in CLEANING in Part 3.

B. For existing surfaces intended to remain such as roofs or terraces that will receive traffic during masonry work, provide plywood traffic ways. Working surfaces adjacent to wall receiving masonry work shall be not less than 4 feet wide.

C. Weather Protection: Cover and protect all exterior openings and partially completed work at the end of the work day to prevent water entry or exposure to hot, dry conditions.

D. Provide necessary support for all masonry that may be affected by work of this section. Submit to Architect proposed methods of support for masonry prior to beginning work.

1.09 Sequencing

A. Execute related work promptly so that temporary weatherproofing can be replaced with the permanent installation of masonry in a timely manner.

1.10 Probes and Test Panels

1. The first 10 square feet of masonry installation shall serve as a test panel for the Architect's and Owner's acceptance of mortar color, tooling and workmanship. Test panel may contain more than one at Architect's request. Do not proceed with the remainder of the Work until the test panel has been reviewed and accepted. When test panel is no longer needed, repair or repoint as required to match the finished work, as directed by the Architect.

Part 2 - Products

2.01 Brick

A. <u>This is an historic building and therefore it is imperative that all masonry repairs closely match the existing construction. The contractor shall take all necessary action to ensure that replacement brick shall exactly match existing brick in size, color and texture</u>

1. Conforming to ASTM 216

2. Grade: SW

3. Type: FBX

B. Color: submit samples to be reviewed by the Architect and the Owner. If no suitable match can be found from the manufacturers standard colors, a custom color match must be provided

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1. Size: Custom to match existing.

   a. The contractor is hereby notified that all bricks may not be of the same size. The contractor shall field measure several bricks to establish a range of sizes.

C. Manufacturers

1. Vermont Brick

2. Watsontown Brick Co.

3. Belden Brick

2.02 Mortar Materials

A. Cement: Portland cement, Type I, ASTM C150

B. Lime: Hydrated Lime, Type S, ASTM C207.

C. Aggregate: ASTM C144. All aggregate used in the Work shall be from the same source in order to produce mortar of uniform color throughout the Work.

D. Water: from municipal water supply and clean at time of use.

E. SPEC-MIX Option: Provide preblended mortar mix incorporating all dry ingredients as supplied by licensee of Spec-Mix licensee and expedite submittal of pigmented sample mixes for approval by Architect and Owner.

1. The Contractor shall effectively communicate all mortar mix requirements to the Spec-Mix licensee and expedite submittal of pigmented sample mixes for approval by Architect and Owner.

2.03 Masonry Reinforcement, Wall Ties, and Anchors

A. Horizontal reinforcement: prefabricated reinforcement, type 304 stainless steel. Provide prefabricated corners and tees as required for the Work.

1. Manufacturer: Hohmann & Barnard

2. Type: 1/8 inch wire

B. Brick veneer anchor: prefabricated wall ties, type 304 stainless steel.

1. Manufacturer: Hohmann & Barnard

2. Model: Flexible Tie

3. Type: #345 bynatie with seismiclip

C. Corrugated brick veneer anchors for Tower corner reconstruction, type 304 stainless steel.

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1. Manufacturer: Heckmann

2. Type: #340-B

D. Threaded rod dowel anchors Type 304 stainless steel threaded rod, set in epoxy for window sill spall repair.

1. Epoxy: Sikadur Injection Gel, manufactured by Sika Corporation. Furnish in manufacturer's co-axial cartridges.

E. Anchors for wall ties: for securement of wall tie anchors to existing masonry, use TAPCON manufactured by Buildex division of Illinois Tool Works;

1. Diameter: ¼ inch

2. Minimum embedment – 1 inch

3. Head type: slotted hex washer head

a. Predrill holes into substrate using only BUILDEX carbide tipped drills designed for this purpose

2.04 Material for Window Sill Spall Repair, and Replacement Mortar Washes

A. Patching mortar shall be JAHN M70 furnished by Cathedral Stone Products, Inc., 7266 Park Circle Drive, Hanover, MD 21076 (800) 684-0901

2.05 Pointing Material for False Column Capitals

A. Mortar for pointing joints in false column capitals shall be JAHN M110 furnished by Cathedral Stone Products, Inc., 7266 Park Circle Drive, Hanover, MD 21076 (800) 684-0901.

Part 3 - Execution

3.01 Product Testing (Masonry Units)

A. Testing of masonry units, as specified under SUBMITTALS, shall be completed and accepted by the Architect prior to installation work.

3.02 Removals – Brick

A. Whenever practical, removals made adjacent to brick to remain shall be racked back, not toothed.

1. Existing brick if not damaged may be reused at the discretion of the Architect.

B. Thoroughly clean out all loose brick or mortar particles, sand, dust, and the like.

1. All mortar shall be removed from the ends, tops, and bottoms of brick intended to remain.

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C. Do not damage existing bricks, wall reinforcement, flashing or other materials intended to remain.

3.03 Shoring

A. It is the responsibility of the Contractor to design and carry out shoring procedures sufficient to comply with applicable regulations, securely support all masonry or other elements left unsupported by the required removals, and permit the work of other trades to proceed.

1. Ensure that shoring procedures are submitted to the Architect in advance as specified in 1.02.B above.

2. If cracks occur in mortar joints of brick intended to remain, cut out the damaged joint area and repoint it after removal of shoring.

3. Point all holes left in mortar by withdrawal of shoring fastenings.

4. Completely remove shoring system when no longer needed.

5. Notify the Owner 48 hours in advance of installation of shoring.

6. Ensure that shoring complies with submittal bearing the seal of licensed Professional Engineer as specified in 1.02.B above.

3.04 Mortar for Repointing

A. Mortar proportions by volume: 1 part Portland cement, 2 parts hydrated lime, and 9 parts and. This is a type "O" mortar per ASTM C270.

B. Mix mortar by machine. Empty mortar container and clean out moist or loose dry mortar before charging.

1. Empty preblended mortar mix bags into machine and add water to bring to required plasticity and consistency for use. Mix 4-6 minutes rather than 3-5 minutes to ensure proper wetting of the oven-dry sand.

2. Discard all mortar older than 2-1/2 hours.

3. Do not retemper colored mortar.

3.05 Mortar for Reconstruction (Alternate 2)

A. Mortar proportions by volume: 1 part Portland cement, 1-1/4 parts hydrated lime, and 6 parts and. This is a type "N" mortar per ASTM C270.

B. Mix mortar by machine. Empty mortar container and clean out moist or loose dry mortar before charging.

C. Empty preblended mortar mix bags into machine and add water to bring to required plasticity and consistency for use. Mix 4-6 minutes rather than 3-5 minutes to ensure proper wetting of the oven-dry sand.

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D. Discard all mortar older than 2-1/2 hours.

E. Do not retemper.

3.06 Masonry Setting – Brick

A. For brick with an initial rate of absorption (per ASTM C67) in excess of 30 mg/30 sq. in./in.: drench brick with water 24 hours prior to use so that they are saturated, surface dry. In hot, dry weather drench brick 3 hours prior to use.

B. Lay all masonry true to line and dimensions, plumb and square, following existing coursing.

C. Hot Weather (as defined in Part 1 above): Spread mortar beds not more than 4 feet ahead of masonry units. Lay masonry unit within 1 minute of spreading mortar. Protect mortar in tubs from the effects of wind and temperature. Do not allow mortar temperature to exceed 120 degrees F.

D. For courses of new brick: do not furrow bed joints. Butter ends of brick with sufficient mortar to fill the head joints.

1. Shove mortar beds and heads to level units in true alignment with the course plane and to eliminate any front-to-rear bevel.

2. Equalize horizontal and vertical joints.

3. Place brick in correct alignment; do not move brick after mortar has begun to set.

E. For course of new brick adjacent to existing brick above: at the top course of new work, do not apply mortar to the brick unit to be set. Mortar the underside of the existing course above, and the top and ends of brick already in place.

1. Add, by pointing, additional mortar as required to develop fully packed bed, head, and vertical joints.

F. Tool joints when mortar is "thumb-print-hard", or, alternatively, when sufficient water has left the mortar to allow tooling without bringing excessive past to the surface.

1. Tool the joints, by hard shoving, to a coved joint edging the brick either side of the joint.

2. Joints shall match the existing joints in size and profile.

G. Visually inspect the Work and correct items not conforming to the Contract Documents, including cutting out and pointing all defective mortar joints. Ensure that weep holes or weep tubes are not plugged.

3.07 Installation of Reinforcement, Ties, and Anchors at Tower Corners

A. Install joint reinforcement on masonry joints at every 3 courses of brick

1. Lap reinforcement at horizontal splices a minimum of 6 inches.

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B. Install brick veneer anchors every three courses of brick.

3.08 Mortar Removals and Repointing of Existing Joints

A. Cut out existing mortar joints to a depth of 1/2 inch (minimum) for joints 1/8 inch or smaller and ¾ inch for joints larger than 1/8 inch.

B. Use grinding wheels or saws. Cut vertical joints prior to cutting horizontal joints. Chisel fillets of mortar left from the blade's curve at head joints and corners.

1. Contractor shall take extreme care to prevent damage to existing masonry units that are to remain. The use of guides or jigs is recommended.

C. During removals, controlled dampening to reduce dust generation and airborne particulate matter will be permitted.

1. Cleaning of slurry on façade will be required if water is used.

D. After mortar removals are complete, thoroughly clean out all loose particles, sand, dust, and the like using fiber brushes and compressed air.

E. Completely wet the cut masonry joint with a tank sprayer pressurized with a hand pump. Remove any remaining water with a blast of compressed air.

F. Point the joints solid to the full depth of the joint using a tuck-pointing trowel or jointing tool.

G. Dress the joint to match the finish of joints in adjacent existing work.

3.09 Replacement of Damaged Brick

A. Remove loose, spalled, and cracked brick and replace with new.

1. Loose bricks: bricks that can be moved out of the wall plane by hand pressure.

B. Brick units to be removed and replaced shall have the vertical mortar joint, on each side of it, saw cut before the horizontal joints are disturbed.

1. Completely clean out mortar joints to expose the edges of the brick remaining in place.

2. Thoroughly clean all loose brick and mortar dust out of the opening.

C. Prior to installing new brick, dampen the faces of the opening and moisten the new brick unit.

D. Place mortar on the ends of the new brick, lay a mortar bed in the opening, and set the new unit in position shoving the mortar bed to level the brick in true alignment and to eliminate any front-to-rear bevel.

1. Shove the vertical joints to equalize joint width on either side. Add, by pointing, additional mortar to develop fully packed vertical joints.

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2. Point and hard shove the upper horizontal joint full of mortar.

E. Tool joints when mortar is "thumb-print hard", or, alternatively, when sufficient water has left the mortar to allow tooling without bringing excessive paste to the surface. Tool the joints, by hard shoving, to a coved joint edging the brick either side of the joint.

F. Completely remove mortar from brick faces and from adjacent wall, following procedures outlined below in article "Cleaning".

3.10 Reconstruction of Tower Corners

A. Contractor shall submit proposed method of reconstruction of towere corners to Architect prior to beginning work.

1. Submittal shall include all temporary support of masonry and necessary structural support of building required to complete the work and shall be signed and sealed by a Professional Engineer licensed in the State of Massachusetts.

B. Remove brick at Tower corners working on only one corner at a time.

1. No more than 4 courses of brick may be removed at any one time.

2. Removals shall be stepped to maintain bearing for brick to remain.

3. Contractor shall take care not to damage masonry to remain

4. Ensure that new mortar is fully cured before removing additional courses of brick in the same corner.

C. Brick units to be removed and replaced shall have the vertical mortar joint, on each side of it, saw cut before the horizontal joints are disturbed.

1. Completely clean out mortar joints to expose the edges of the brick remaining in place.

2. Thoroughly clean all loose brick and mortar dust out of the opening.

D. Prior to installing new brick, dampen the faces of the opening and moisten the new brick unit.

E. Place mortar on the ends of the new brick, lay a mortar bed in the opening, and set the new unit in position shoving the mortar bed to level the brick in true alignment and to eliminate any front-to-rear bevel.

1. Shove the vertical joints to equalize joint width on either side. Add, by pointing, additional mortar to develop fully packed vertical joints.

2. Point and hard shove the upper horizontal joint full of mortar.

F. Tool joints when mortar is "thumb-print hard", or, alternatively, when sufficient water has left the mortar to allow tooling without bringing excessive paste to the surface. Tool the joints, by hard shoving, to a coved joint edging the brick either side of the joint.

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G. Completely remove mortar from brick faces and from adjacent wall, following procedures outlined below in article "Cleaning"

3.11 Reconstruction of Brick Façade (Alternate 2)

A. Prior to beginning reconstruction of select areas of the brick façade, contractor shall survey entire areas to be reconstructed and notify the Architect of any discrepancies or hazardous conditions.

B. Contractor shall erect temporary support and protection for all areas of the brick to remain.

1. Submit shop drawings of proposed method of support for each location signed and sealed by a Professional Engineer licensed in the State of Massachussetts

C. Remove and store windows in areas where brick façade reconstruction is to be performed. Provide a temporary weathertight enclosure where windows have been removed.

D. Brick units to be removed and replaced shall have the vertical mortar joint, on each side of it, saw cut before the horizontal joints are disturbed.

1. Completely clean out mortar joints to expose the edges of the brick remaining in place.

2. Thoroughly clean all loose brick and mortar dust out of the opening.

E. Prior to installing new brick, dampen the faces of the opening and moisten the new brick unit.

F. Place mortar on the ends of the new brick, lay a mortar bed in the opening, and set the new unit in position shoving the mortar bed to level the brick in true alignment and to eliminate any front-to-rear bevel.

1. Shove the vertical joints to equalize joint width on either side. Add, by pointing, additional mortar to develop fully packed vertical joints.

2. Point and hard shove the upper horizontal joint full of mortar.

G. Tool joints when mortar is "thumb-print hard", or, alternatively, when sufficient water has left the mortar to allow tooling without bringing excessive paste to the surface. Tool the joints, by hard shoving, to a coved joint edging the brick either side of the joint.

H. Completely remove mortar from brick faces and from adjacent wall, following procedures outlined below in article "Cleaning"

3.12 Cleaning

A. Perform daily clean up of fallen debris, mortar droppings, sand, dirt, and rubbish to the satisfaction of the Owner.

1. Remove mortar droppings on porous surfaces such as brick with a wood scraper after initial set has occurred. Remove mortar droppings from smooth surfaces

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with a wet rag or burlap immediately before any set has occurred. Perform removals of mortar droppings continuously as the work progresses.

a. Final cleaning of new with Light Duty Restoration Cleaner by Prosoco.

B. Thoroughly inspect all brick surfaces to be left exposed in the finished Work and spot clean soiled areas.

End of Section 04 01 20 - Brick Restoration

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7.3.3 Roof Guidelines

Division 7 – Thermal and Moisture Protection

Section 07 31 00 – Slate Shingles

Part 1 - General

1.01 Description

A. The principal items of work are related to the installation of a new slate roofing system at all roofs, mansard faces, corner tower faces, main tower faces, daily seals, work called for by the Drawings, and other work necessitated by these operations.

1.02 Quality Assurance

A. The contractor shall submit in writing evidence to demonstrate experience of work on a minimum of 5 projects of historic significance.

B. The Contractor shall have not less than 10 years of experience in slate roof installation.

C. Personnel engaged in and about the work shall be skilled and experienced roofers who will fit and fasten each slate.

1. The foreman of the crew shall have had at least 10 years experience in work of similar nature and scope.

1.03 Definitions

A. "end of the work day": Time when work is stopped for any reason; either completion of planned hours of work or early termination due to weather or other causes.

1.04 Submittals

A. Submit list of all materials proposed for use. Submit technical data sheet for slate shingles and each manufactured product.

B. Submit shop drawings of slate installation at roof edges, valleys, hips and ridges.

C. Submit a minimum of 3 sample slate shingles showing the full range of color ans texture. Samples shall be full sized slates.

D. Submit samples of roofing felt.

E. Submit sample of ice and water barrier.

F. Submit test results from an independent testing laboratory for the following:

1. ASTM C120: Test Method for Flexural Testing of Slate

2. ASTM C121: Test Method for Water Absorption of Slate

3. ASTM C217: Test Method for Weather Resistance of Slate

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1.05 Delivery, Storage and Handling

A. Immediately upon delivery of slate to jobsite, place them on planks, skids, or framework which is level and not less than 4-inches above the ground.

B. Slates shall be laid horizontally to a height not exceeding 12-inches per layer.

C. Cover slate with coated roofing felt, weighted down.

D. Materials shall not be stored on the roof deck in such a manner as to overstress and/ or damage the deck and the supporting structure. Placing of loads at mid-spans of framing shall be avoided. Superimposed loads shall be well distributed.

1.06 Sequencing

A. The work shall be organized such that units of work are established. Removal of existing materials, preparation of substrates, installation of membranes and underlayments, and the installation of a temporary or the permanent flashings shall be completed as a unit for a predetermined area of the roof.

1.07 Temporary Protection Materials

A. Materials shall be provided and maintained on the site at all times for temporary roofing, flashing, and other protection when delays or changed weather conditions do not permit the completion of a work units as described in Section 1.06 above.

1.08 Reference Standards

A. ASTM C120 – Test Method for Flexural Testing of Slate.

B. ASTM C121 – Test Method for Water Absorption of Slate.

C. ASTM C217 – Test Method for Water Resistance of Slate.

D. ASTM C406 – Roofing Slate.

E. ASTM D226 – Asphalt Saturated Organic Felt used in Roofing and Waterproofing.

F. National Slate Association: Slate roofs 1925 (1977).

G. NRCA Roofing and Waterproofing Manual – Fourth Edition

1.09 Warranty

A. The contractor shall provide a written "materials and workmanship" warranty, including weathertightness and weatherproofness, for all Work performed under this section.

   1. Warranty shall be for a period for <u>2-years</u> from the Architect's final inspection and acceptance of the work.

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Part 2 - Products

2.01 Slate

A. Roofing slate shall be commercial standard roofing slate, grade S-1 shingles.

1. Approved suppliers:

   a. Camara Slate Company, 963 South Main Street, Fair Haven, Vermont, 802-265-3200

   b. New England Slate Company, 363 Vermont Route 30 South, Poultney, Vermont, 802-287-2295.

   c. The Vermont Structural Slate Company, 3 Prospect Street, Fair Haven, Vermont, 800-343-1900.

2. Colors: to match existing

3. Size: to match existing

   a. Standard rectangular shape at hip roof and corner tower roofs

   b. Fish scale shape at mansard roofs

4. Thickness: ¼" to 3/8"

5. Texture: Smooth

6. Exposure: to match existing

7. Headlap: 3inches typical

B. All slate shall be hard, dense, sound and punched. **Drilled slates will not be accepted.**

C. Slates less than to 3/4-inch thick or 20-inches in length shall have two nail holes.

D. Slates with broken corners on the exposed ends shall not be installed when either the base or leg of the right triangular piece broken off is greater than 1 ½". Slate with broken corners are acceptable for cutting stock.

E. Knots or Knurl are rounded defects that affect the smoothness of split. They are acceptable on the exposed portion of the top face but on other parts will prevent the close contact of shingles. Shingles having knots or knurls on the covered portions projecting in excess of 1/16" shall not be used if they prevent proper fit and contact.

F. The curvature of shingles shall not exceed 1/8" in 12 inches. Curved slates shall be trimmed and holed to permit them to be laid with the convex side facing up.

G. Slates shall be free from ribbons.

H. Face dimensions shall not differ from those specified by more than 1/8"

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I. Not more than 1% of broken slates, including those having cracks materially precluding ringing when sounded, shall be accepted.

J. Slates with a strong grain must be produced "on the grain," that is, the direction of the grain of the stone must be parallel to the long dimension of the shingle. Slates shall be randomly selected from each shipment and tested for grain direction to ensure proper fabrication.

K. Performance Standards

1. Absorption: 0.25% maximum.

2. Depth of Softening: 0.002 in. maximum.

L. Modulus of Rupture: 9,000 psi minimum.

M. The owner shall be furnished with a stock of 2% extra slates for future roof repairs.

2.02 Nails

A. Nails for use with slate shall be copper wire, flat head slating nails with diamond point and barbed shaft.

1. Gauge:

a. 11 gauge minimum for roofing slates

b. 9 gauge minimum for wall slates.

B. Length: sufficient for 1-1/2-inches minimum penetration into roof or wall sheathing.

C. Head size: ¼ inch diameter

2.03 Ice and Water Barrier

A. Self-adhering membrane of rubberized asphalt integrally bonded to polyethylene sheeting.

1. Ultra by W.R. Grace and Company

a. Mastic shall be Bituthene Mastic.

b. Primer for use on masonry surfaces shall be Bituthene P-3000.

2.04 Roofing Felt Underlayment

A. Slope Shield by Vapro Shield LLC. 866-731-7663. www.vaproshield.com

2.05 Cement

A. Waterproof Elastic Slater's cement shall be approved by the National Slate Association.

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1. Rain Buster 850 by Top Industrial, Inc. 800-473-1617

   a. Color: gray

Part 3 - Execution

3.01 Inspection

A. Examine the substrates and conditions under which work is to be installed. Do not proceed with work until unsatisfactory conditions have been corrected.

3.02 Ice and Water Barrier (membrane)

A. Install membrane on dry surfaces in fair weather when surface and air temperature is greater than 40 degrees F.

B. Remove all dirt, dust, loose nails or other protrusions from surfaces to which membrane is to be installed.

   1. Prime all masonry or concrete surfaces to which membrane is to be installed.

C. Install membrane in strict accordance with manufacturer's printed application procedures, precautions and limitations.

D. Precut membrane to facilitate installation.

E. Remove release paper and install membrane onto the roof decking.

   1. Work from low point to high point of roof.

   2. Overlap side laps a minimum of 4-inches.

   3. Overlap end laps a minimum of 6-inches.

F. Roll membrane onto surface with a steel roller, using firm, positive pressure to ensure full adherence to substrate. Do not stretch membrane.

3.03 Roofing Felt

A. Roofing felt shall be laid in horizontal layers in shingle fashion and well secured along laps and ends to properly hold felt and protect the structure until covered by the slate.

B. Roofing felt shall overlap a minimum of 12" at all ridges and hips to form double thickness.

C. Roofing felt shall overlap a minimum of 2" at all valleys.

D. Roofing felt shall extend over membrane ice and water barrier.

3.04 Slate Installation

A. Slate shall be installed to match existing pattern from the eave to the ridge.

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B. Install slate so that no through joints occur from the roof surface to the felt paper.

1. Center joints in slate on underlying slate.

2. Joints may not be less than 3-inches from any underlying joint.

C. Slate shall overlap the course below to match existing.

D. Exposure of slate shall match existing.

E. Where hand punching of holes in slate is required, holes are to be punched from the underside of the slate, using a hand or maul punch and slater's hammer.

F. All cutting and punching shall be done on a slater's stake.

G. Exposed nail heads are not permissible except at the top course where this is unavoidable Exposed nail heads shall be covered with elastic cement Ridge slates shall be laid in elastic cement spread thickly over unexposed surface of under courses, nailed securely in place, and pointed with elastic cement

H. In setting nails, head should touch the slate and should not be driven "home" or draw the slate, but left with heads just clearing the slate so that the slate hangs on the nail.

3.05 Starter Course

A. Install slate starter course at the eave of the roof.

1. Length of starter course shall be full length of slate less the length of exposure.

2. Starter slate shall be installed upside down (chamfered edge down).

3.06 Ridges

A. Ridges shall be laid with copper ridge cap fabrication as specified in Section 07 60 00.

3.07 Valleys

Valleys shall be laid to form open valleys by laying the slate to overlap the copper flashing a minimum of 6".

3.08 Copper capped hip (main roof)

A. Hips shall be laid with copper cap fabrication as specified in Section 07 60 00.

3.09 Slate Hip (Mitered Hip) at Corner Towers

A. Inspect substrate and install wood batten strips / nailers as required by new hip installation. Use pressure treated wood.

B. Install new saddle hip slates so that their edges butt at the ridge line. Saddle hip slates shall be installed over new copper step flashing.

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C. New copper step flashings shall be formed into a V shape where each leg of the V covers each side of the hip.

D. The bottom of the step flashing piece shall be placed over the top of the downhill slate and under the bottom of the uphill slate

E. Step flashings shall be secured into place as slates are nailed above them. No copper step flashing shall be exposed when the hip is complete.

F. Hip slates shall have a 3" head lap.

Do not seal butt joint of completed hip. The use of slaters cement shall be limited. Do not set hip in a full bed of sealant.

3.10 Cleaning

A. Perform daily clean up of all waste and debris resulting from these operations.

End of Section

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7.3.4 Exterior Finishes Guidelines

Division 6 – Wood and Plastics, and Composites

Section 06 45 20 – Exterior Finish Carpentry

Part 1 - General

1.01 Description

A. The principal items of work are related to the replacement of exterior wood siding and decorative moldings and elements including but not limited to cornice and fascia moldings, pilasters, capitals, quoins, casings, balusters and keystones with new wood elements,work called for by the Drawings and other work necessitated by the operations.

B. All new moldings, ornament, and decorative elements shall be fabricated to match the profiles and sizes of the existing.

1.02 Definitions

A. Lumber grading agencies, and the abbreviations used to reference the, include the following:

1. NeLMA: Northeastern Lumber Manufacturer's Association
2. NLGA: National Lumber Grades Authority
3. RIS: Redwood Inspection Service
4. SPIB: The Southern Pine Inspection Bureau
5. WCLIB: West Coast Lumber Inspection Bureau
6. WWPA: Western Wood Products Association
7. SCS Systems: Certification of recycled content

1.03 Submittals

A. Submit list of all materials proposed for use. Submit technical data sheet for each manufactured product.

B. Submit samples of wood trim to be used for window sills, jambs, and casings.

C. Submit full size shop drawings of all decorative moldings and elements showing profiles, dimensions, and installation methods.

1.04 Reference Standards

A. Architectural Woodwork Institute (AWI): Architectural Woodwork Quality Standards Guide.

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1.05 Quality Assurance

A. Ensure that all personnel engaged in the Work of this section are qualified carpenter journeymen, who may be assisted by carpenter apprentices qualifying for their journeyman status.

1. Common labor may be used for tasks not requiring journeyman skills.

2. Ensure that the foreman of the crew has had at least five years experience in work of similar nature and scope.

3. Ensure that the foreman of the crew is on site while the work of this section is in progress.

1.06 Delivery, Storage and Handling

A. Protect wood during transit, delivery, storage and handling to prevent damage, soiling and deterioration.

B. Keep all products dry. Store materials 6 inches minimum above the ground surface. Protect against exposure to weather and contact with damp or wet surfaces.

1. Cover stored materials until ready for use. Place and anchor covering in a manner to assure adequate ventilation under the covering.

C. Deliver all packages in original manufacturer's unopened packaging.

D. Protect materials from high temperatures from storage within job trailers that are exposed to direct sun.

E. Protect uncoated portions of urethane products from ultraviolet exposure.

1.07 Job Conditions

A. Weather Limitations: Proceed with installation of exterior finish carpentry only when existing and forecasted weather conditions will permit work to be performed at least one coat of specified finish applied without exposure to rain, snow or dampness.

B. Field Measurements: Where finish carpentry is to be filled to existing construction, verify actual dimensions of existing conditions prior to fabrication of new woodwork.

C. Protect installed work from damage by other trades until final acceptance of all work by the Owner.

1. Any woodwork having mars, cuts scratches or visual imperfections of any kind will not be accepted.

1.08 Warranty

A. The manufacturer of all cellular PVC and urethane components shall be warranted free of manufacturing defects for the lifetime of the installation.

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Part 2 - Products

2.01 General Material and Fabrication Requirements

A. All millwork is to be fabricated to match the dimensions, profiles, and details of the materials to be replaced.

B. All wood shall be thoroughly seasoned and kiln dried.

C. All wood shall be clear on all exposed faces and edges, free of checks, cracks or other blemishes that would mar the appearance of the installed wood.

2.02 Exterior Wood Products

A. Spanish or Western Red Cedar

1. Grade B Clear

2.03 Fasteners - Wood

A. Nails shall be size and type to suit application.

1. All nails shall be stainless steel.

B. Screws shall be of size and type to suit application.

1. All screws shall be stainless steel.

Part 3 - Execution

3.01 Examination

A. Examine all substrate conditions and surfaces upon which finish woodwork is to be installed. Do not proceed with finished woodwork until unsatisfactory substrate conditions have been corrected.

3.02 Preparation – Wood Materials

A. Remove existing items to be reinstalled. Remove items to avoid damage. Protect during removal, storage, handling and reinstallation.

1. Replace all woodwork damaged during removals, storage and reinstallation at no cost to the Owner.

B. Back prime all woodwork (that is not prefinished in the shop) on all surfaces that will be concealed with two coats of wood primer specified in Section 09 90 00.

C. Exposed ends as a result of saw cutting shall receive 1 coat of primer prior to installation of the wood element.

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3.03 Installation - Wood

A. Install woodwork plumb, level and free of distortion. Shim where required with concealed shims.

B. Provide tight joints to conceal shrinkage.

1. Miter exterior joints.

2. Cope interior joints.

3. Fit butt joints with concealed spine.

C. Molding profiles shall match existing. Shop drawings are required.

D. Fastening:

1. Fasteners shall be hand nailed, power nailed, or screwed.

a. Power nailing: Adjust nailing gun to prevent excessive nailing pressure or over drilling the nail. Adjust for ambient and material temperatures.

2. Pre-drill material as necessary to avoid splitting.

3. Ring shank nails shall not be used.

4. Fasteners shall be long enough to penetrate a 1-1/2 inch solid wood substrate a minimum of 1-1/2 inch.

5. Staples, small brads, and wore nails shall not be used to fasten members.

6. Fasten trim into a flat, solid wood substrate. Do not fasten trim into a hollow substrate.

E. Fastener Schedule:

1. Fasteners shall be fastened 16 inches on center, maximum, along the length of a board.

2. Fasteners shall be fastened 4 inches on center, maximum, along the width of the board.

3. Fasteners shall not exceed more than 2 inches from the end of each board.

4. Trimboards over 12 inches or wider, as well as sheets, will require additional fasteners.

F. Blind nail finish work to the greatest extent possible. Where surface nailing is used, set and fill nails to match adjacent wood.

G. Sand unstained wood surfaces to produce a uniform smooth surface. Always sand in the direction of the wood grain.

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3.04 Cleaning

A. Do not perform wood cutting operations on new roofing.

B. Clean up all debris promptly so that other operations may be performed in the work area.

End of Section 06 45 20

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7.4 Structural Analysis

7.4.1 Dead and Live Load Analysis Calculations

Gravity Loads

Dead loads

1" board = 3psf
1/4" slate = 10psf
Douglas Fir timber frame = 34.75psf
brick = 38 psf
lightweight concrete = 10 psf
1/4" linoleum = 1.0 psf
ceiling = 1.0 psf
MEP = 5.0 psf
insulation = 2.0 psf

Live Loads

classroom = 50 psf
open plan area = 100 psf

Snow Load = 35 psf
35(.29) = 10.15 lb/ft = W_S

Roof dead load (W_{DR}) = 1" board = 3.0 psf
1/4" slate = 10 psf
douglas fir timber frame = 34.75 psf
ceiling = 1.0 psf
MEP = 5.0 psf
insulation = 2.0 psf

W_{DR} = 55.75 psf × (0.29 ft) = 16.17 lb/ft
W_{DR} = 16.17 lb/ft

Floor 3 dead load (W_{D3}) = ceiling = 1.0 psf
MEP = 5.0 psf
insulation = 2.0 psf
1/4" linoleum = 1.0 psf
lightweight concrete = 10 psf
brick = 38 psf

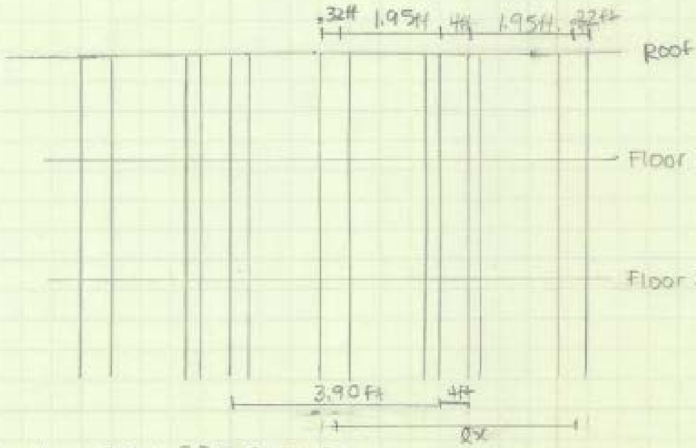
W_{D3} = 57 psf × (0.29 ft) = 16.53 lb/ft
W_{D3} = 16.53 lb/ft

Floor 2 dead load (W_{D2}) = ceiling = 1.0 psf
MEP = 5.0 psf
insulation = 2.0 psf
1/4" linoleum = 1.0 psf
lightweight concrete = 10 psf
brick = 38 psf

W_{D2} = 57 psf × (0.29 ft) = 16.53 ft
W_{D2} = 16.53 ft

W_{L3} = (50 psf + 100 psf) × (0.29 ft) = 43.5 lb/ft
W_{L2} = 43.5 lb/ft

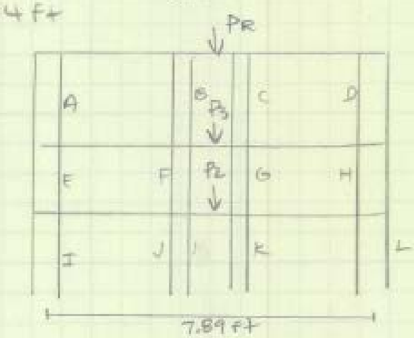
$W_R = 1.2W_{DR} + 1.6W_S$ = 1.2(16.17 lb/ft) + 1.6(10.15 lb/ft) = 35.64 lb/ft
$W_3 = 1.2W_{D3} + 1.6W_{L3}$ = 1.2(16.53 lb/ft) + 1.6(43.5 lb/ft) = 89.44 lb/ft
$W_2 = 1.2W_{D2} + 1.6W_{L2}$ = 1.2(16.53 lb/ft) + 1.6(43.5 lb/ft) = 89.44 lb/ft



$.32+1.95+4+1.95+.32 = 8.54\text{ ft}$

$8.54-.65 = 7.89\text{ ft}$

$\ell_x = 7.89\text{ ft}$



$w_R(\ell x) = 35.64\text{ lb/ft}(7.89\text{ ft})$

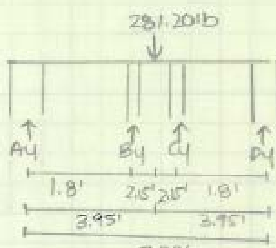
$P_R = 281.20\text{ lb}$

$w_3 = 89.44\text{ lb/ft}(7.89\text{ ft})$

$P_3 = 705.68\text{ lb}$

$w_2 = 89.44\text{ lb/ft}(7.89\text{ ft})$

$P_2 = 705.68\text{ lb}$



$\curvearrowleft + \Sigma M_A = 0 = -1.8\text{ ft}(B_y) + 281.20\text{ lb}(3.95\text{ ft}) - 6.1\text{ ft}(C_y) - D_y(7.89\text{ ft})$

$C_y = 2.15/3.95\ D_y$

$A_y = D_y$

$B_y = C_y$

$\curvearrowleft + \Sigma M_A = 0 = -1.8\text{ ft}(2.15/3.95\ D_y) + 281.20\text{ lb}(3.95\text{ ft}) - 6.1\text{ ft}(2.15/3.95\ D_y) - 7.89\text{ ft}\ D_y$

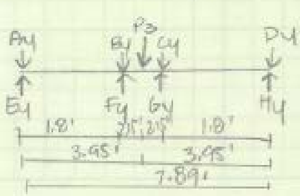
$1110.74 = 12.19\ D_y$

$D_y = 91.12\text{ lb}$

$A_y = 91.12\text{ lb}$

$B_y = 49.60\text{ lb}$

$C_y = 49.60\text{ lb}$



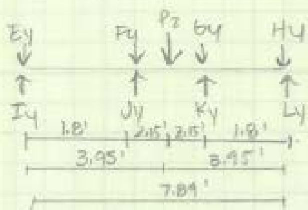
$\curvearrowleft + \Sigma M_E = 0 = (B_y = 49.60\text{ lb})(1.8\text{ ft}) - E_y(1.8\text{ ft}) + (705.68\text{ lb})(3.95\text{ ft}) + (C_y = 49.60\text{ lb})(6.1\text{ ft}) - G_y(6.1\text{ ft}) + (D_y = 91.12\text{ lb})(7.89\text{ ft}) - H_y(7.89\text{ ft})$

TOPS 35500

$G_y = 2.15/3.95\, H_y$
$E_y = H_y$
$F_y = G_y$

$\Sigma M_E = 0 = (B_y = 49.60)(1.8) - 1.8(2.15/3.95\, H_y) + (705.68)(3.95) + (C_y = 49.60)(6.1) - 6.1(2.15/3.95\, H_y) + (D_y = 91.12)(7.89) - 7.89 H_y$

$3898.2308 = 12.19 H_y$
$H_y = 319.79\ lb$
$E_y = 319.79\ lb$
$F_y = 174.06\ lb$
$G_y = 174.06\ lb$

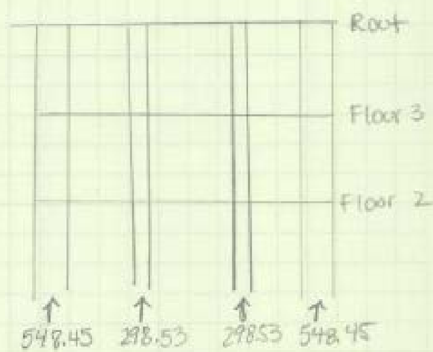


$\Sigma M_I = 0 = (F_y = 174.06\,lb)(1.8\,ft) - J_y(1.8\,ft) + (705.68\,lb)(3.95\,ft) + (G_y = 174.06\,lb)(6.1\,ft) - K_y(6.1\,ft) + (H_y = 319.79\,lb)(7.89\,ft) - L_y(7.89\,ft)$

$I_y = L_y$
$J_y = (2.15/3.95) L_y$
$J_y = K_y$

$\Sigma M_I = 0 = (F_y = 174.06)(1.8) - 1.8(2.15/3.95\, L_y) + (705.68)(3.95) + (G_y = 174.06)(6.1) - (6.1)(2.15/3.95\, L_y) + (H_y = 319.79)(7.89) - L_y(7.89)$

$6685.65 = 12.19 L_y$
$L_y = 548.45\ lb$
$I_y = 548.45\ lb$
$J_y = 298.53\ lb$
$K_y = 298.53\ lb$



7.4.2 Seismic Analysis Calculations

Seismic Load Calculations

Seismic Loading Calculations

From ASCE 7, Chapter 22 Contour Maps:

$S_S = 18 \Rightarrow .18$ $S_1 = 7 \Rightarrow .07$

From ASCE 7 Chapter 20

Site class = D (default site class) (glacial till)

From ASCE 7 Section 11.4.3
$F_a = 1.6$ $F_v = 2.4$

$S_{MS} = F_a S_S = (1.6)(.18)$
$S_{MS} = .288$

$S_{M1} = F_v S_1 = (2.4)(.07)$
$S_{M1} = .168$

$S_{DS} = 2/3\, S_{MS} = 2/3(.288)$
$S_{DS} = .192$

$S_{D1} = 2/3\, S_{M1} = 2/3(.168)$
$S_{D1} = .112$

$T_a = (.0019/\sqrt{C_W})\, h_n$

$C_W = (100/A_B) \sum_{i=1}^{x} (h_n/h_i)^2 \left(A_i / 1 + 0.83(h_i/D_i)^2\right)$

*see spreadsheet for Cw calculation

$C_W = (100/7053.76)(45280.11) = 641.93$

$T_a = (0.0019/\sqrt{641.93})(53) = .00397 = .004$
$T_0 = 0.2\, S_{D1}/S_{DS} = 0.2(.112/.192) = .116$
T_L according to figure 22-12 $T_L = .06$

$T_a = T$
$T_a = .004 < T_0 = .116 \therefore S_a = S_{DS}(.4 + .6(T/T_0))$
$S_a = .192(.4 + .6(.004/.116)) = .08077 = .08$
$S_a = .08$

From table 1.5-2 ASCE 7
importance factors

$I_S = 1.0$ (snow)
$I_i = 1.0$ (ice)
$I_W = 1.0$ (ice for wind)
$I_e = 1.0$ (seismic)

from table 12.2-1 : seismic force resisting system = ordinary plain masonry shear walls

2

R_a = 1 1/2
Ω_0 g = 2 1/2
C_d = 1 1/4
h_n limitation = NL (no limits)

Cs = SDS / (R/Ie) = .192/(1.5/1.0) = .128

Check Cs = Ta = .004 ≤ T_L = .06 ✓ → use C_s = SD1/T(R/Ie)
Cs = .112/(.004)(1.5/1.0) = 18.6
.128 < 18.6 ✓
Cs = .044 SDS Ie ≥ .01 = .044(.192)(1.0) = .008 → use .01

Where S1 < .75   S1 = .07 < .75 ✓ then use table 11.6-1 if
1. Ta < .08 Ts   Ta = .004 < .8(.583) = .4664
.004 < .4664 ✓
2. Ta < Ts ✓
3. Cs was found using Cs = SDS/(R/Ie) ✓

From table 11.6-1
SDS = .192   0.167 ≤ .192 < .33
risk category II
use design category B

According to section 12.3.1.1 → can be idealized as flexible diaphragm because it is a masonry shear wall.

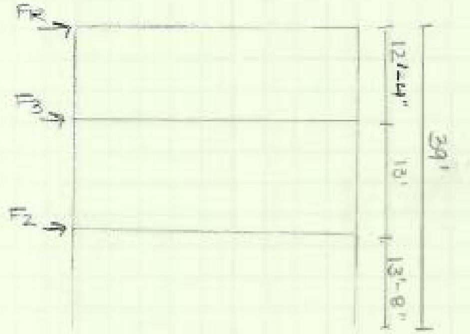
redundancy ρ = 1.0 because seismic design category B

vertical distribution of seismic forces:
Fx = Cvx V
$C_{vx} = (w_x h_x^k) / \sum_{i=1}^{n} w_i h_i^k$

*see spread sheet.

V = Cs W

W = 825.89 K   Cs = .128
V = Cs Ws = (.128)(825.89) = 105.71 K



FR = 62.22 K
F3 = 30.73 K
F2 = 12.76 K

Cw Calculations

Wall	Ai (ft2)	Di (ft)	hi (ft)	hn (ft)	((hn/hi)^2)(Ai/(1+0.83(hi/Di)^2))
1	224	22.5	9.5	53	6073.286044
2	1122.12	41.64	26.67	53	3305.840218
3	646.12	34.51	26.67	53	1705.961919
4	144.55	9.5	26.67	53	75.69486934
5	406.16	37.33	9.5	53	11996.71986
6	482.84	25.49	26.67	53	999.05282
7	224.05	10	26.67	53	128.164834
8	156.05	9.5	26.67	53	81.71694472
9	75.51	3.06	24.67	53	6.34260694
10	168.29	3.06	54.99	53	0.581062299
11	63.22	5.62	11.25	53	324.3573144
12	127.29	5.62	22.64	53	48.20957435
13	116.62	6.55	17.8	53	145.0162652
14	130.97	6.55	20	53	105.2513897
15	97.52	5.62	17.35	53	102.1277982
16	172.34	5.62	30.66	53	20.03593662
17	156.05	9.5	26.67	53	81.71694472
18	197.05	9.5	26.67	53	103.1869526
19	613.41	23	26.67	53	1144.823804
20	143.47	9.5	26.67	53	75.12931791
21	561.47	32.08	26.67	53	1409.03264
22	288.48	12.77	26.67	53	246.5772415
23	77	4	19.25	53	28.86269797
24	42.82	5.56	7.7	53	782.7125307
25	472.56	22.72	26.67	53	870.5648726
26	601.09	32.08	26.67	53	1508.460701
27	142.39	9.5	26.67	53	74.56376648
28	174.19	83.99	26.67	53	634.7814352
29	207.17	9.5	26.67	53	108.486379
30	812.35	34.51	26.67	53	2144.86189
31	381.45	35.01	9.5	53	11188.71166
				SUM	**45520.83229**
AB (ft^2)	7053.7				
100/AB	0.014177				
Cw	645.3469	rounded	Cw	645.35	

W Calculations

floor 2 loads			
wall	length of walls	height	trib area
1	26.33	13.67	359.93
2	21.75	13.67	297.32
3	18.83	13.67	257.41
4	13	13.67	177.71
5	10.58	13.67	144.63
6	13	13.67	177.71
7	10.25	13.67	140.12
8	13	13.67	177.71
9	10.83	13.67	148.05
10	13	13.67	177.71
11	22.92	13.67	313.32
12	13.08	13.67	178.8
13	13.08	13.67	178.8
14	13.08	13.67	178.8
15	33.83	13.67	462.46
16	12.17	13.67	166.36
17	5.42	13.67	74.091
18	2.67	13.67	36.499
19	5.17	13.67	70.674
20	7.08	13.67	96.784
21	20.17	13.67	275.72
22	2.5	13.67	34.175
23	5.5	13.67	75.185
24	20.33	13.67	277.91
25	4.33	13.67	59.191
26	3.33	13.67	45.521
27	15.67	13.67	214.21
28	3.83	13.67	52.356
29	7.67	13.67	104.85
30	15.42	13.67	210.79
31	15.42	13.67	210.79
32	7.5	13.67	102.53
33	7.42	13.67	101.43
34	15.42	13.67	210.79
35	4.67	13.67	63.839
36	19.08	13.67	260.82
37	11.67	13.67	159.53
38	10.42	13.67	142.44
39	33.33	13.67	455.62
40	12.83	13.67	175.39
41	12.08	13.67	165.13
42	12.08	13.67	165.13
		sum	7378.2
	movable partitions DL (psf)	15	
	partition DL (lb)	110674	
	partition DL (k)	110.67	

floor	
floor area (sf)	7053.7
light weight concrete weight (psf)	10
linoleum weight (psf)	1
ceiling area	7053.7
chanel suspended system (psf)	1
insulation (psf)	2
concrete DL (lb)	70537
concrete DL (k)	70.537
linoleum DL (lb)	7053.7
linoleum Dl (k)	7.0537
chanel suspended system DL (lb)	7053.7
chanel suspended system DL (k)	7.0537
insulation DL (lb)	14107
insulation DL (k)	14.107
sum	98.752
wx floor 2	209.43

floor 3						
wall	length of walls	height	trib area		floor area and loads same (k)	98.752
	9.17	13.67	125.35			
	16.75	13.67	228.97			
	9.17	13.67	125.35			
	133.42	13.67	1823.9			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	7	13.67	95.69			
	5	13.67	68.35			
	6.25	13.67	85.438			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	12.5	13.67	170.88			
	13	13.67	177.71			
	17.33	13.67	236.9			
	25.5	13.67	348.59			
	7.33	13.67	100.2			
	5.75	13.67	78.603			
	18.67	13.67	255.22			
	9.58	13.67	130.96			
	5.67	13.67	77.509			
	20.25	13.67	276.82			
	50.25	13.67	686.92			
	20.25	13.67	276.82			
	6	13.67	82.02			
	6	13.67	82.02			
	14	13.67	191.38			
	14.5	13.67	198.22			
	20.25	13.67	276.82			
	5.92	13.67	80.926			
	5.42	13.67	74.091			
	20.25	13.67	276.82			
	52.33	13.67	715.35			
	5.33	13.67	72.861			
	2.42	13.67	33.081			
	19.58	13.67	267.66			
	8.75	13.67	119.61			
	5.83	13.67	79.696			
	1.17	13.67	15.994			
	9.25	13.67	126.45			
	20.08	13.67	274.49			
	23.17	13.67	316.73			
	5.75	13.67	78.603			
	5.75	13.67	78.603			
	14.33	13.67	195.89			
	20.08	13.67	274.49			
		sum	10649			
	moveable partitions	15				
	partition dl (lb)	159734				
	partition dl (k)	159.73				
					wx floor 3 (k)	258.49

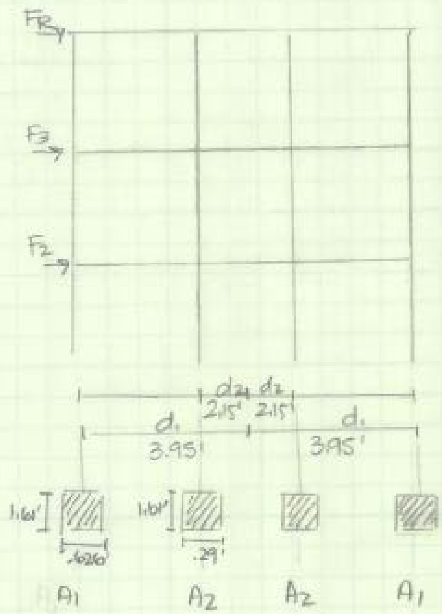
roof			
roof area (sf	7053.7		
asphalt (psf)	10		
1" board (psf	3		
ceiling (psf)	1		
insulation (p	2		
timber framir	34.75		
asphalt (lb)	70537		
asphalt (k)	70.537		
1" board (lb)	21161.1		
1" board (k)	21.1611		
ceiling (lb)	7053.7		
ceiling (k)	7.0537		
Insulation (lb	14107.4		
insulation (k	14.1074		
timber framir	245116.075		
timber framir	245.116075		
sum	357.975275		
		wx roof (k)	357.98
		effective weight (W)	825.89

Fx Calculations

k	1		V (k)	105.71			
level x	hx (ft)	hx^k	wx (k)	wxhx^k (k-ft)	Cvx	Fx (k)	
roof	39	39	357.9753	13961.03573	0.588634	62.22447	
3	26.67	26.67	258.4858	6893.814953	0.290661	30.7258	
2	13.67	13.67	209.4255	2862.846407	0.120705	12.75973	
			825.8865	23717.69708	1	105.71	

Seismic Analysis Calculations

Seismic Loading



$A_1 = .626 ft \times 1.61 ft$ $\quad$ $A_2 = .29 ft \times 1.61 ft$

$A_1 = 1.04 ft^2$ $\quad$ $A_2 = 0.47 ft^2$

$d_1 = 3.95 ft$ $\quad$ $d_2 = 2.15 ft$

$\Sigma I = 2A_1 d_1^2 + 2A_2 d_2^2$

$= 2[(1.04 ft^2)(3.95 ft)^2] + 2[(0.47 ft^2)(2.15 ft)^2]$

$= 32.45 + 4.34$

$\Sigma I = 36.80 ft^4$

$\sigma = Mc/I = M d_1 / \Sigma I$

$M = F_R(39 ft) + F_3(26.67 ft) + F_2(13.67 ft)$

$F_R = 41.04 K$

$F_3 = 20.26 K$

$F_2 = 8.42 K$

$M = (41.04K)(39 ft) + (20.26K)(26.67 ft) + (8.42K)(13.67 ft) = 2255.9956 K ft$

$M = 2256 K \cdot ft$

$\sigma = (2256 K \cdot ft)(3.25 ft) / 36.80 ft^4 = 204.804$

$\sigma = 204.80 K/ft^2$

$F = \sigma A$

$F_1 = (204.80 K/ft^2)(1.04 ft^2) = 212.99 K$ $\quad$ $F_1 = 212.99 K$

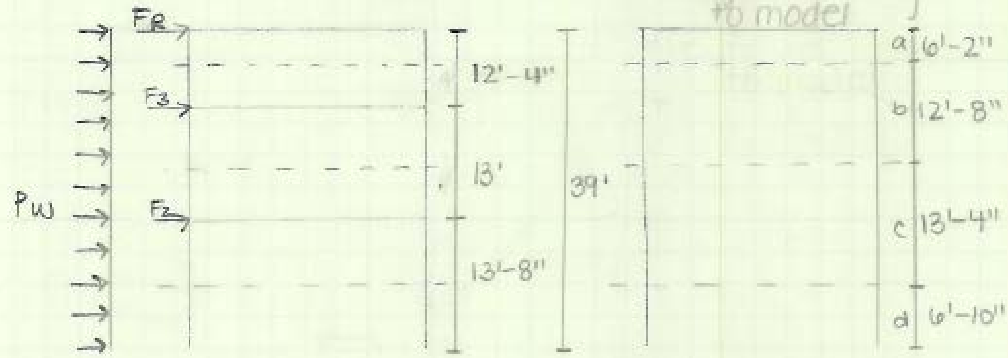
$F_2 = (204.80 K/ft^2)(0.47 ft^2) = 96.26 K$ $\quad$ $F_2 = 96.26 K$

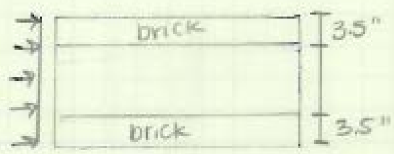
7.4.3 Wind Analysis Calculations

1

Wind loading

*heights according to model





solid wall thickness = w

$w = 7" \rightarrow w/2 = 3.5" = .29167ft$

$P_w = 17psf$

$F_R = P_w \times a \times w/2$

$= (17psf)(6.167ft)(.29167ft)$

$F_R = 30.58 lb$

ℓ = total length = 171'-1"

ℓ_x = wall section length = 8.54'

$F_3 = P_w \times b \times w/2$

$= (17psf)(12.67ft)(.29167ft)$

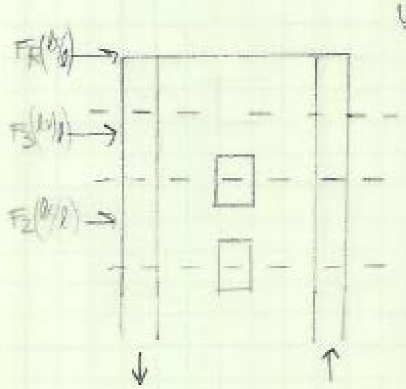
$F_3 = 62.81 lb$

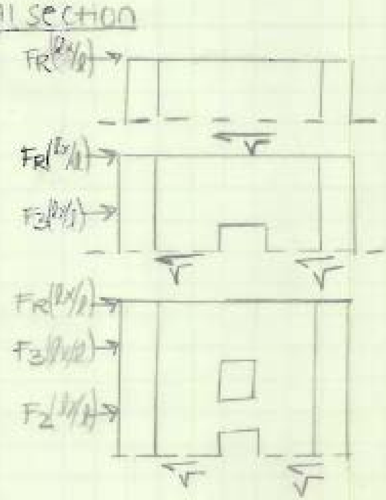
$F_2 = P_w \times c \times w/2$

$= (17psf)(13.33ft)(.29167ft)$

$F_2 = 66.11 lb$

wall section



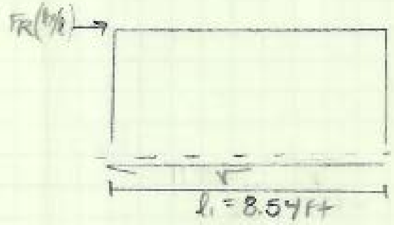


$\ell x/\ell = (8.54')/(171'-1") = .05$

$F_R(\ell x/\ell) = (30.58\text{ lb})(.05) = 1.529\text{ lb}$

$F_3(\ell x/\ell) = 62.81\text{ lb}(.05) = 3.14\text{ lb}$

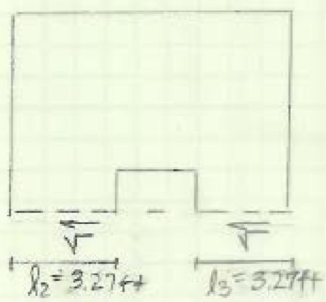
$F_2(\ell x/\ell) = 66.11\text{ lb}(.05) = 3.31\text{ lb}$



$v_R = F_R(\ell x/\ell)/\ell_1(\text{solid wall thickness (w)})$

$v_R = 1.529\text{ lb}/(8.54\text{ ft})(.292\text{ ft})$

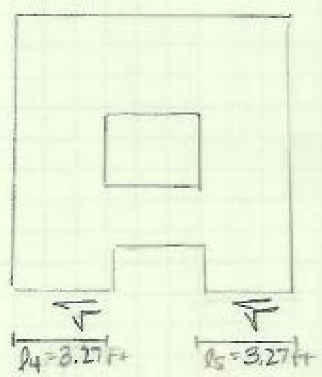
$v_R = 0.613\text{ psf}$



$v_3 = F_3(\ell x/\ell)/(\ell_2+\ell_3)(w)$

$v_3 = 3.14\text{ lb}/(3.27\text{ ft}+3.27\text{ ft})(.292\text{ ft})$

$v_3 = 1.64\text{ psf}$



$v_2 = F_2(\ell x/\ell)/(\ell_4+\ell_5)(w)$

$v_2 = 3.31\text{ lb}/(3.27\text{ ft}+3.27\text{ ft})(.292\text{ ft})$

$v_2 = 1.73\text{ psf}$

7.4.4 Autodesk Robot Structural Analysis

A structural analysis was attempted in *Autodesk Robot Structural Analysis*, however due to loading errors the model was not used and new calculations were performed. The next sections outline *Robot* and how it would have been used in the project if errors had not occurred.

Autodesk Robot Structural Analysis Professional (Robot) Background Information

Autodesk Inc, has been creating 2D and 3D design software since its release of *AutoCAD* in the 1980's. *Autodesk* has grown to develop multiple manufacturing, building and construction, and media and entertainment design software that are used to "visualize, simulate and analyze real world performance early in the designing process to save time and money, enhance quality and foster innovation" (Autodesk Expands BIM Software Offering for Structural Analysis, 2008). *Autodesk Robot Structural Analysis Professional* is a software package created by *Autodesk* in order to allow users to create and analyze complex models in minutes, as opposed to hours required for traditional methods.

Robot includes a wide range of features that allows users to not only analyze a variety of structures but also model and design buildings. With the building design layout, engineers can see floor plan views that will assist in easily creating columns and then generating beam and girder framing layouts from them. It allows structural engineers to have the capability to explore different possible design alternatives as well as analyze the linear and nonlinear behaviors of these structural designs. *Robot* can analyze nonlinearity, tension and compression members and supports, cables, plastic hinges as well as p-delta analysis. In addition the data from the analysis can be shared in different output formats as well. Figure 95 shows a couple of different output formats, table and color-coded deformation model (Autodesk Robot Structural Analysis Professional, 2012).

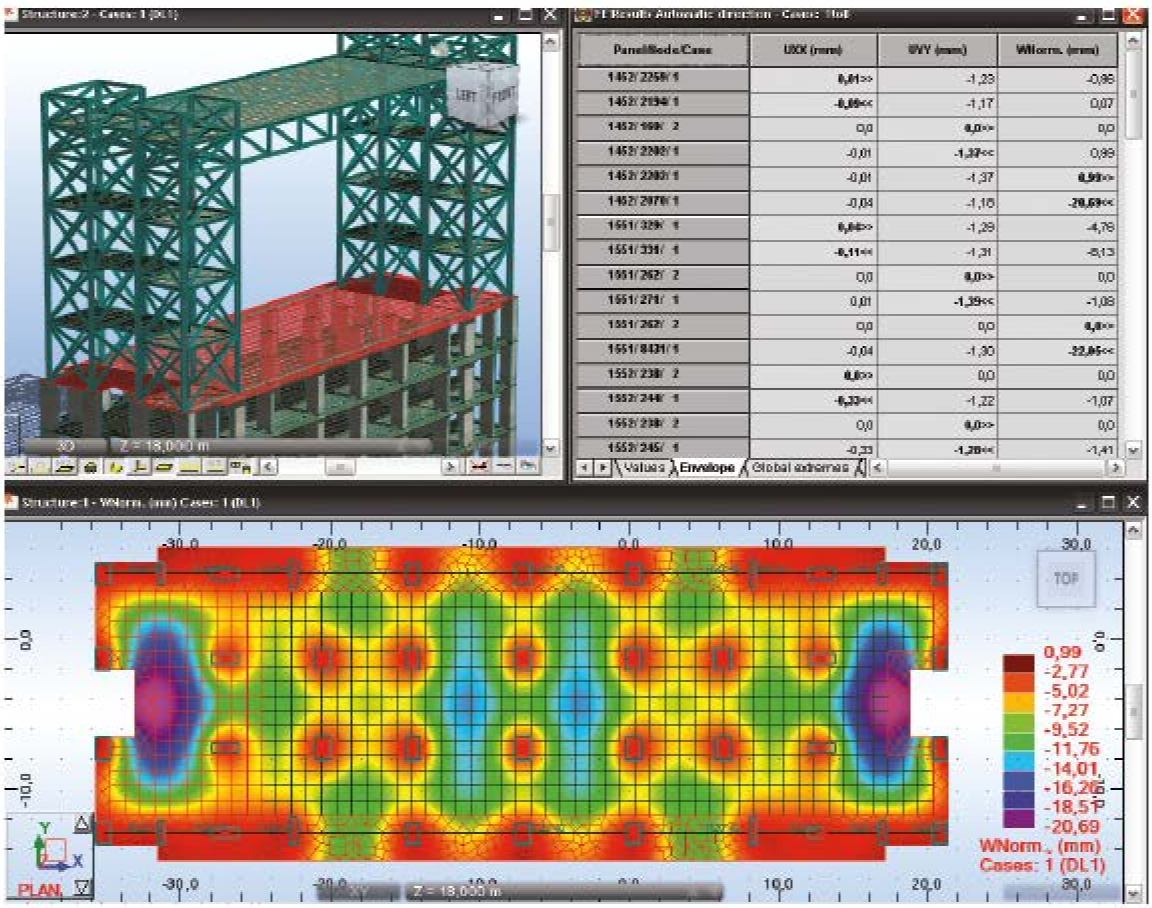


Figure 95: Robot Analysis Data Output (Autodesk Robot Structural Analysis Professional, 2012)

Autodesk Robot Structural Analysis Professional is also an open API or Application Programming Interface, meaning it can be easily integrated with BIM and *Autodesk Revit* and other programs with open API. Figure 96 shows an example of how *Autodesk Revit Structures* design can be integrated with *Robot* and analyzed (Autodesk Robot Structural Analysis Professional, 2012). In addition to being an open API program *Robot* has other features that allow it to be used by many different companies and countries. *Robot* has a database of more than 40 international steel design codes and 30 reinforced concrete design codes in addition to many different languages. It has more than 60 sections and material databases from around the world, with country specific shapes, units and building codes, allowing for successful international project completion. An example of how *Robot* can be used for different international construction is an analysis can be performed in one language, and then the output of the data and visualizations with the analysis information can be produced in another. *Autodesk Robot Structural Analysis Professional* is a software package that can easily be integrated with others, can easily be related to different countries and can perform difficult structural analyses in minutes (Autodesk Robot Structural Analysis Professional, 2012).

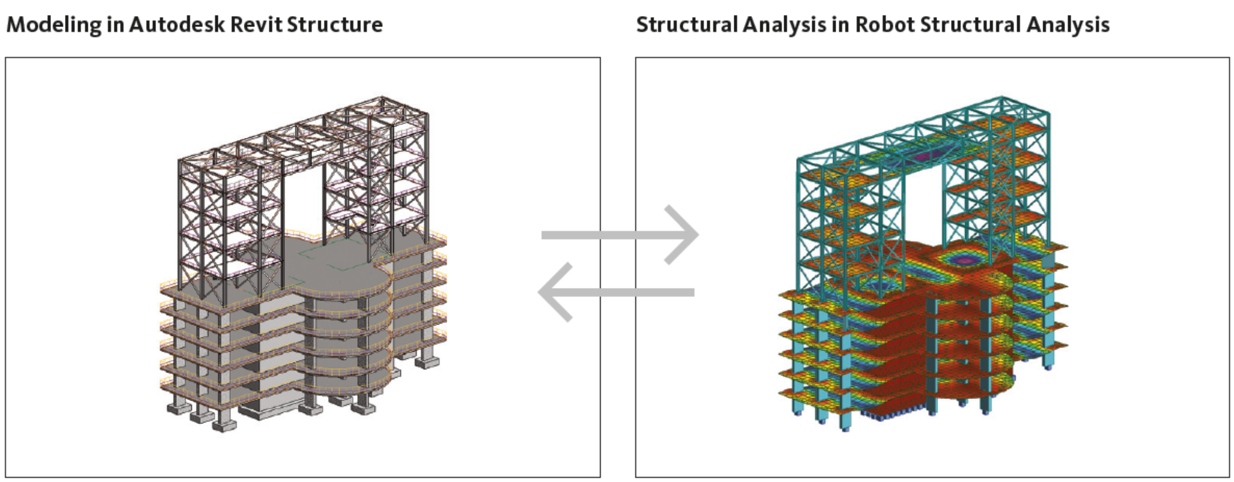


Figure 96: Revit Structure to Robot (Autodesk Robot Structural Analysis Professional, 2012)

Modeling the Washburn Wall Section in Robot

The first step to creating the section was to open *Robot* and pick "to create a Shell Design." This step is shown in **Error! Reference source not found.**. A shell design was chosen opposed to a building design or frame design because Washburn's structure and wall section would be better represented in 3D as a network of solid elements. In addition it was not completed as a building design because only one wall section was being analyzed, not the entire building structure.

In order to determine the complete structural code compliance of Washburn it was concluded that a structural analysis should be conducted to determine the structural integrity of the building. Completing the associated structural analysis calculations by hand is a very lengthy process; therefore, the group used *Autodesk Robot Structural Analysis* (*Robot)* in order to analyze Washburn's structure. A section of Washburn's wall was on the focus of study, and an analysis of its performance under gravity and lateral loads was completed. **Error! Reference source not found.** depicts the wall section as well as the dimensions of a typical window.

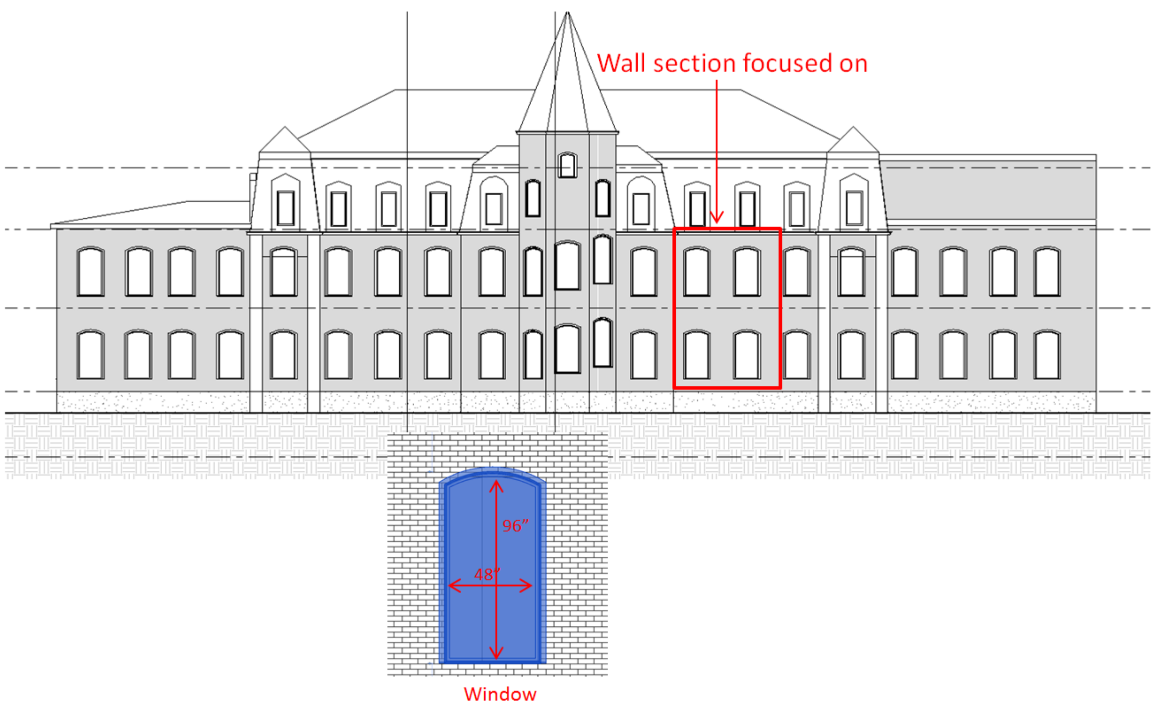
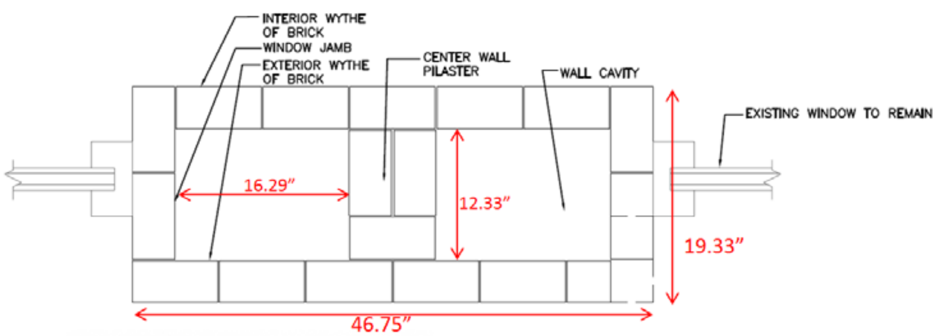
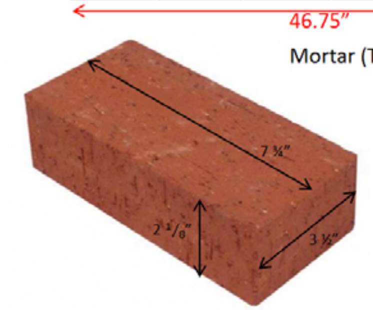


Figure 97: Washburn Wall Section and Window

Washburn has a unique structure, in the fact that its structural columns are comprised of bricks bonded together to form a composite section similar to an enlarged concrete block. Figure 98 shows the layout of the brick column as well as the dimension of the bricks used, and the calculations to find the actual length and width of the brick "column." The brick has a length of 7.75", a width of 3.5" and a height of 2.125," while the mortar has a thickness of 1.67". These dimensions were compared to the column representation (seen in top of Figure 98) and calculations were completed to determine the dimensions of the brick column. These brick column dimensions were modeled in *Robot* as part of the structural representation of the wall section. The main steps completed to create the wall representation and then perform the structural analysis in *Robot* are outlined in the following sections.



Mortar (Type O) = $^1/_6$"



$$5(7.75") + 2(3.5") + 6(.167") = 46.75"$$

$$2(7.75") + 1(3.5") + 2(1.67") = 19.33"$$

$$23.375" - (2(3.5") + (1.67")/2) = 16.29"$$

$$19.33 - (2(3.5")) = 12.33"$$

Figure 98: Brick Column Dimensions

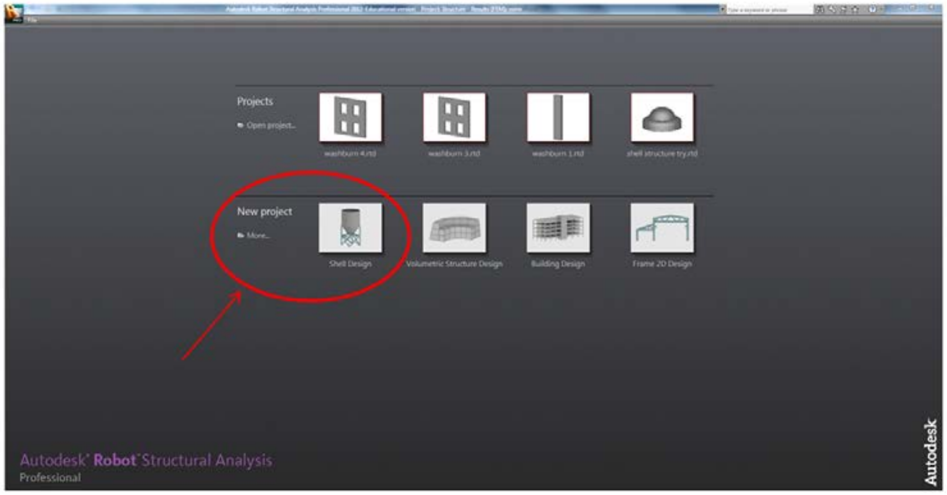


Figure 99: Step 1: Picking a project type

Step 2 was to define a new material in *Robot*. This step is depicted in Figure 100. A new material was created because *Robot* did not have the specification for the brick and mortar in its existing database. Values for the material's engineering properties, such as elastic modulus E, Poisson's ratio v etc., were found by referencing many sources to find the average material properties.

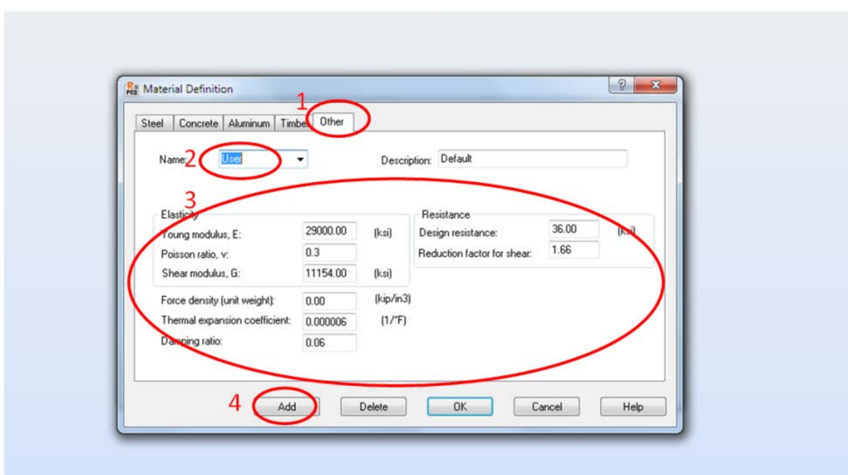


Figure 100: Step 2: Defining a new material

The third step was to create a column with the same width and length as the built-up brick column (dimensions shown in Figure 101). Figure 101 demonstrates how the column was produced in *Robot*. A cube was drawn to be 46.75" in the x direction, 19.33" in the y direction and 328" in the z direction. The 328" is in reference to the full height of the wall segment which was gathered from the *Revit* Model created by the group from *Hoffman Architect's* model.

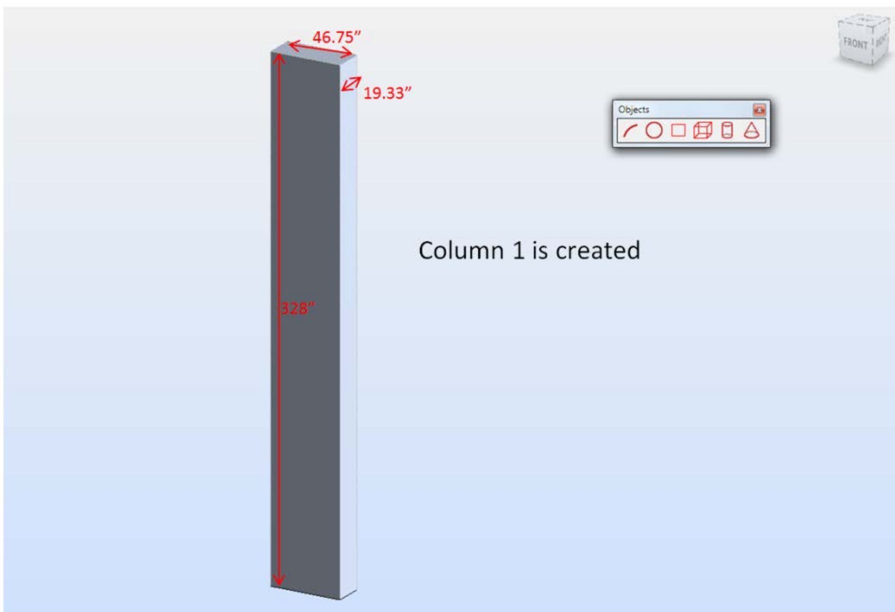


Figure 101: Step 3: Creating column 1

Next the cavities were created in the column cross section. This step is represented in Figure 102 in a 2D and 3D view. These cavities were created by defining cubes inside the column that were 16.29" long and 12.33" wide, and then subtracting the volume of these cubes from the original column. Based on pictures of Washburn's most recent renovation, it was assumed that the cavities span the entire height of the column.

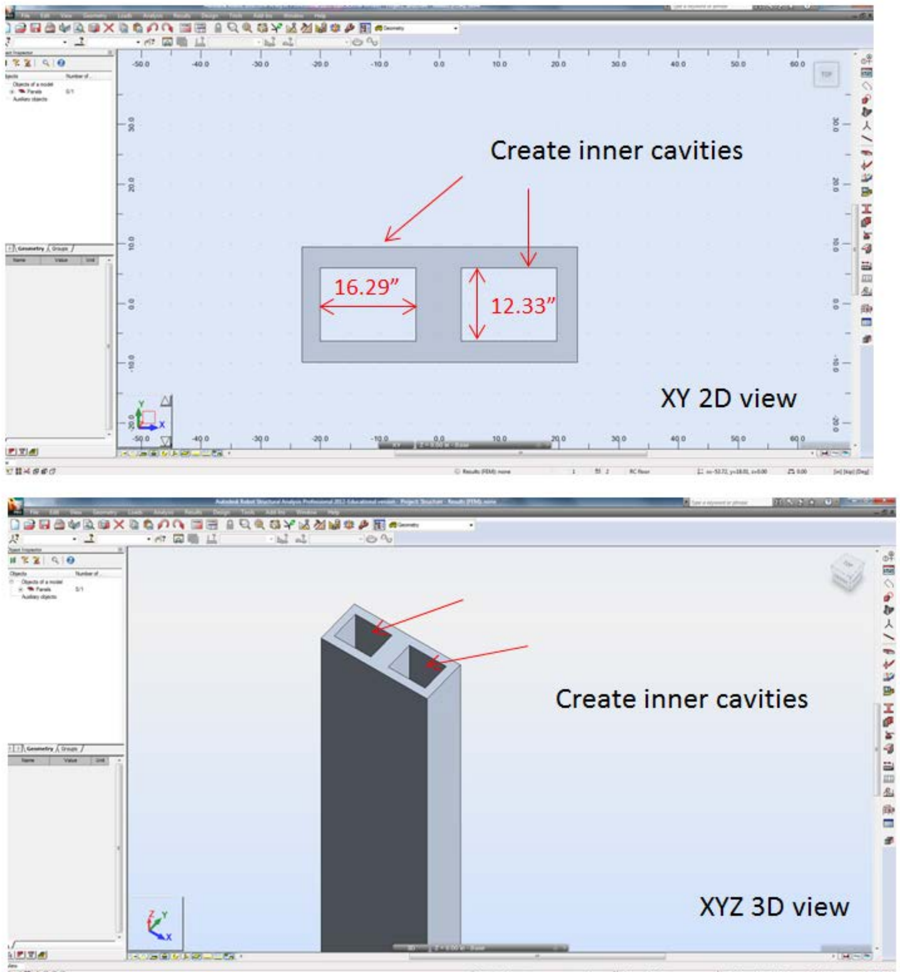


Figure 102: Step 4: Creating inner cavities

The completion of the first hollow-core column provided a model that was copied to create two more columns on either side, as seen in Figure 103. Figure 103 represents these 3 columns in 2D and 3D views. These columns were spaced a window length, or four feet, apart. This window dimension was determined from the *Revit* model created by the group. The complete window dimensions can be seen in Figure 97.

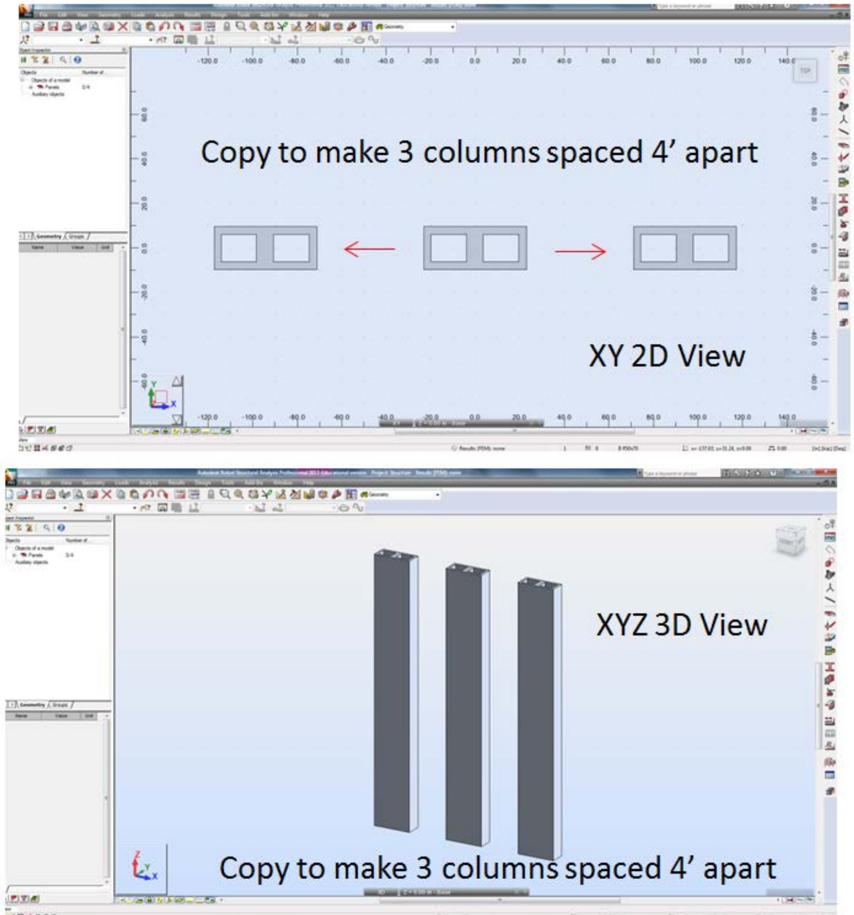


Figure 103: Step 5: Creating multiple columns

Step 6, depicted in Figure 104, shows the first step to creating the wall sections in between the wall columns and in between the ground and the windows. According to the Washburn *Revit* Model created by the group the ground floor windows were placed two feet above the ground. The dimension to these sections in between the windows and ground is represented in Figure 105.

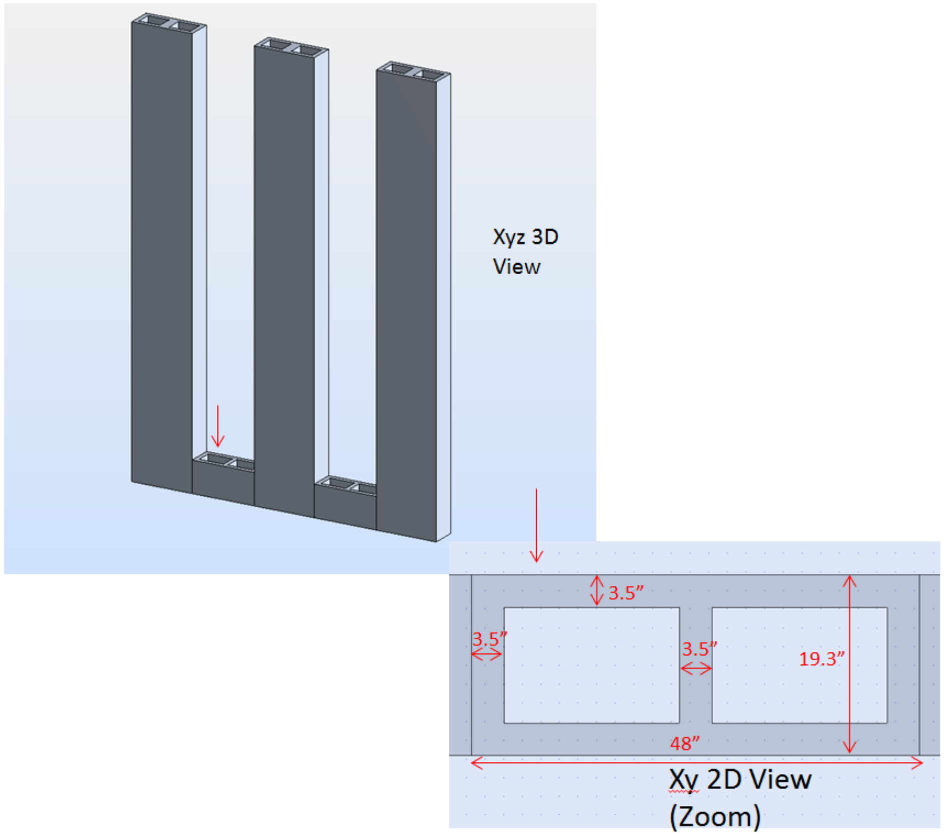


Figure 104: Step 6: Creating inner columns

The next step, in creating the wall section depiction in *Robot* was to create the wall sections in between the windows of the ground and second floors. Figure 105 is a picture of one of Washburn’s windows. The window in this figure is dimensioned as 96” high with an arced top. On top of the arced window one can see that there is an arced formation of bricks, 7.75” in height. This value was added to the window height in order to determine at what height the section between the two windows would start at. The in between window wall sections as modeled in *Robot* are seen in **Error! Reference source not found.**. These sections were defined 103.75” above the previously drawn sections between the ground and window.

Figure 105: Washburn Window Height

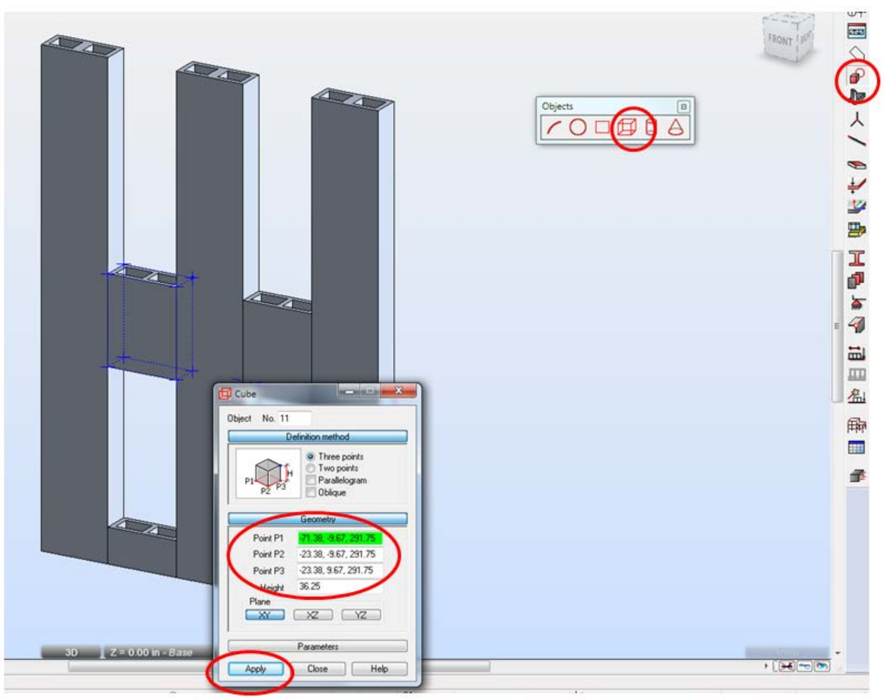


Figure 106: Step 7: Creating middle inner column

After these middle sections were created, top sections in between the roof and the windows needed to be completed in *Robot*. These sections were created at a height of 103.75" above the middle sections, to provide room for the windows and brick arch. Figure 107 shows the column and the height above the middle section it was placed at. After the column was created inner cavities were also created the same dimensions as seen in Figure 108. After these inner cavities were created the section was copied and created again above the other second floor window. Figure 108 depicts the wall section and wall cavities that mimic Washburn's basic wall structure.

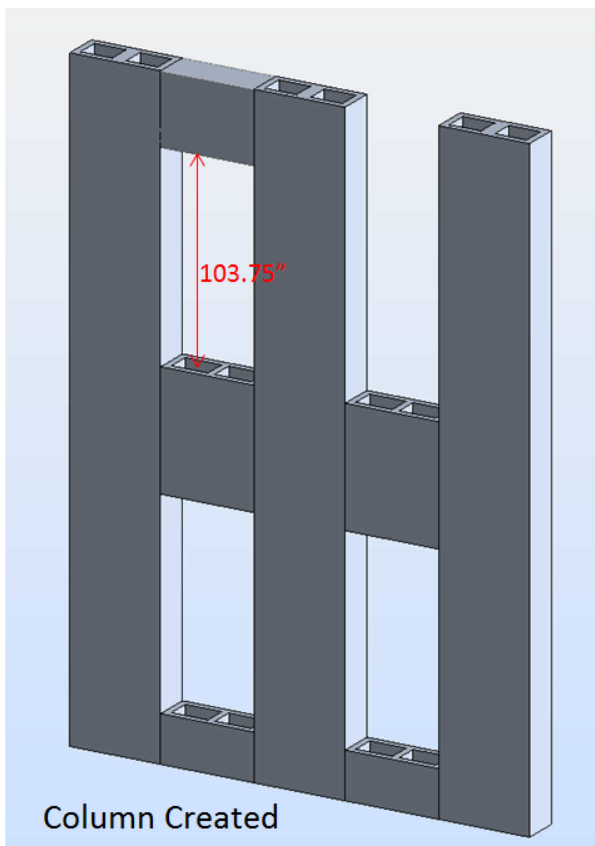


Figure 107: Step 8: creating upper inner columns

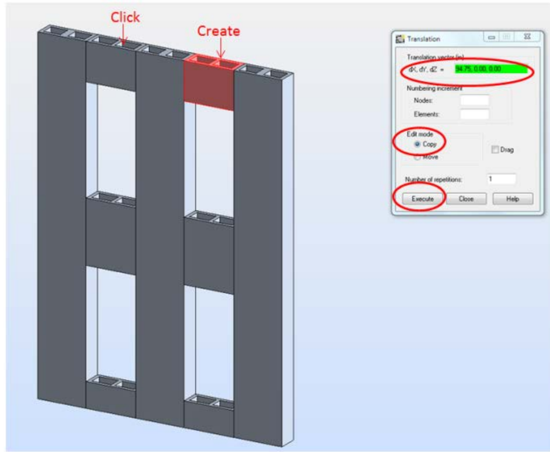


Figure 108: Step 9: All columns created

Figure 109 represents step 10: meshing the wall structure in *Robot*. The meshing tool of *Robot* allows the program to break down the structure into smaller elements to analyze each and perform a more accurate analysis.

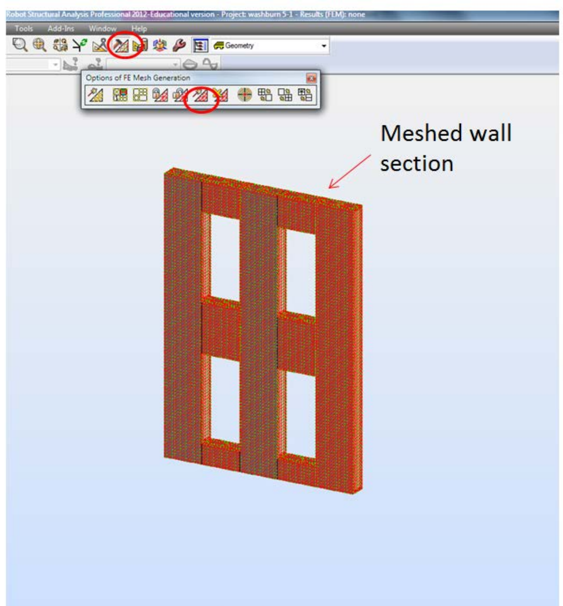


Figure 109: Step 10: Meshing

After the columns have been meshed arch elements were created at the top of the window openings to mimic the brick arc seen in Figure 110. The arc elements were then meshed and joined to the structure so that the loads would also be performed on these elements and the structure would act as one element. The final all meshed structure is shown in Figure 111. After the wall section is fully created and meshed, supports were added to the structural model, a representation of this step is shown in Figure 112.

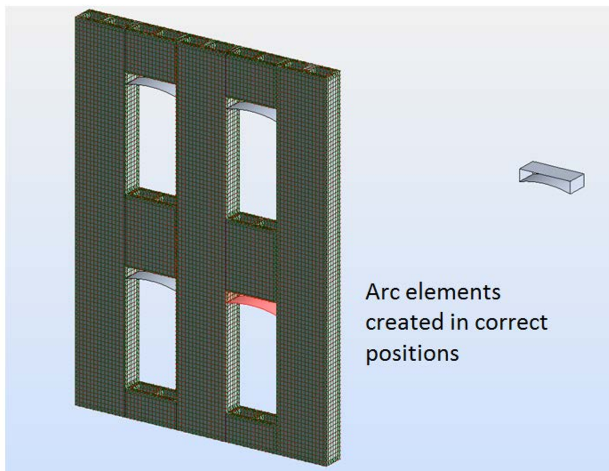


Figure 110: Step 11: Creating Arc elements

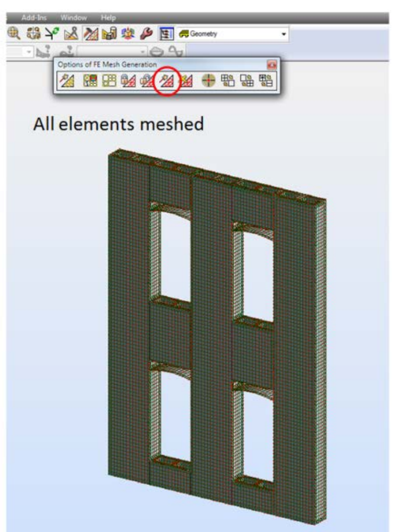


Figure 111: Step 12: Meshing arc elements

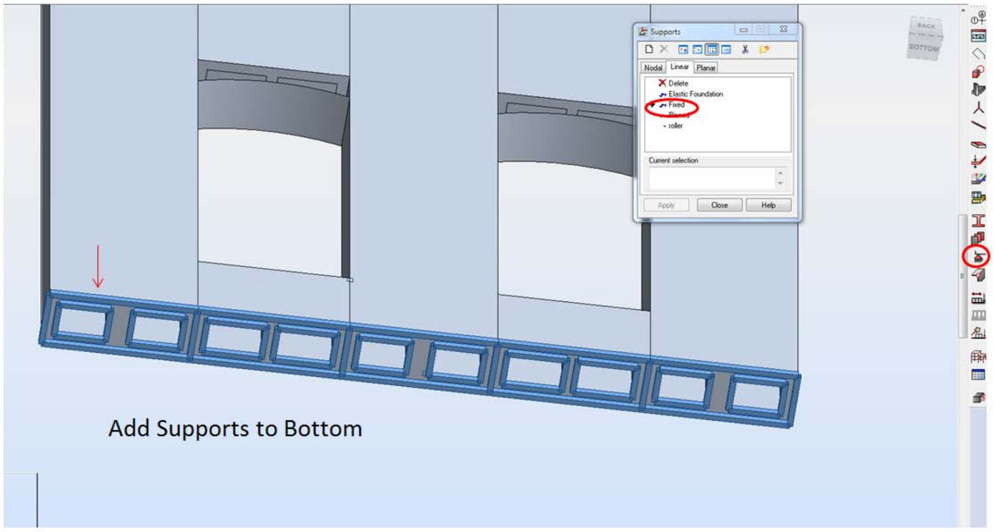
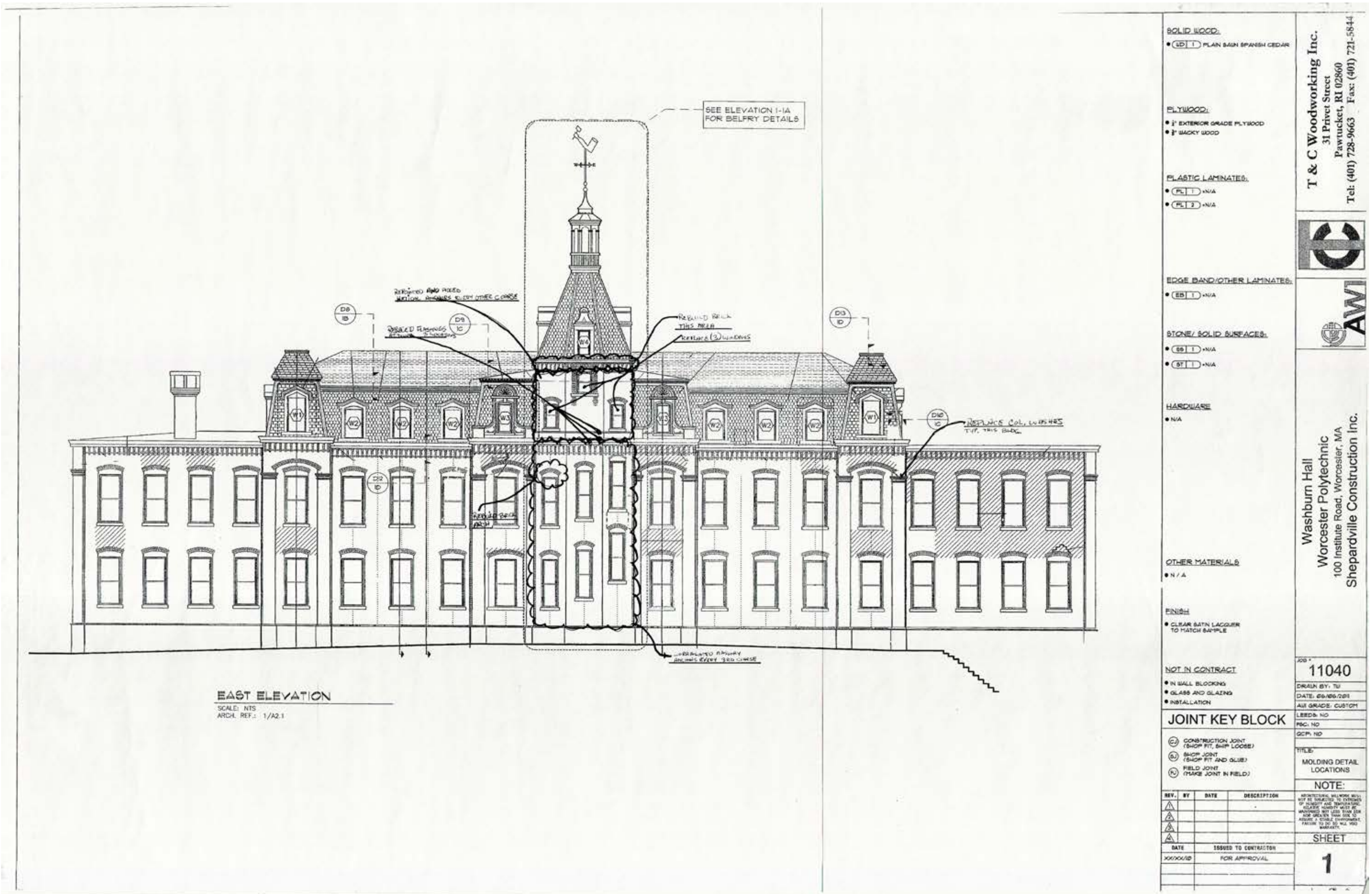
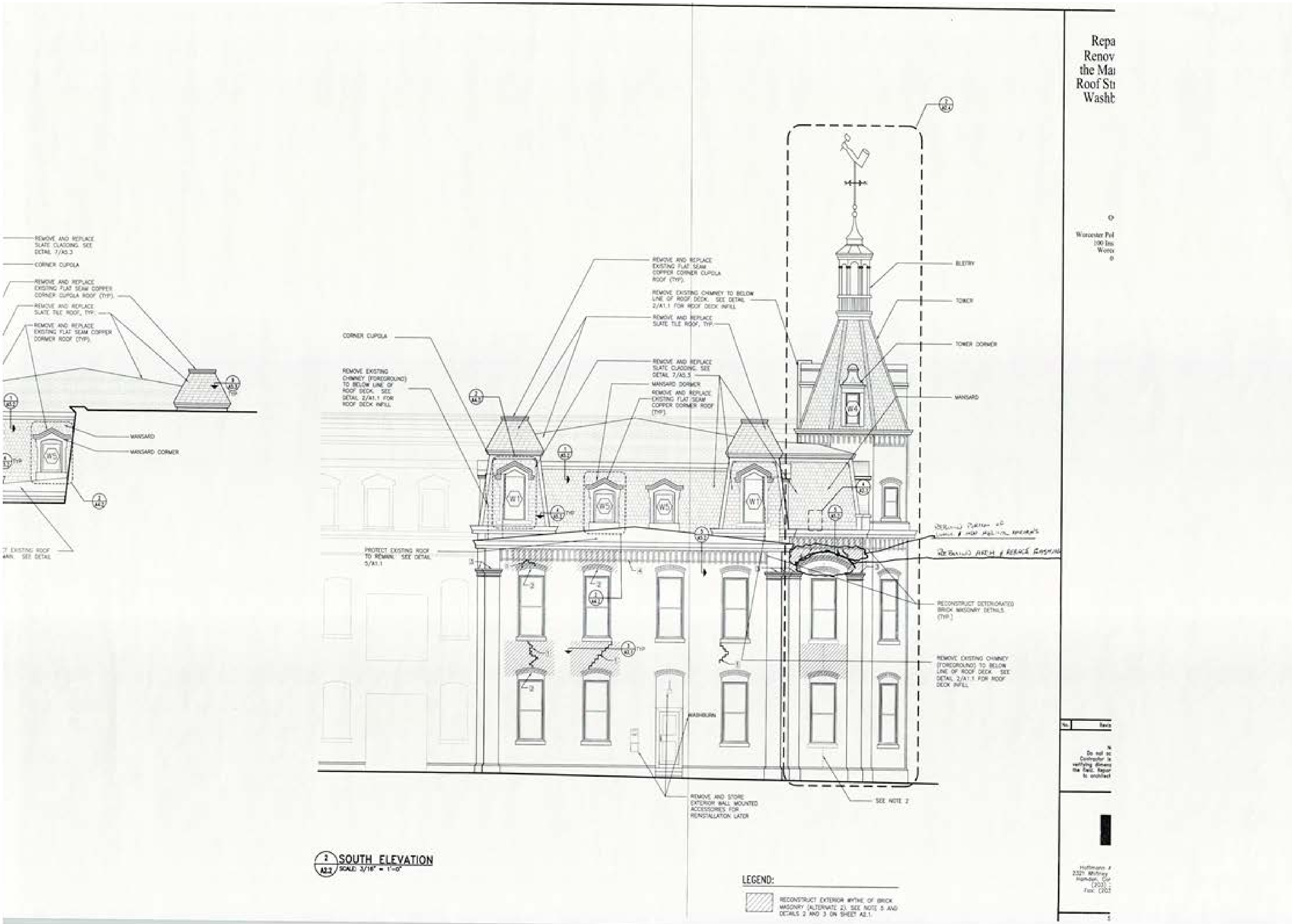


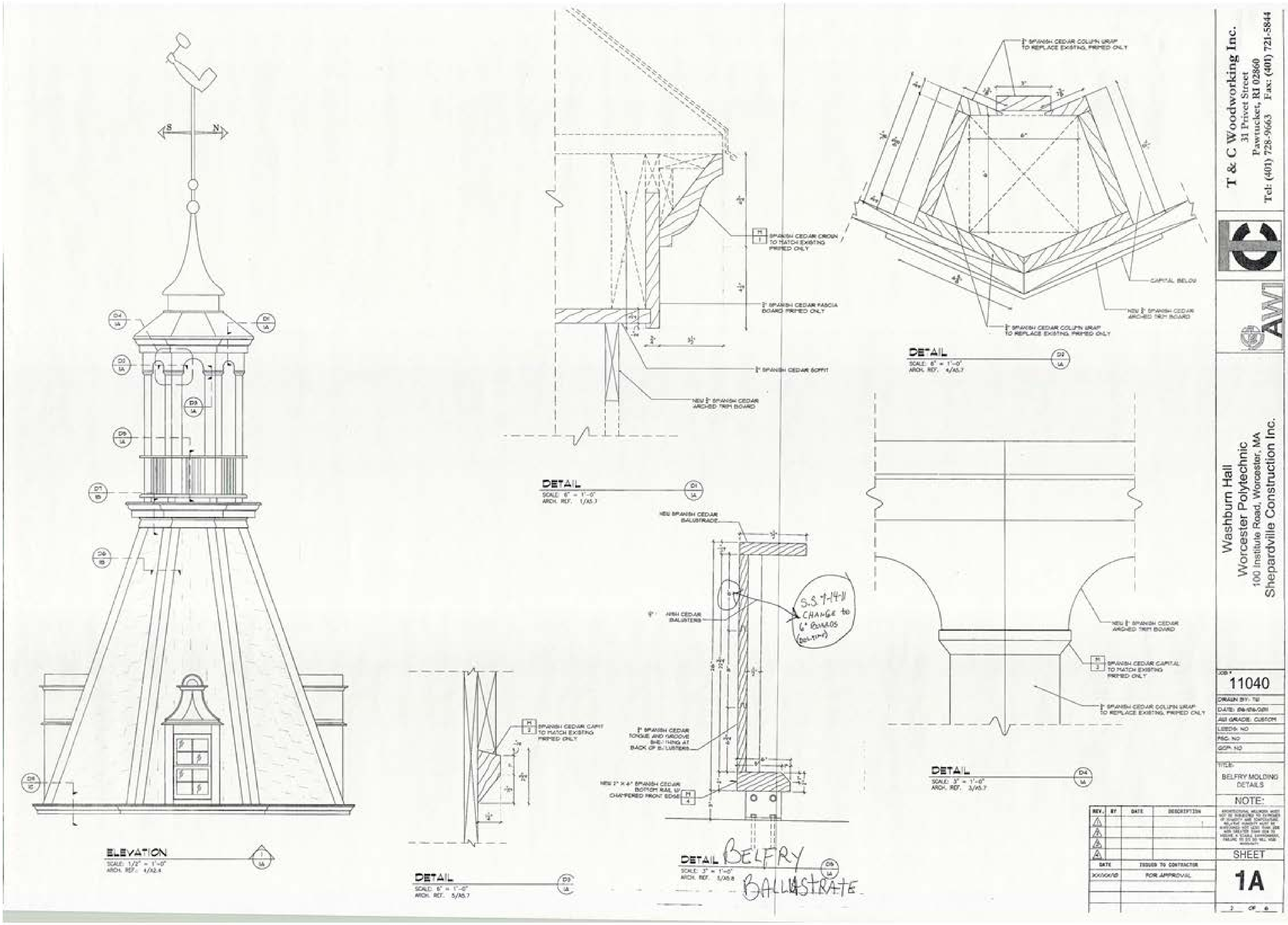
Figure 112: Step 13: Adding Supports

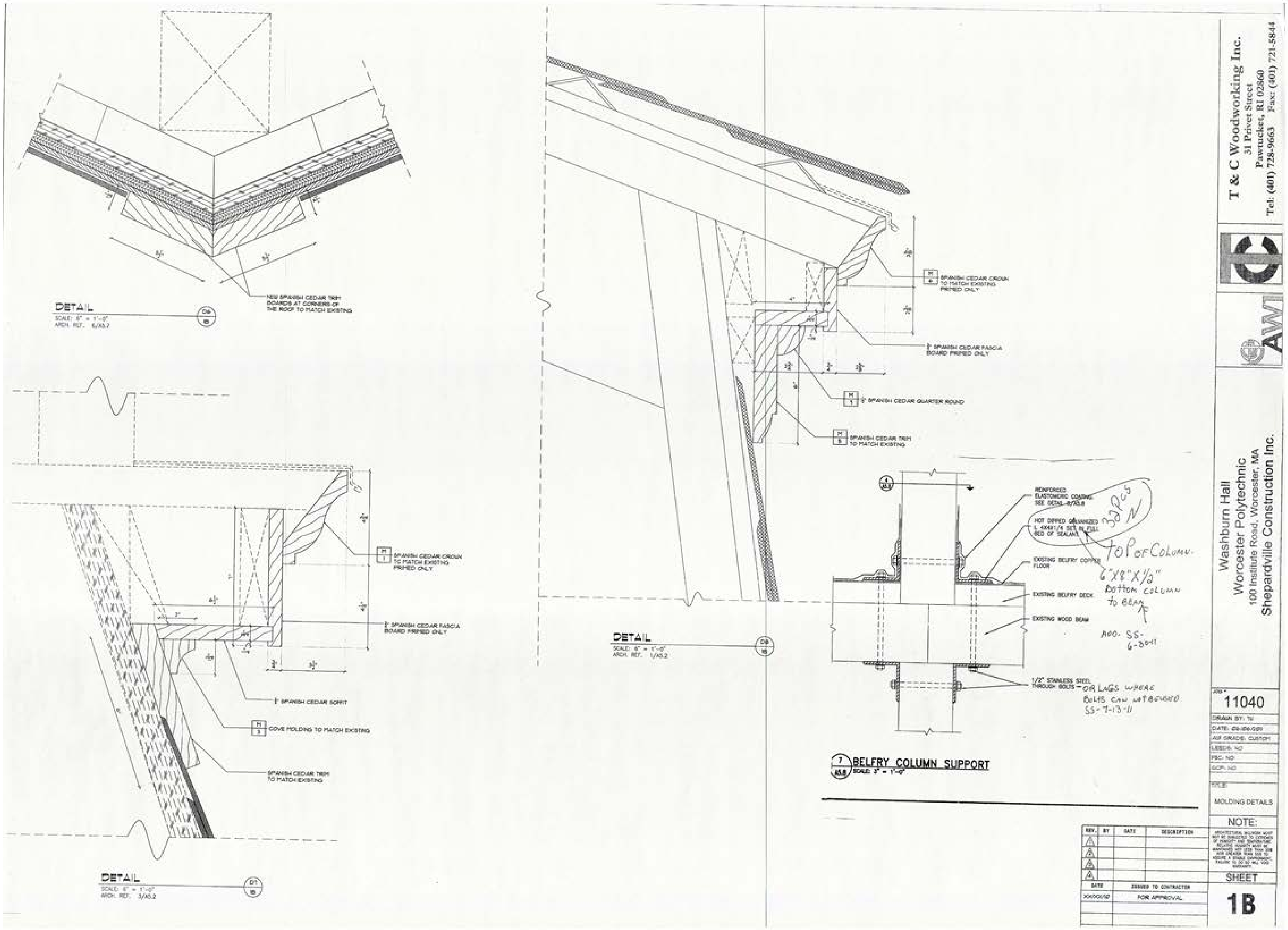
7.5 Washburn As-Builts from Cutler



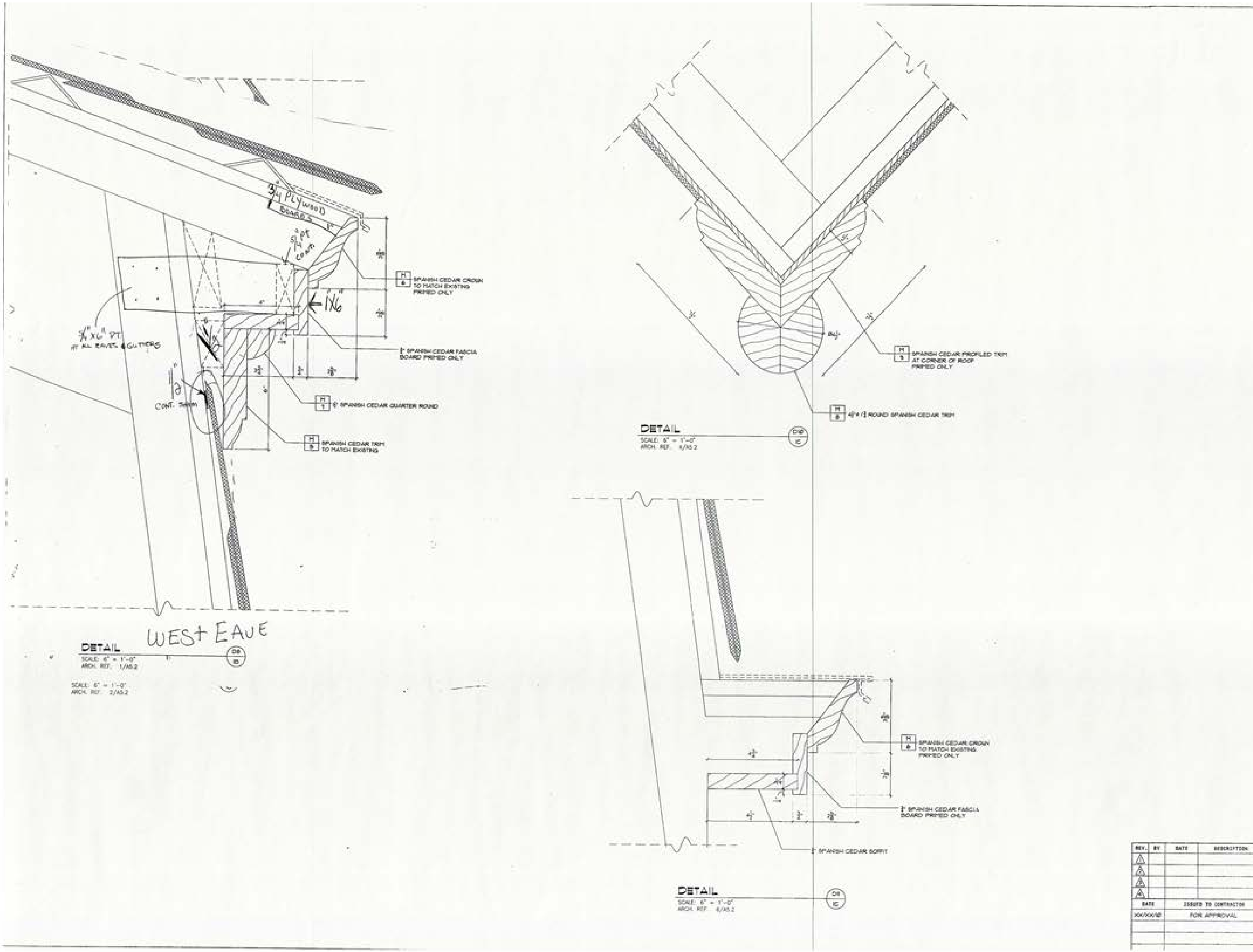


REMOVE AND REPLACE SLATE CLADDING. SEE DETAIL 7/A5.3
CORNER CUPOLA
REMOVE AND REPLACE EXISTING FLAT SEAM COPPER CORNER CUPOLA ROOF (TYP).
REMOVE AND REPLACE SLATE TILE ROOF, TYP.
REMOVE AND REPLACE EXISTING FLAT SEAM COPPER DORMER ROOF (TYP).
MANSARD
MANSARD DORMER
W5
REMOVE AND REPLACE EXISTING FLAT SEAM COPPER CORNER CUPOLA ROOF (TYP).
REMOVE EXISTING CHIMNEY TO BELOW LINE OF ROOF DECK. SEE DETAIL 2/A1.1 FOR ROOF DECK INFILL
REMOVE AND REPLACE SLATE TILE ROOF, TYP.
CORNER CUPOLA
REMOVE EXISTING CHIMNEY (FOREGROUND) TO BELOW LINE OF ROOF DECK. SEE DETAIL 2/A1.1 FOR ROOF DECK INFILL
REMOVE AND REPLACE SLATE CLADDING. SEE DETAIL 7/A5.3
MANSARD DORMER
REMOVE AND REPLACE EXISTING FLAT SEAM COPPER DORMER ROOF (TYP)
W1
W5
W5
W1
W4
PROTECT EXISTING ROOF TO REMAIN. SEE DETAIL 5/A1.1
BLETRY
TOWER
TOWER DORMER
MANSARD
RECONSTRUCT DETERIORATED BRICK MASONRY DETAILS (TYP.)
REMOVE EXISTING CHIMNEY (FOREGROUND) TO BELOW LINE OF ROOF DECK. SEE DETAIL 2/A1.1 FOR ROOF DECK INFILL
WASHBURN
REMOVE AND STORE EXTERIOR WALL MOUNTED ACCESSORIES FOR REINSTALLATION LATER
SEE NOTE 2
2 A2.2 SOUTH ELEVATION
SCALE: 3/16" = 1'-0"
LEGEND:
RECONSTRUCT EXTERIOR WYTHE OF BRICK MASONRY (ALTERNATE 2). SEE NOTE 5 AND DETAILS 2 AND 3 ON SHEET A2.1.


T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844
AWI
Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.
11040
BELFRY MOLDING DETAILS
NOTE:
SHEET
1A
ELEVATION
DETAIL
DETAIL
DETAIL
DETAIL
DETAIL BELFRY BALLUSTRATE
S.S. 7-14-11 CHANGE to 6" Balusters



DETAIL
NEW SPANISH CEDAR TRIM BOARDS AT CORNERS OF THE ROOF TO MATCH EXISTING
SPANISH CEDAR CROWN TO MATCH EXISTING PRIMED ONLY
SPANISH CEDAR FASCIA BOARD PRIMED ONLY
SPANISH CEDAR QUARTER ROUND
SPANISH CEDAR TRIM TO MATCH EXISTING
SPANISH CEDAR SOFFIT
COVE MOLDING TO MATCH EXISTING
DETAIL
DETAIL
REINFORCED ELASTOMERIC COATING
HOT DIPPED GALVANIZED
EXISTING BELFRY COPPER FLOOR
EXISTING BELFRY DECK
EXISTING WOOD BEAM
1/2" STAINLESS STEEL THROUGH BOLTS
OR LAGS WHERE BOLTS CAN NOT BE USED SS-7-13-11
TOP OF COLUMN
6"X8"X1/2" BOTTOM COLUMN TO BEAM
BELFRY COLUMN SUPPORT
T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844
AWI
Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.
11040
MOLDING DETAILS
NOTE:
SHEET
1B
FOR APPROVAL



T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844

Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.

JOB #
11040

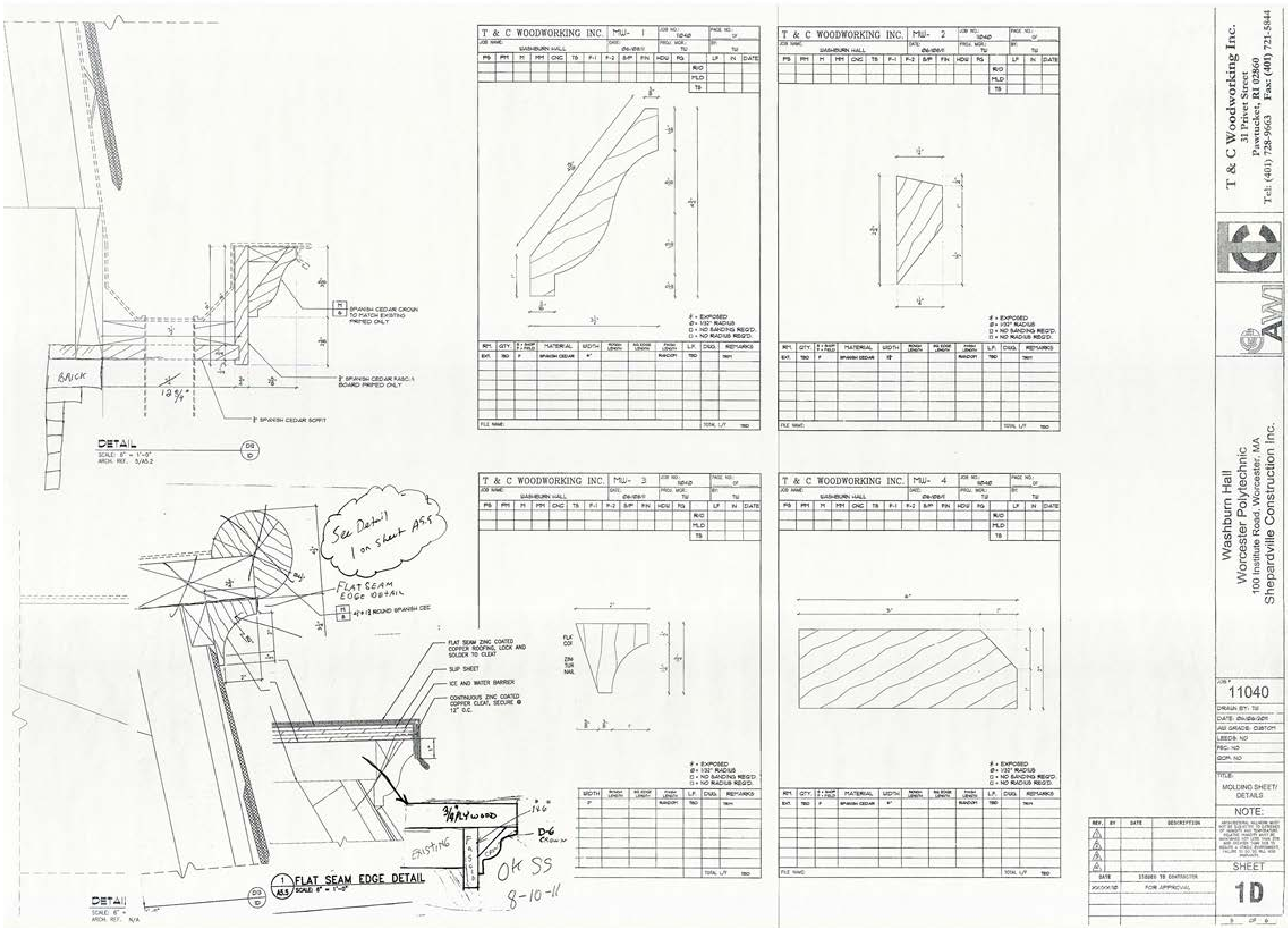
DRAWN BY: TJ
AWI GRADE: CUSTOM
LEEDS: NO
FSC: NO
TITLE:
MOLDING DETAILS

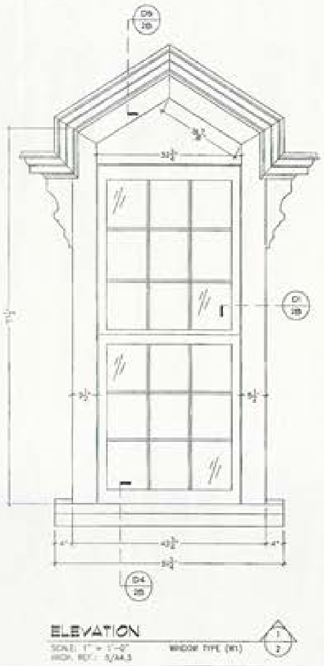
NOTE:

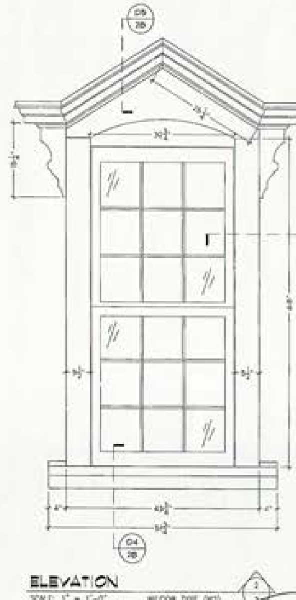
REV.	BY	DATE	DESCRIPTION
1			
2			
3			
4			

DATE	ISSUED TO CONTRACTOR
XX/XX/12	FOR APPROVAL

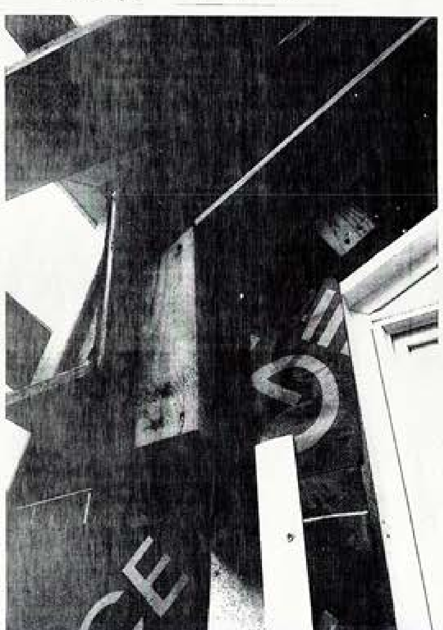
SHEET
1C

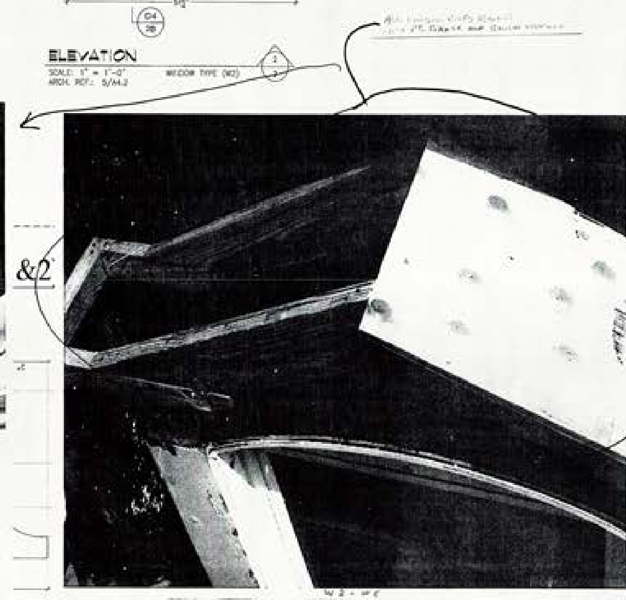

T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844
Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.
T & C WOODWORKING INC. MW- 1
T & C WOODWORKING INC. MW- 2
T & C WOODWORKING INC. MW- 3
T & C WOODWORKING INC. MW- 4
WASHBURN HALL
SPANISH CEDAR CROWN TO MATCH EXISTING PRIMED ONLY
SPANISH CEDAR FASCIA BOARD PRIMED ONLY
SPANISH CEDAR SOFFIT
BRICK
DETAIL
See Detail 1 on Sheet A5.5
FLAT SEAM EDGE DETAIL
FLAT SEAM ZINC COATED COPPER ROOFING, LOCK AND SOLDER TO CLEAT
SLIP SHEET
ICE AND WATER BARRIER
CONTINUOUS ZINC COATED COPPER CLEAT, SECURE @ 12" O.C.
3/4 PLYWOOD
EXISTING
FASCIA
CROWN
D-6 CROWN
OK SS
8-10-11
11040
MOLDING SHEET/ DETAILS
NOTE:
SHEET
1D



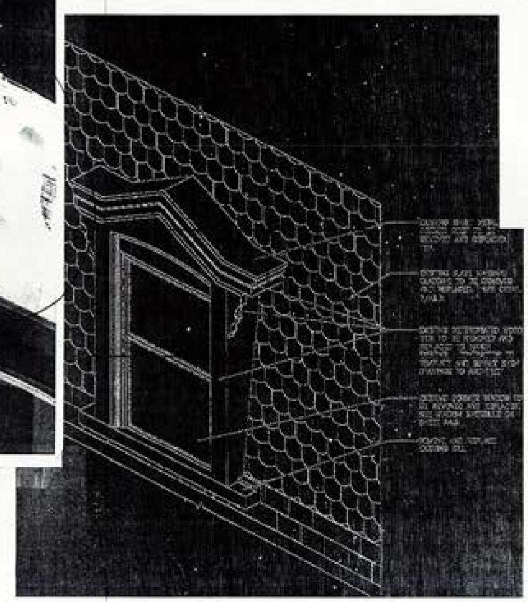


WINDOW TYPE (W1)





WINDOW TYPE (W2)



SOLID WOOD:
- (WD 1) PLAIN SAWN SPANISH CEDAR

PLYWOOD:
- ¾" EXTERIOR GRADE PLYWOOD
- ¾" WACKY WOOD

PLASTIC LAMINATES:
- (PL 1) =N/A
- (PL 2) =N/A

EDGE BAND/OTHER LAMINATES:
- (EB 1) =N/A

STONE/ SOLID SURFACES:
- (SS 1) =N/A
- (ST 1) =N/A

HARDWARE
- N/A

OTHER MATERIALS
- N / A

FINISH
- CLEAR SATIN LACQUER TO MATCH SAMPLE

NOT IN CONTRACT
- IN WALL BLOCKING
- GLASS AND GLAZING
- INSTALLATION

JOINT KEY BLOCK

- (CJ) CONSTRUCTION JOINT (SHOP FIT, SHIP LOOSE)
- (SJ) SHOP JOINT (SHOP FIT AND GLUE)
- (FJ) FIELD JOINT (MAKE JOINT IN FIELD)

REV.	BY	DATE	DESCRIPTION
1			
2			
3			
4			

DATE	ISSUED TO CONTRACTOR
XX/XX/XX	FOR APPROVAL

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Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.

JOB # 11040

DRAWN BY: TU

DATE: [illegible]

AWI GRADE: CUSTOM

LEEDS: NO

FSC: NO

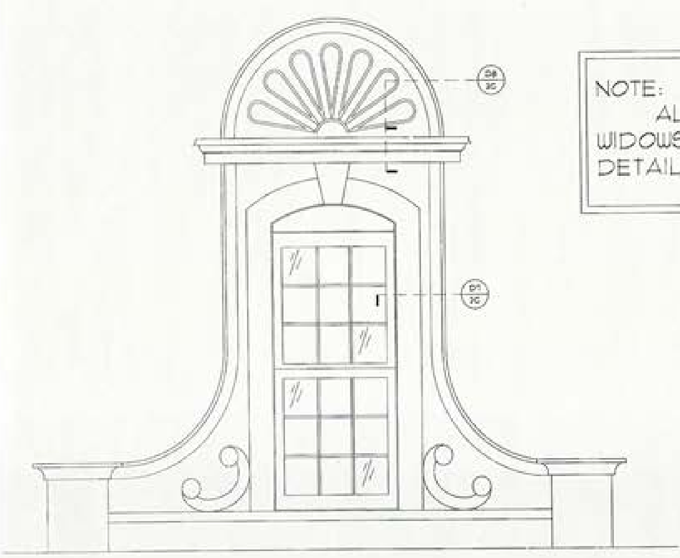
SCM: NO

TITLE: WINDOW ELEVATION

NOTE:

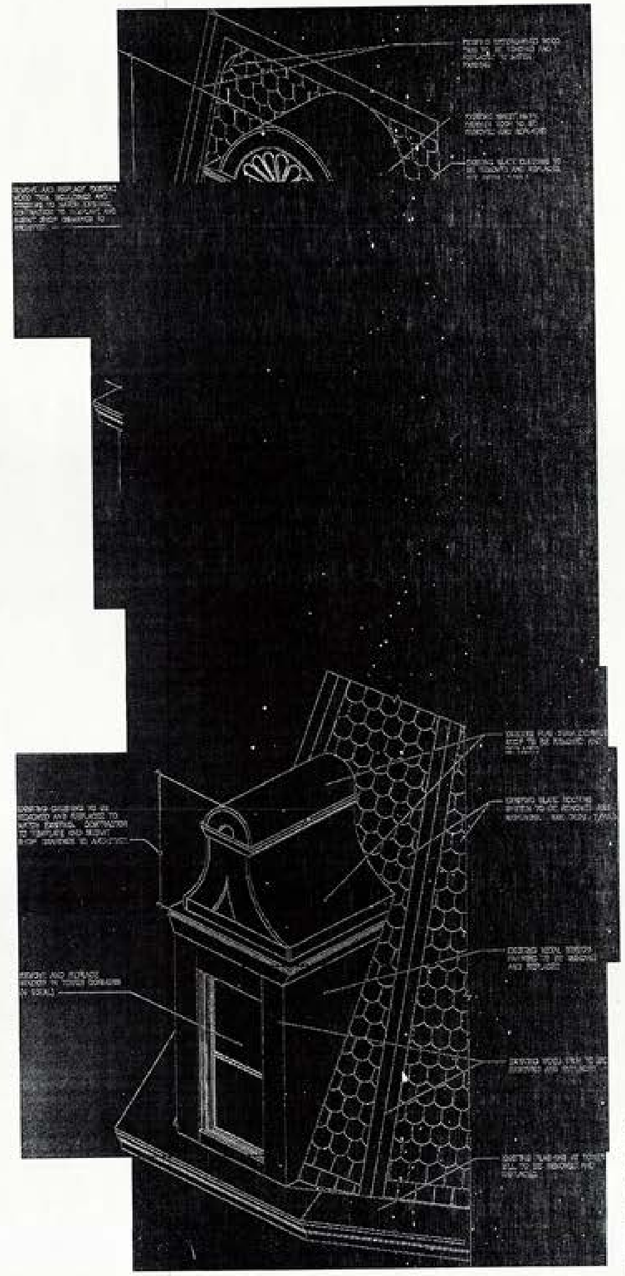
SHEET 2

WINDOW TYPE (W3)



NOTE:
ALL MILLWORK AT WIDOWS TO MATCH EXISTING DETAILS

ELEVATION



NOTE:
ALL MILLWORK AT WIDOWS TO MATCH EXISTING DETAILS

ELEVATION

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Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844

Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.

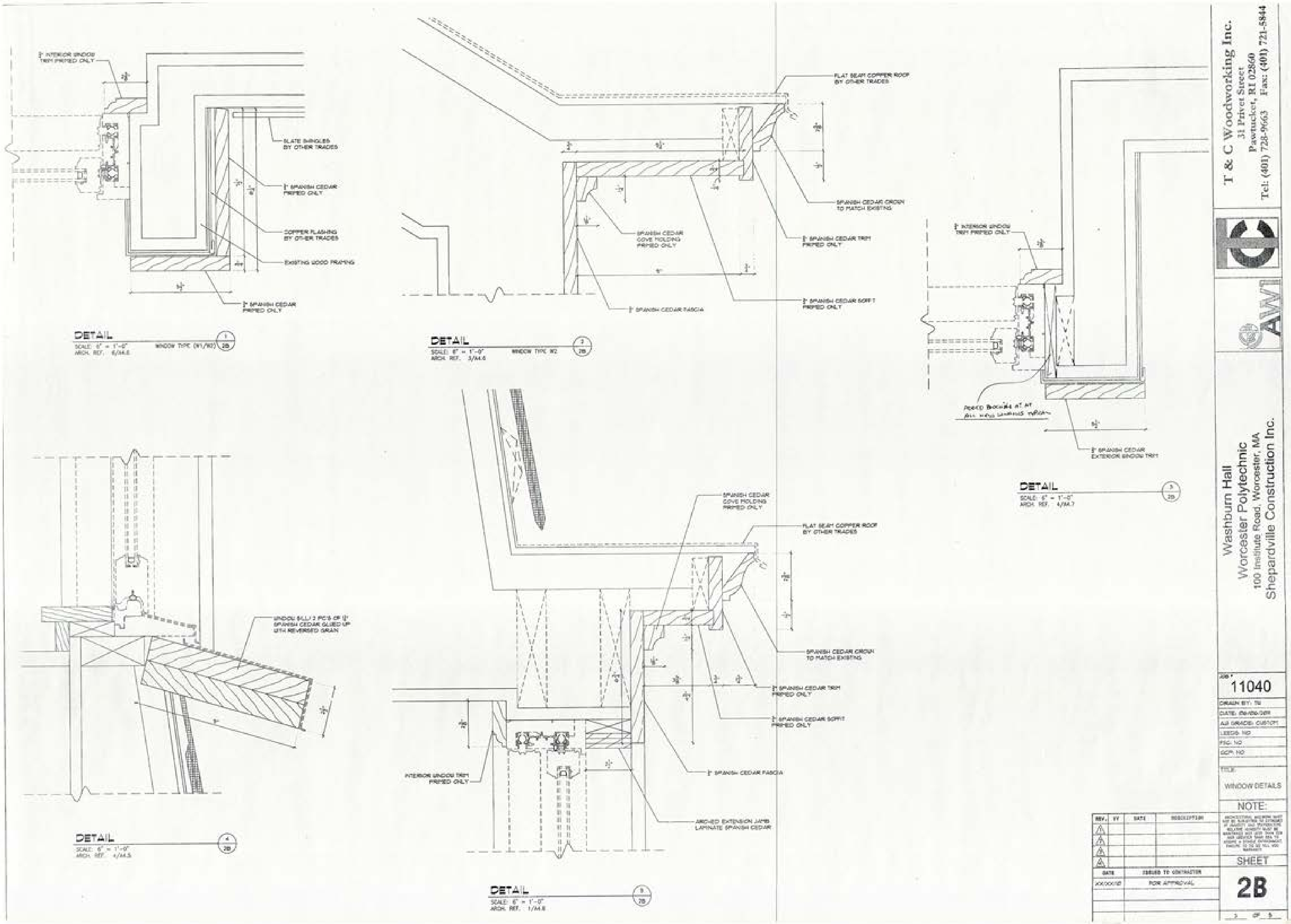
11040

WINDOW ELEVATIONS

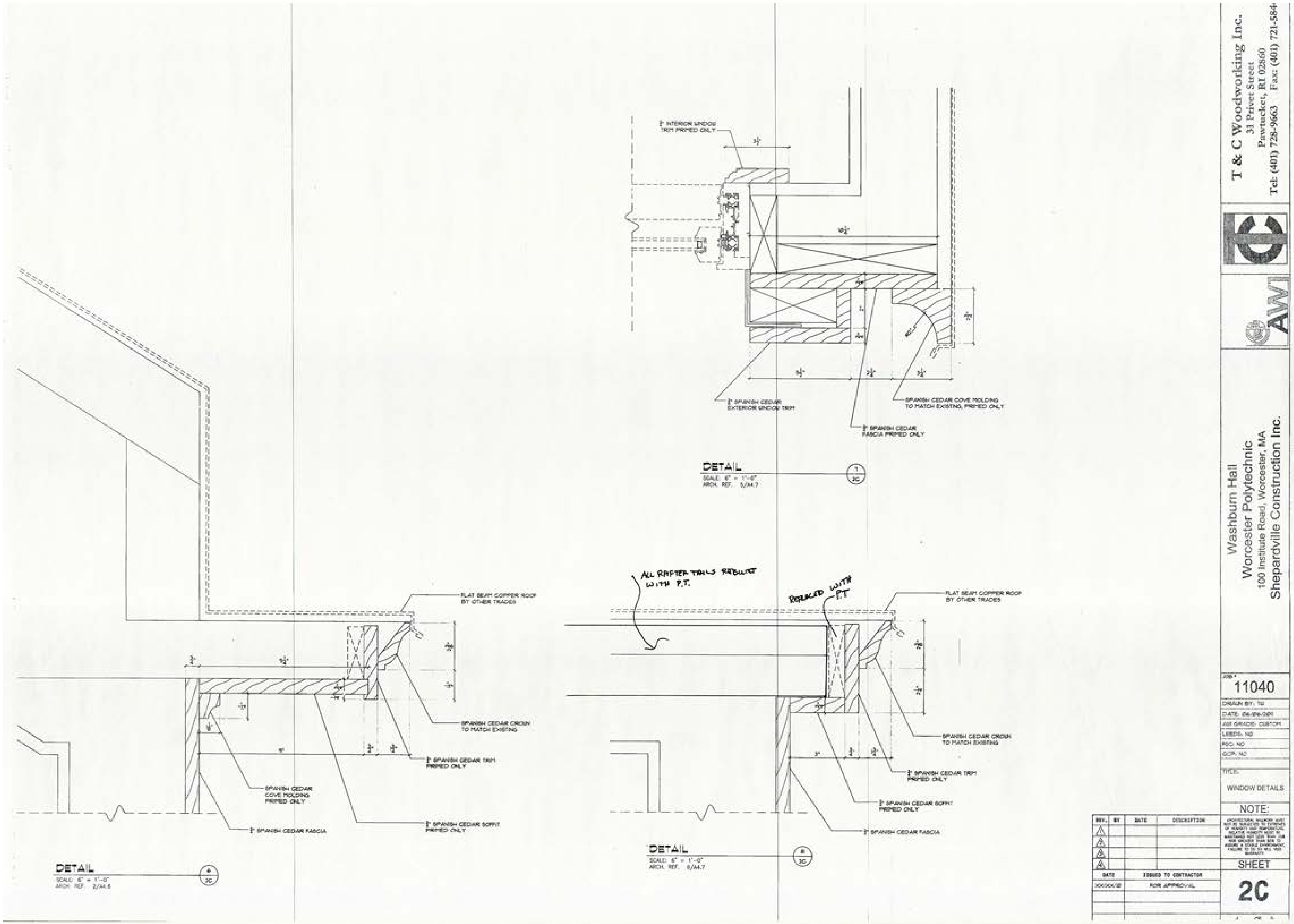
NOTE:

SHEET

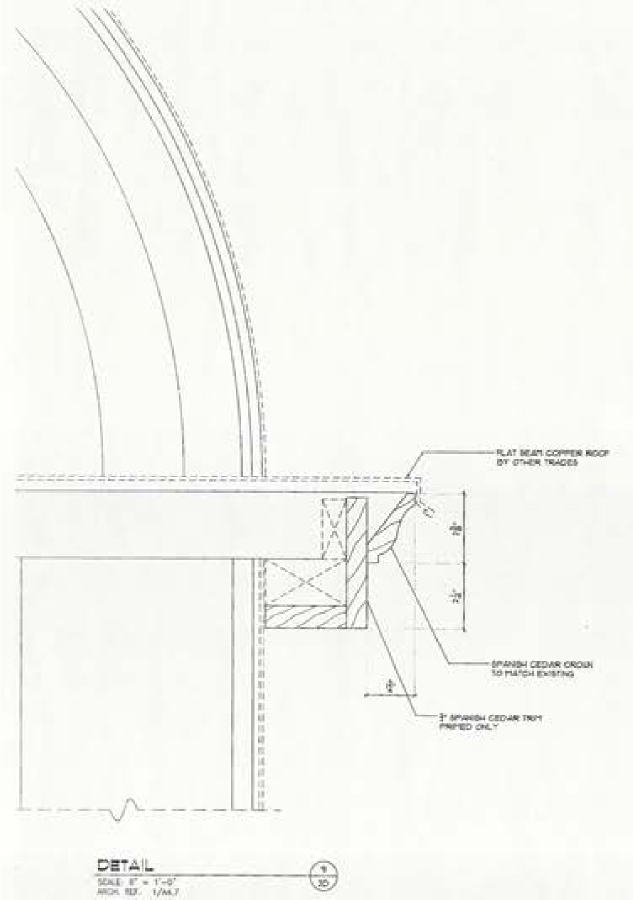
2A

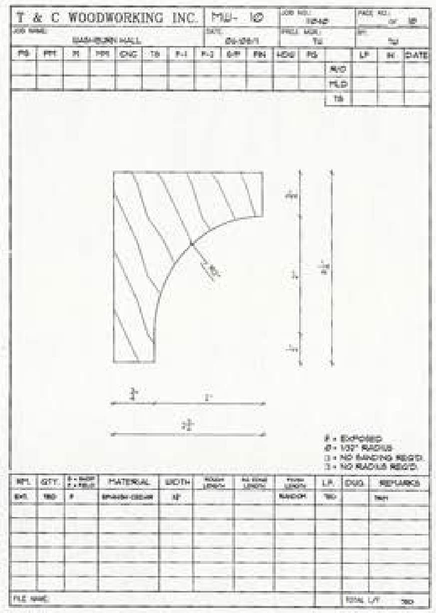


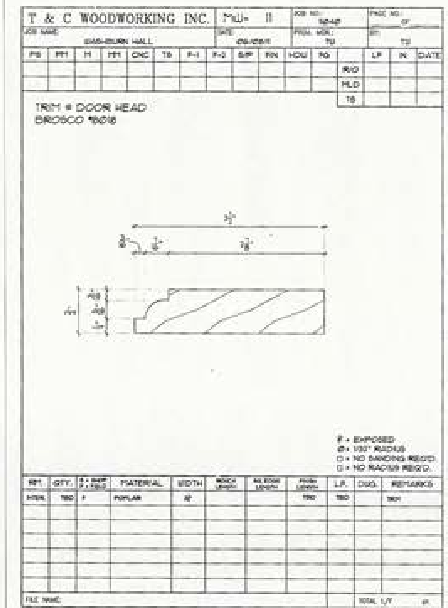
SLATE SHINGLES BY OTHER TRADES
COPPER FLASHING BY OTHER TRADES
EXISTING WOOD FRAMING
DETAIL
FLAT SEAM COPPER ROOF BY OTHER TRADES
SPANISH CEDAR CROWN TO MATCH EXISTING
SPANISH CEDAR COVE MOLDING PRIMED ONLY
DETAIL
DETAIL
DETAIL
DETAIL
T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5844
Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.
11040
WINDOW DETAILS
NOTE:
SHEET
2B

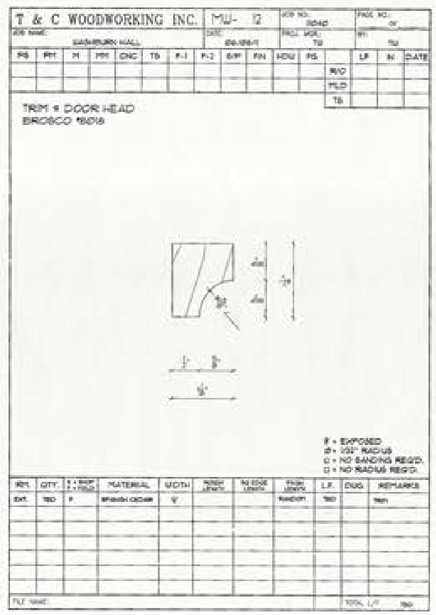


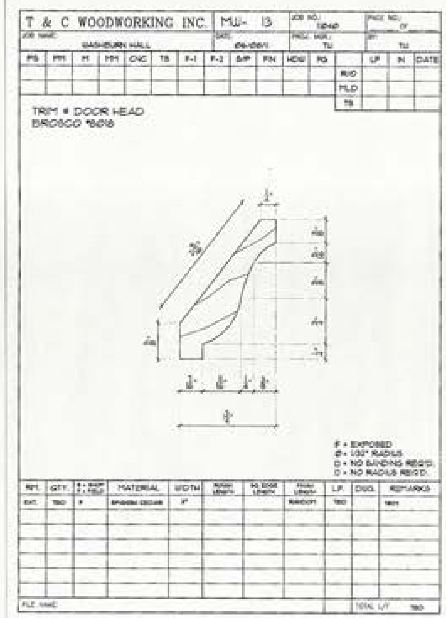
INTERIOR WINDOW TRIM PRIMED ONLY
SPANISH CEDAR EXTERIOR WINDOW TRIM
SPANISH CEDAR COVE MOLDING TO MATCH EXISTING, PRIMED ONLY
SPANISH CEDAR FASCIA PRIMED ONLY
DETAIL
SCALE: 6" = 1'-0"
ARCH. REF. 5/A4.7
FLAT SEAM COPPER ROOF BY OTHER TRADES
SPANISH CEDAR CROWN TO MATCH EXISTING
SPANISH CEDAR TRIM PRIMED ONLY
SPANISH CEDAR COVE MOLDING PRIMED ONLY
SPANISH CEDAR SOFFIT PRIMED ONLY
SPANISH CEDAR FASCIA
DETAIL
SCALE: 6" = 1'-0"
ARCH. REF. 2/A4.8
ALL RAFTER TAILS REBUILT WITH P.T.
REPLACED WITH P.T.
FLAT SEAM COPPER ROOF BY OTHER TRADES
SPANISH CEDAR CROWN TO MATCH EXISTING
SPANISH CEDAR TRIM PRIMED ONLY
SPANISH CEDAR SOFFIT PRIMED ONLY
SPANISH CEDAR FASCIA
DETAIL
SCALE: 6" = 1'-0"
ARCH. REF. 6/A4.7
T & C Woodworking Inc.
31 Privet Street
Pawtucket, RI 02860
Tel: (401) 728-9663 Fax: (401) 721-5847
AWI
Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.
11040
TITLE:
WINDOW DETAILS
NOTE:
REV. BY DATE DESCRIPTION
DATE ISSUED TO CONTRACTOR
FOR APPROVAL
SHEET
2C











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Tel: (401) 728-9663 Fax: (401) 721-5844

AWI

Washburn Hall
Worcester Polytechnic
100 Institute Road, Worcester, MA
Shepardville Construction Inc.

JOB # 11040

DRAWN BY: TU

TITLE: WINDOW DETAILS MOLDING SHEETS

NOTE:

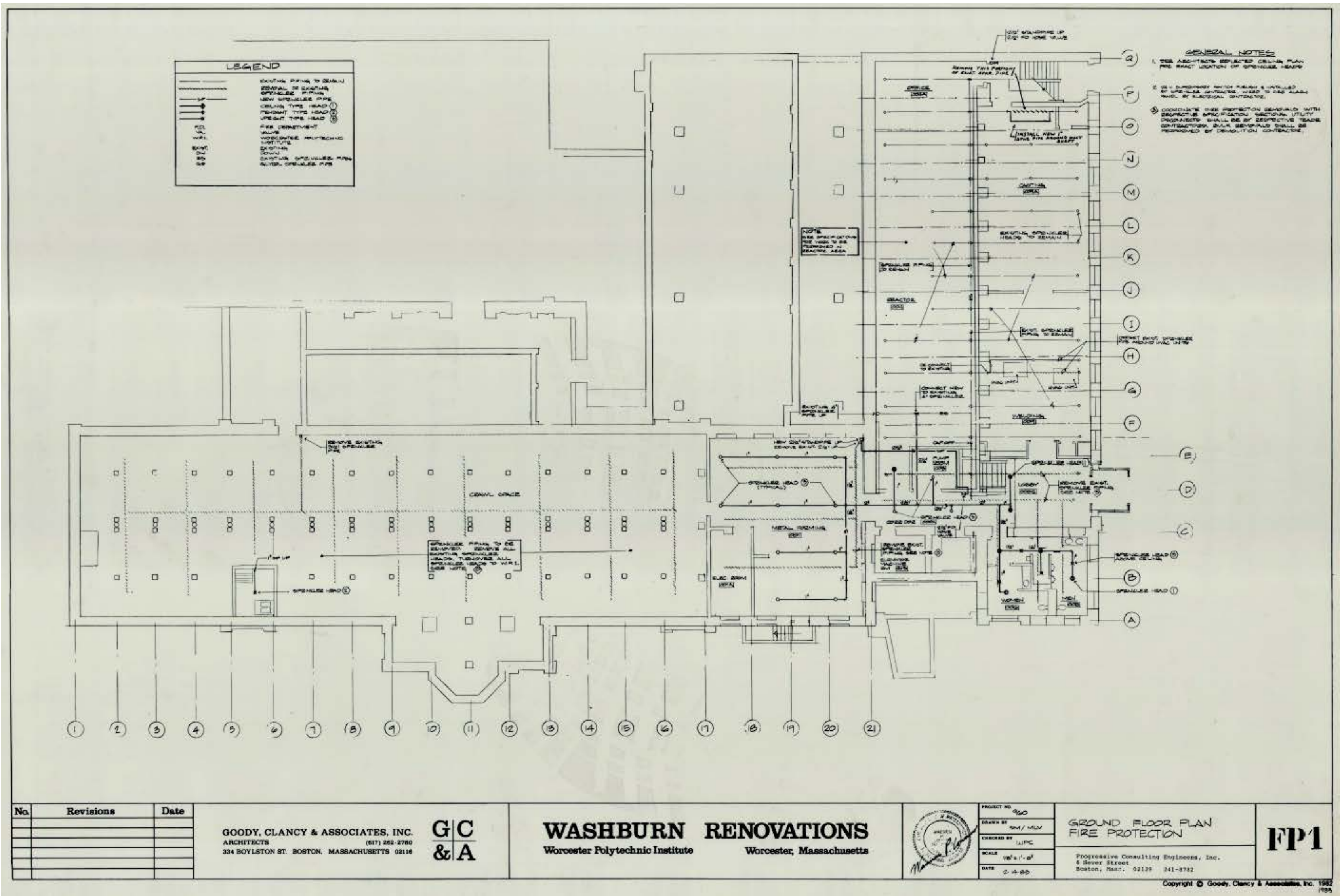
REV.	BY	DATE	DESCRIPTION
1			
2			
3			
4			

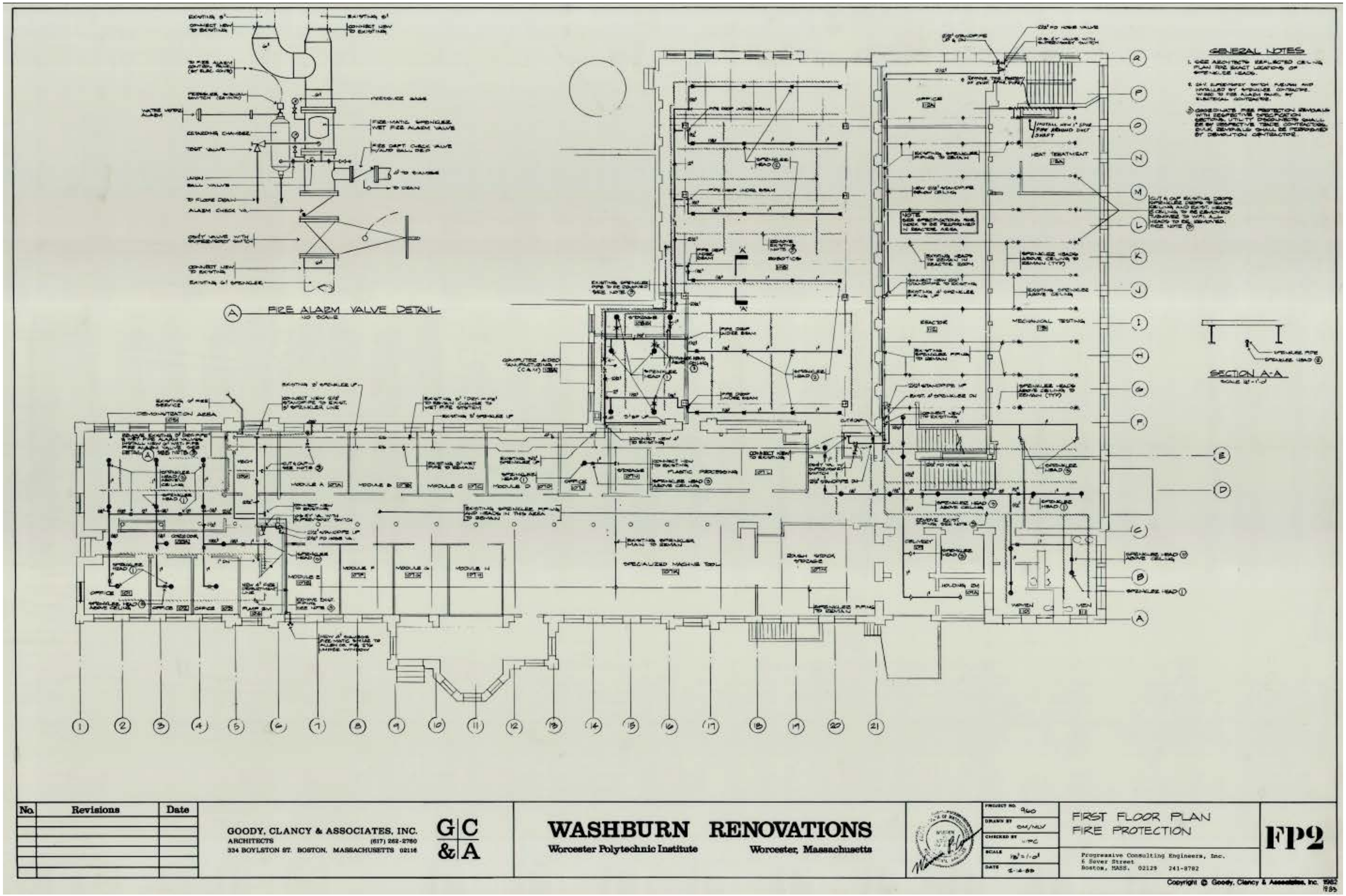
DATE	ISSUED TO CONTRACTOR
	FOR APPROVAL

SHEET

2D

7.6 Washburn Fire Protection Plans




GENERAL NOTES
FIRE ALARM VALVE DETAIL
NO SCALE
SECTION A-A
MODULE A
MODULE B
MODULE C
MODULE D
MODULE F
MODULE G
MODULE H
PLASTIC PROCESSING
SPECIALIZED MACHINE TOOL
MECHANICAL TESTING
HEAT TREATMENT
REACTOR
OFFICE
No.
Revisions
Date
GOODY, CLANCY & ASSOCIATES, INC.
ARCHITECTS
(617) 262-2760
334 BOYLSTON ST. BOSTON, MASSACHUSETTS 02116
G|C
&|A
WASHBURN RENOVATIONS
Worcester Polytechnic Institute
Worcester, Massachusetts
FIRST FLOOR PLAN
FIRE PROTECTION
Progressive Consulting Engineers, Inc.
6 Bover Street
Boston, MASS. 02125 241-8782
FP2
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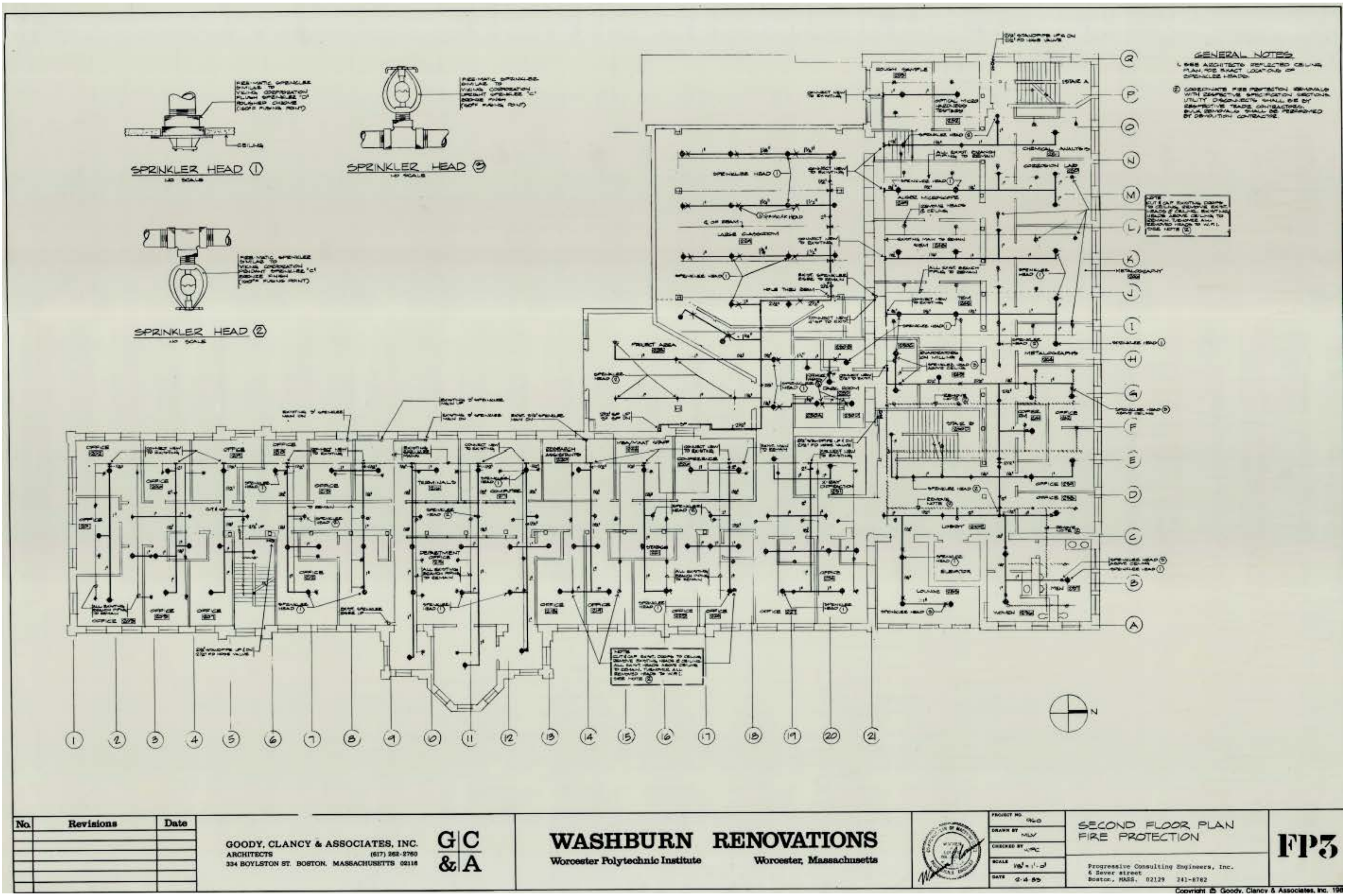
SPRINKLER HEAD ①
SPRINKLER HEAD ③
SPRINKLER HEAD ②
GENERAL NOTES
No. Revisions Date
GOODY, CLANCY & ASSOCIATES, INC.
ARCHITECTS (617) 262-2760
334 BOYLSTON ST. BOSTON, MASSACHUSETTS 02116
G|C &|A
WASHBURN RENOVATIONS
Worcester Polytechnic Institute
Worcester, Massachusetts
SECOND FLOOR PLAN
FIRE PROTECTION
Progressive Consulting Engineers, Inc.
6 Sever street
Boston, MASS. 02129 241-8762
FP3
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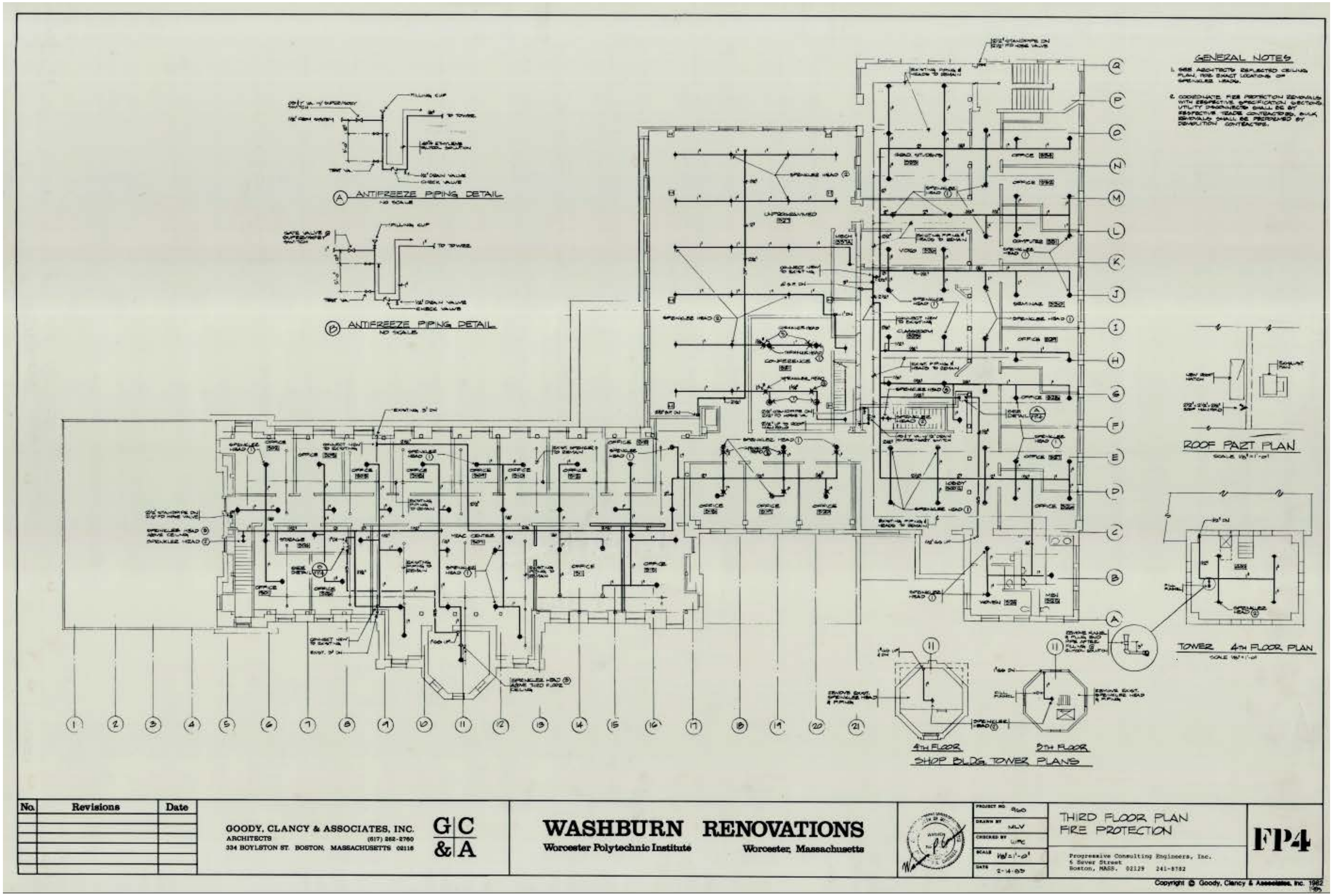
GENERAL NOTES
ANTIFREEZE PIPING DETAIL
ANTIFREEZE PIPING DETAIL
ROOF PART PLAN
TOWER 4TH FLOOR PLAN
4TH FLOOR
5TH FLOOR
SHOP BLDG. TOWER PLANS
No. Revisions Date
GOODY, CLANCY & ASSOCIATES, INC.
ARCHITECTS (617) 262-2760
334 BOYLSTON ST. BOSTON, MASSACHUSETTS 02116
GC &A
WASHBURN RENOVATIONS
Worcester Polytechnic Institute
Worcester, Massachusetts
THIRD FLOOR PLAN
FIRE PROTECTION
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7.7 Software User's Guides

7.7.1 Guide to Washburn BIM Model in Autodesk Revit

The following is a guide to using and viewing the Washburn BIM model the project team created in *Autodesk Revit*. These sections detail the steps to needed perform the desired tasks to be beneficial to WPI Department of Facilities.

Changing Views

Once the model opens in Revit different views of the model in 3D and plan view can be selected.

1. Open Washburn Model, the screen will show Figure 113.

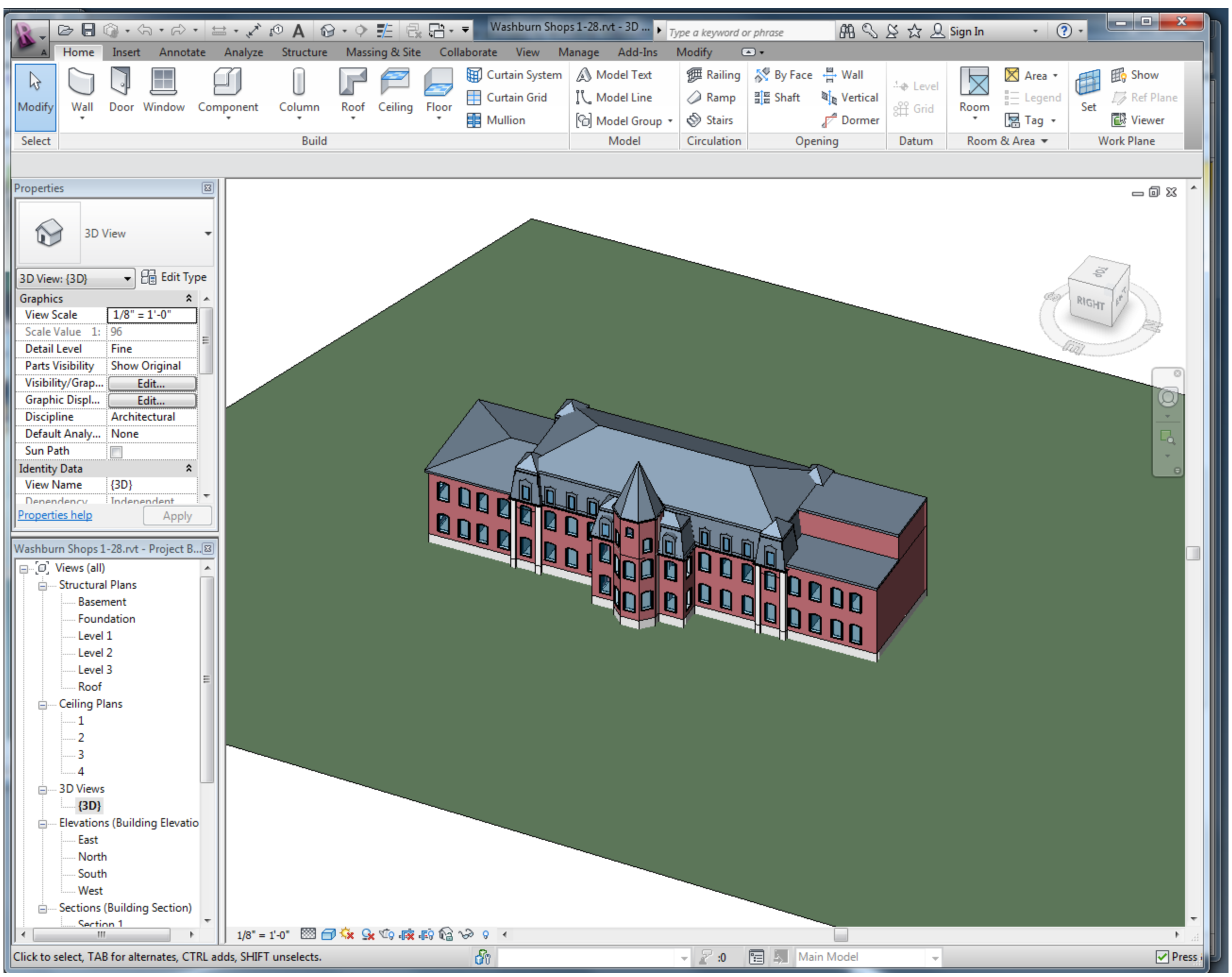


Figure 113: Opening Screen of Software

2. On the left-hand side of the screen click on Views in the Project Browser (Figure 114) to open. View 3D model, Floorplans, Elevations, Sections and Schedules.

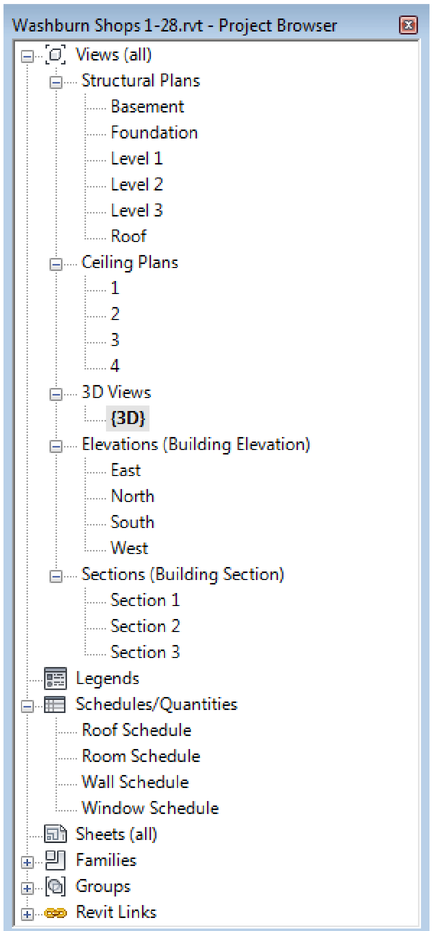


Figure 114: View of Project Browser

Viewing 3D Model

The 3D model of Washburn can be viewed at various angles and can be moved around in order to get different perspectives.

1. On 3D view of model click and drag to move building left, right, up or down.
2. To spin model use navigation cube in upper right-hand corner of screen (Figure 115). Click and drag cube or select side to snap to view. Click on the Home to return to the original view.

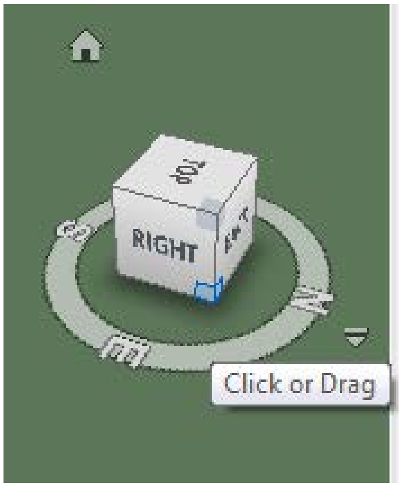


Figure 115: Revit Navigation Cube

Selecting Items

A specific item can be selected in the 3D model to view its properties and data. The properties of walls, windows etc. can be seen in this manner.

1. To select an item, move the building and click on the desired element.
2. Once an item is selected, it will be highlighted as shown in Figure 116.

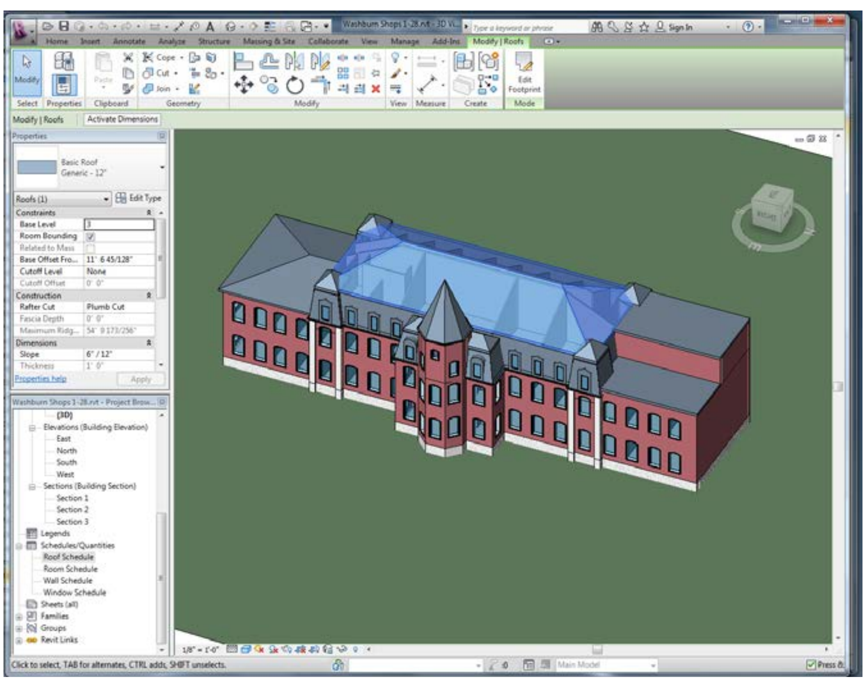


Figure 116: Selected Item in Model

Viewing Item Data

The renovation information from the most recent project on Washburn can be viewed in the model. The data associated with the project is attached to the item on which the work was completed.

1. After an item in the model is selected and highlighted, its associated properties box will be shown (Figure 117).

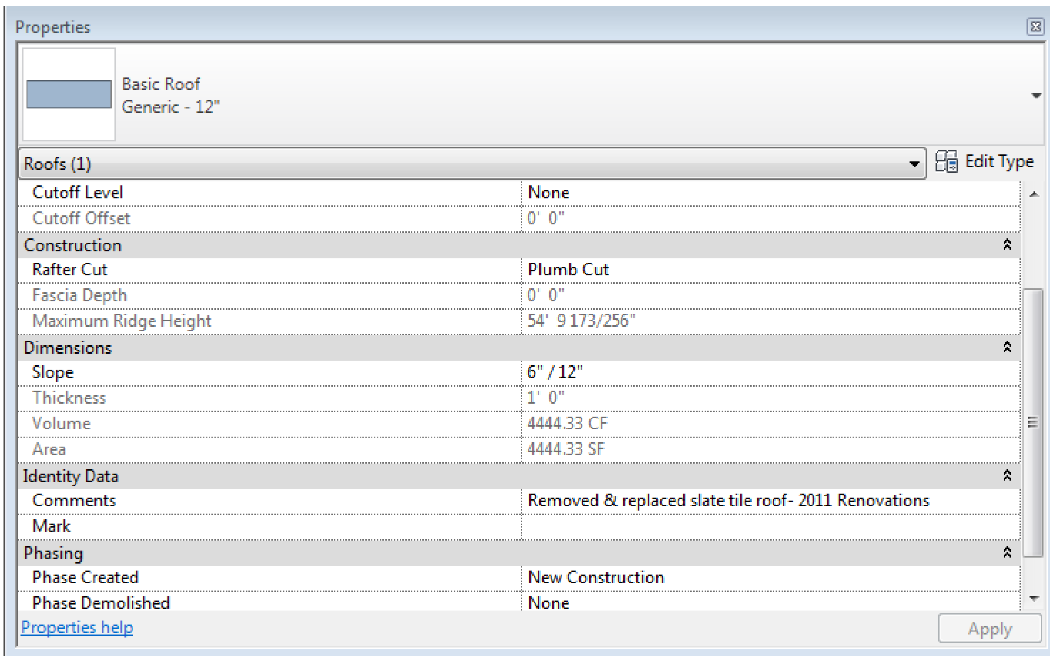


Figure 117: Properties Window in Model

2. The renovation data can be viewed under Identity Data and Comments.

Using Item Schedules

The BIM model also includes Schedules of the main project items. There is a schedule for Roof, Room, Wall and Window.

1. To view a specific schedule it can be selected in the Project Browser (Figure 118).

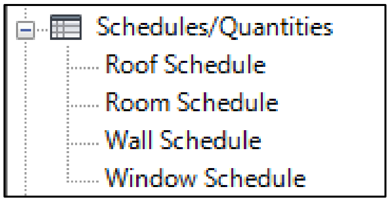


Figure 118: Schedule List in Project Browser

2. Figure 119 shows an example of a schedule. Certain data is displayed for each item along with the renovation information. Select an item in the schedule and it will also be highlighted in the 3D model and vice-versa.

Wall Schedule		
Structural Usage	Type	Comments
Non-bearing	Generic - 24"	
Non-bearing	Generic - 24"	Replaced column washes- 2011 Renovations
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	Repointed & added helical anchors every other coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	
Non-bearing	Generic - 18"	Repointed & added helical anchors every other coarse- 2011 Renovations
Non-bearing	Generic - 18"	Corrugated masonry anchors every 3rd coarse- 2011 Renovations
Non-bearing	Generic - 18"	

Figure 119: View of Item Schedule

For Further Information

The given guide provides instructions for viewing the model and accessing the data attached. For further information on using this software, Autodesk provides tutorials and guides for Revit on their website.

7.7.2 Guide to Washburn BIM Model in Autodesk Design Review

The following is a guide to using and viewing the Washburn BIM model the project team created converted to a dwfx file to be usable in *Autodesk Design Review*. This software can be considered more versatile with a greater ease of use. These sections detail the steps to needed perform the desired tasks to be beneficial to WPI Department of Facilities.

Viewing 3D Model

Once the model is opened in Design Review, it can be moved and viewed at various angles to see the building at different perspectives.

1. Open Washburn Model in Design Review, the screen shows Figure 120.

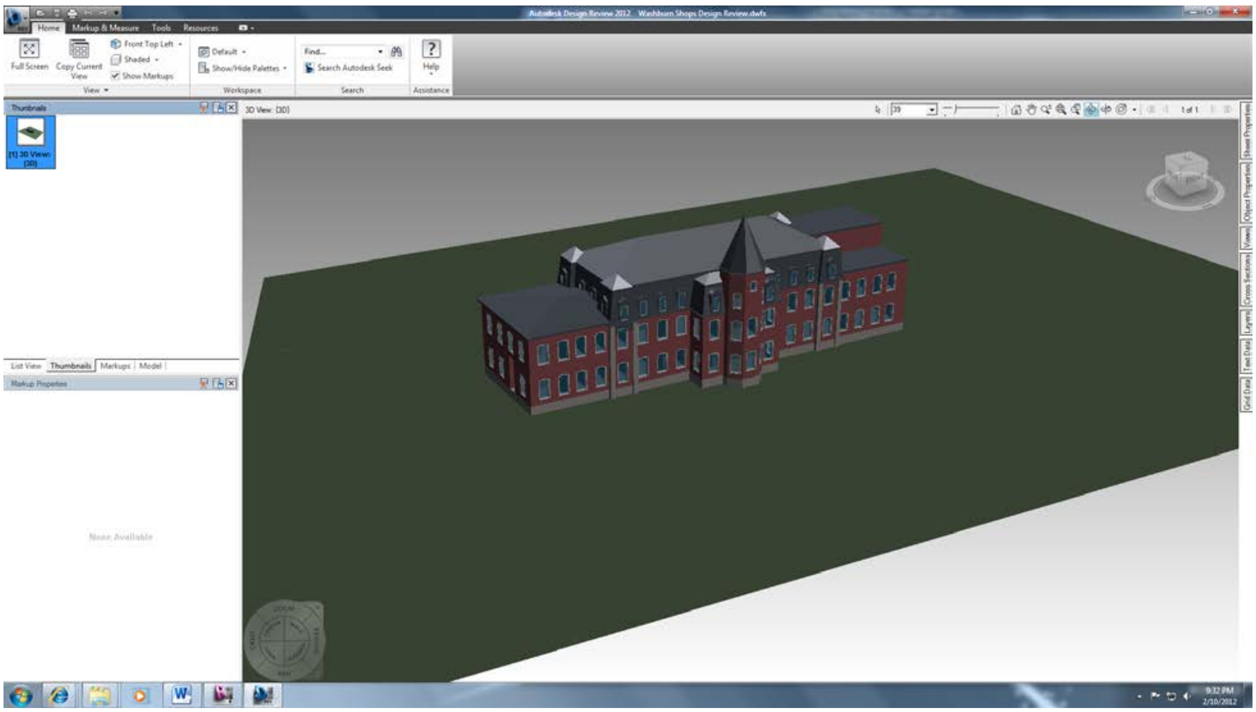


Figure 120: Design Review Opening Screen of Washburn Model

2. Move and rotate the model by clicking and dragging with the mouse
3. The model can also be moved with the navigation cube in upper right-hand corner of screen (Figure 121). Clicking on Top or an edge of the cube will make the model zoom to that angle of the model.

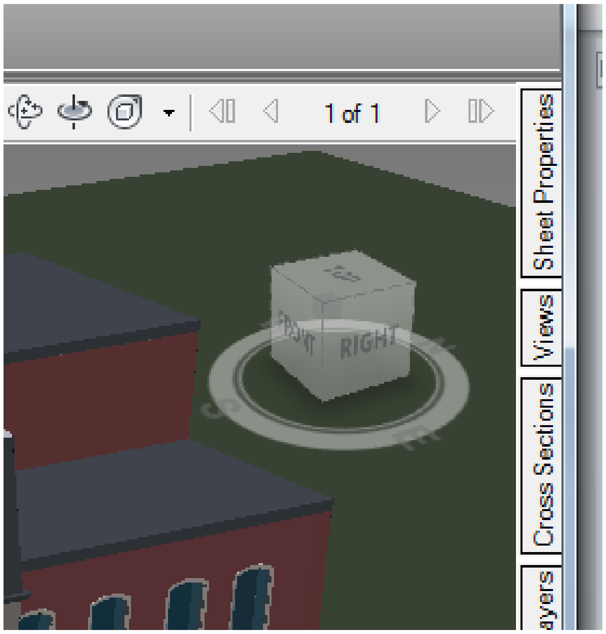


Figure 121: Design Review Navigation Cube

Selecting Items

A specific item can be selected in the 3D model to view its properties and data. The properties of walls, windows etc. can be seen in this manner.

1. To select an item, move the building and click on the desired element.
2. Once an item is selected, it will be highlighted as shown in Figure 122.

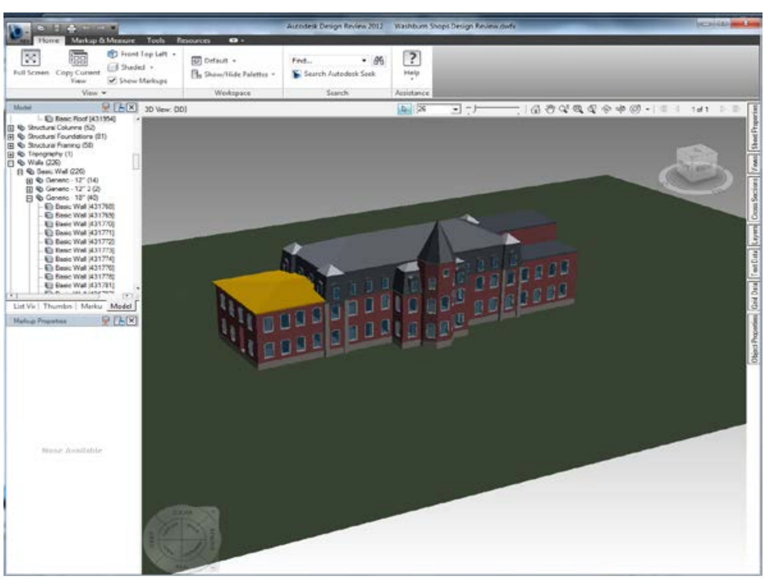


Figure 122: Item Selected in Model

3. An item can also be selected from the list on the left hand side of the screen when the Model tab is selected (Figure 123).

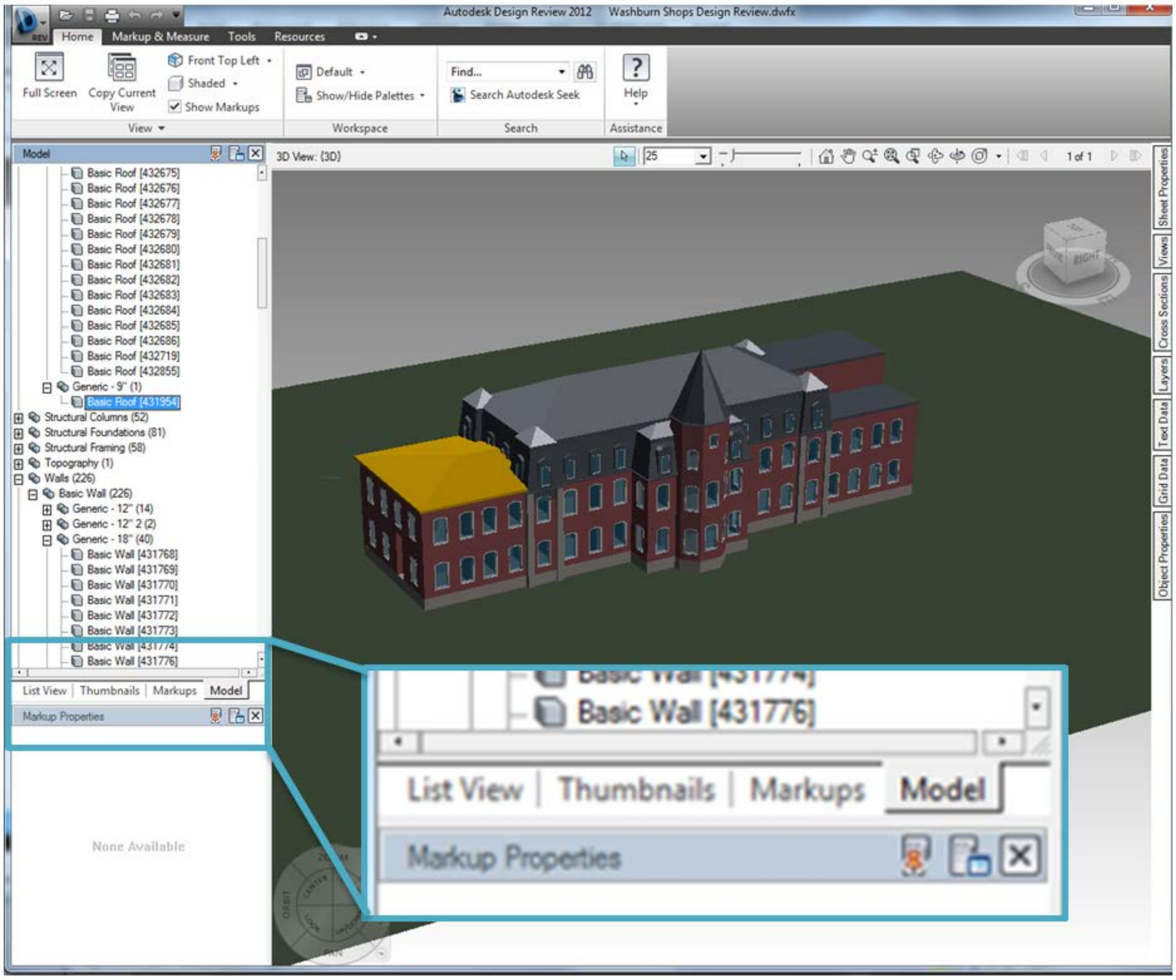


Figure 123: Item Selected from List in Model

Viewing Item Data

The renovation information from the most recent project on Washburn can be viewed in the model. The data associated with the project is attached to the item on which the work was completed.

1. Once and item is selected, to view properties click on Object Properties (Figure 124) on the right side of the screen

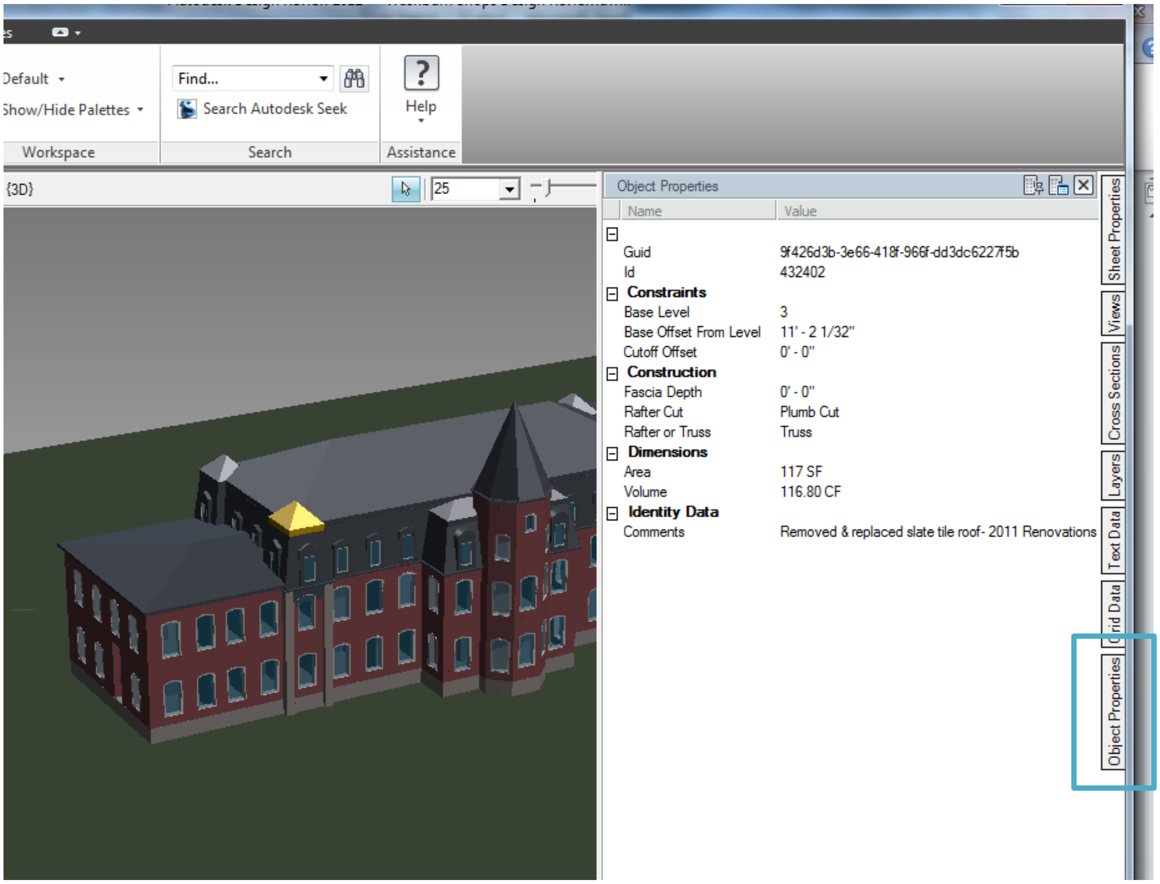


Figure 124: View of Item Properties

2. A box will appear on the right of the screen. The renovation data can be viewed under Identity Data.

For Further Information

The given guide provides instructions for viewing the model and accessing the data attached. For further information on using this software, Autodesk provides tutorials and guides for Design Review on their website. Design Review can also be downloaded there.

7.8 Interview Notes

7.8.1 Meeting with Chris Salter- WPI Department of Facilities

September 12th 2011 9am

Meeting Notes:

Background

- Washburn built 1868
    - Original 3 story
    - Added 2 story wings, 1880's 1890's
    - Same architect and GC
    - Masonry walls hollow
- Masonry 2 stories then timber frame
- Timber framing at midpoint between windows, evenly spaced

Building Codes

- Mass 8th edition update
- 30-40% cost of building when updated = must bring up to code
- Last major renovation, early 80s
- Thermal-no insulation
- Seismic-not designed for

Expectations

- Want to have existing conditions on record
- Complete set of drawings from us
- No original drawings, drawings for 80s renovations
- Show timber framing in drawings
    - Elevations
    - Floor plans
    - Structural drawings
- Understand load timber on interior wall
- Design for flaws
    - Fill void with lightweight concrete
- Identifying and cataloging existing conditions
    - Forecasting based on building codes
    - Cost of investment threshold for code compliance

Renovation Project Details

- Hoffman Engineering/Architects
- Post assessment by Hoffman, things to consider
- Cost approximately $1.6 million
- Timber structure work- mansard
    - Wood rotten
- Fixing some masonry
    - Arches, flashing and cocking
- Bell tower loose
- Stripped and leveled roof, ice and water dam
- Finished end of A term

Project Outline

- History
- Description existing conditions
- Flaws
- Compliance and cost thresholds
- Challenges in future
- Code improvement issues
- Requirements and how to make building comply
- Potential methods of resolution

Wednesday 9:30am construction meetings

37 Lee St

Salter, superintendent, Hoffman

7.8.2 Meeting with Frank Horanzy- Lead Electrician WPI

November 2nd 2011

- Alarm Panel: 2001 Simplex Model
- If a new panel was to be installed, it would be the Simplex 4100 (Stratton Hall Summer 2011)
- Panel needs replacing, can't even buy new parts for this model (taken from old buildings)
- Non-addressable System (panel indicates which floor, but not which detector was set off)
- New smoke detectors (12 yrs old), others are from the 1970's
- Flow switch (starts flows)
- Alarm on switch pipe sets system into distress

- Recent fire from construction
    - Smoke traveled above ceiling panels and out into hall where a panel was missing. Smoke hadn't even reached detector before someone noticed smoke and pulled a switch
- Smoke detectors are very far away from one another and need to be replaced
- Entire system is tested in the summer and some testing is done over Christmas break
- When alarm is activated in an academic building, alarm is sent to campus police who address the situations
- When alarm is activated in dorms or in Goddard (chemicals/gases), Simplex and Campus Police receive the alarm
- All pieces of fire system are simplex
- 2nd floor, old 70's smoke detector on side of door
- A few fire doors in buildings that close when smoke is detected
- Building was over-sprinklered due to wood construction
- Smoke detectors were installed in ducts in rm 342 and two others 15 years ago
- Building Fire system consists of
    - Panel
    - Flow Switch
    - Smoke detectors (3 in ducts)
    - Fire Doors
    - Sprinklers
    - Fire Department Hose connections on each floor
    - Elevator alarm to return to floor of fire

7.8.3 Meeting with Dave Guertin- Cutler Associates

November 2nd 2011 3:30pm

Meeting Notes:

Mortar

- Old- Putty mortar
- No cement, just lime and water
- Joint 1/8in 3/16in, repointed

Outcroppings of Tower- refer to Drawing #1

- Refaced
- Brick not tied in
- In cavity tied bricks in
    - Used brick tie- metal 3/4in stainless steel
    - Every other course brick tie
- Originally were stacked bond

    - Added ties and staggered

Brick Testing

- None completed before or after construction

Replacing Bricks

- Replaced with Portland cement
    - Heavy duty mortar- mortar, lime, sand (Dave will send guidelines)
- Original scope- repoint all bricks in building
    - Because of hollow walls, only tower repointed
- Cavities not tied to back wall- seismic issue
- Tower in original scope
- Stacked bricks, mortar in cavity
- Arches- filled/replaced and tied to back wall
- No major structural work on building
    - Just tower, tied and staggered

Roof

- Slate
- 3/4in plywood screwed down
- 2 ½" x 8" plank= original roof
    - Not rotted
- Plywood, then ice and water shield, then slate slip guard

Tower

- Angles to reinforce tower
    - 6" x 8" x ½" through bolted to post and beam
    - 4" x 4" x ¼" on top and bolted

Rotting Wood

- Tower gutter section- Drawing #1
    - 2 6" x 6" beams, replaced with 6x6 pressure treated
- Backside of Tower
    - Rafters
    - Like a shelf- replaced with pressure treated

Windows- refer to Drawings #1 and #2

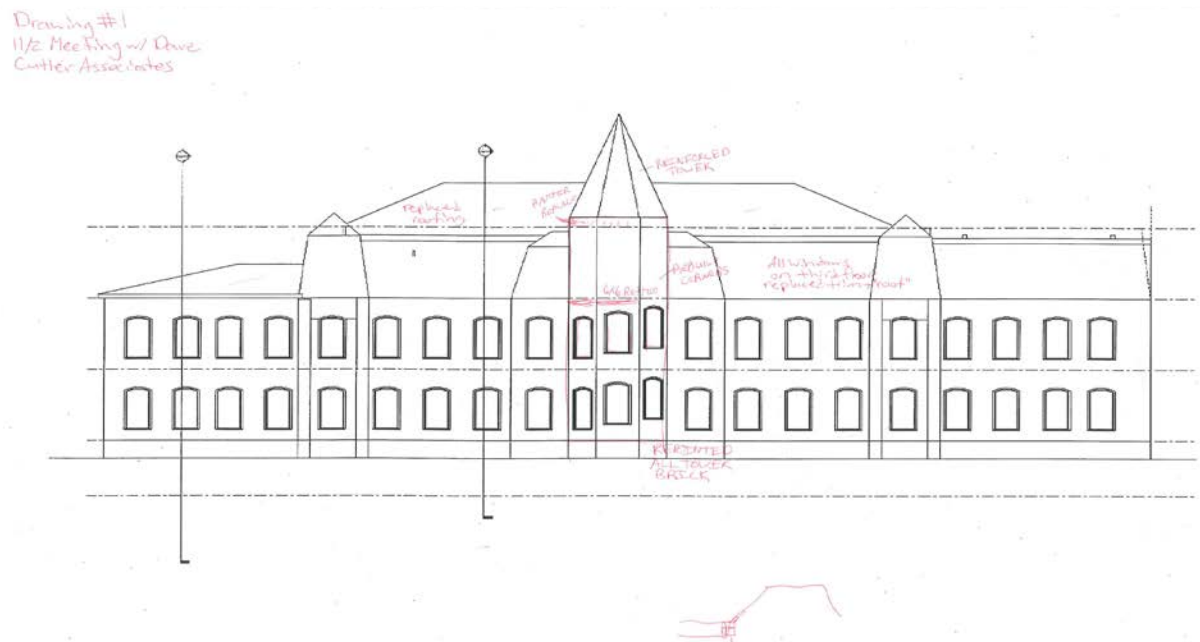
- Every "roof" of window replaced with pressure treated wood- rotted
- Flashing replaced, zinc coated copper
- Nails copper and stainless steel fasteners
- All windows on third level and dormers
- Tower 2nd level 3 replacement windows (mid window higher)
    - Divided light

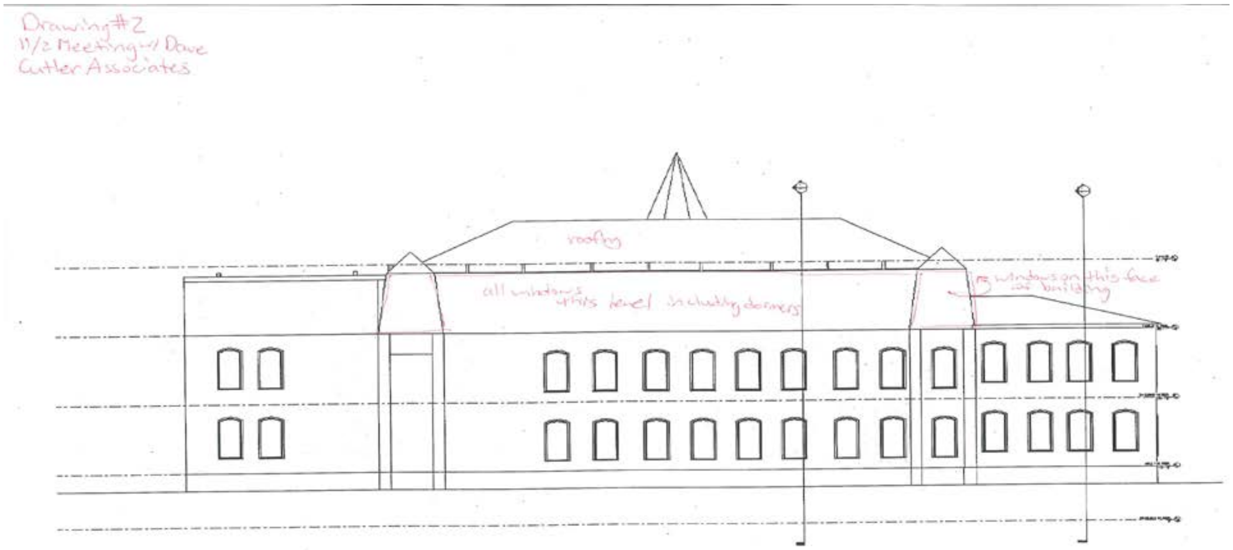
- Front, over loading dock and Boynton face of building
    - New windows on third level

Interior Work

- Only trim of all fixed windows

Dave will send drawings of detailed work





7.8.4 Meeting with Steve Susca of Hoffman Architects

Questions

- What was your role in the renovation and what previous work have you done similar to Washburn?
    - o We were retained to perform a condition assessment of the building envelope particularly with respect to the mansard. Widespread leaking was occurring at the roof and mansard and numerous structural issues were noted in the brick façade. We were asked to assess these defects and opine on their root causes and provide a recommended program of repairs. This was the first project we have done with WPI.

- How was Washburn different from this project?

- What was the overall purpose and scope of the project?

- The purpose of the project was to stop the leaks and restore the structural integrity of the façade. Ancillary goals were to repair or replace damaged or otherwise deteriorated portions of the building envelope and maintain the historical appearance of the building. The original scope of the project included the following major items:

- *Removal and replacement of the slate roof of the original Washburn Shops building, including installation of new plywood sheathing, ice and water barrier and underlayment felt;*
- *Slate roof replacement at the Tower, including installation of new plywood sheathing, ice and water barrier and underlayment felt;*
- *Slate cladding removal and replacement at the mansard, including installation of new plywood sheathing, ice and water barrier and underlayment felt;*
- *Removal and replacement of all copper and lead coated copper flashings including:*
- *Valley flashings;*
- *Step flashings;*
- *Counter flashings*
- *Base flashings;*
- *Eave flashings;*
- *Ridge Caps, and*
- *Crickets.*
- *Replacement of the copper belfry roof;*
- *Replacement of flat seam copper roofing at dormers, and corner cupolas;*
- *Protection of all roofs below the Work;*
- *Window replacement at the mansard and upper tower;*
- *Structural reinforcement of the Belfry atop the tower;*

- *Removal and replacement of all exterior wood trim and mouldings at the main building and the Tower inclusive of the belfry including priming and painting of the new trim and mouldings to match existing;*
- *Full repointing of all masonry joints in the building façade including brick, window sills, false column capitals, and granite foundation blocks;*
- *Removal of three abandoned chimneys and restoration of the roof decking;*
- *Masonry restoration including:*
- *Masonry window arch reconstruction (to be eliminated if Alternate 2 is chosen);*
- *Repair of cracks in brick façade (to be eliminated if Alternate 2 is chosen);*
- *Replacement of spalled and cracked brick, and*
- *Restoration of brick masonry dentils.*
- *Realignment of gutters at the base of the mansard to remove all dips, sags and other defects;*
- *Replacement of joint sealant around all windows that are to remain*

However due to budgetary constraints, some of the original scope was eliminated from this project and deferred to later years. This mainly consisted of masonry repairs (repointing, crack repair, reconstruction of select areas, etc.) outside of the tower

- How was the scope of repointing Washburn established?

  Our original scope was to repoint the entire building. The mortar in the joints was found to be in pretty bad condition and in need of replacement after 150 years.

  - Which sections were prioritized?

    Due to budgetary constraints, much of this work was eliminated. Hoffmann Architects was not involved in determining which parts were taken out of the project. Chris Salter may be able to answer this better for you.

- What were the guidelines that they had to follow? Can you share them with me?

  - Were there any guidelines for the brick and mortar and method of brick laying?

  - Was there any testing done on the bricks or mortar? How did you determine these guidelines?

    - If cant give me guidelines: Well what codes did they reference? A masonry code in ASCE? etc.
    -

I've attached a specification for brick restoration which should be able to answer these questions.

- I learned that brick ties were incorporated into the building by the renovation was the purpose of the brick ties to bring it up to codes or was it just to strengthen it?

During the investigation phase of the project, it was found that there were very few ties installed when the building was constructed and many of them had been pretty severely corroded. Historic Buildings are allowed some leeway with respect to meeting the current building codes. For this reason, the main purpose of installing the brick veneer ties was to provide better anchorage of the façade to the structure.

- Were similar reinforcements incorporated in other structural elements?

  The construction of this building is somewhat unique. the façade of the building is also a portion of the overall structure. The hollow walls that were discovered are actually not walls at all but large open core brick columns that also function as the walls. Therefore the veneer ties also served as a portion of the structural reinforcement for the building.

- How much work would you say was done on the building? What percentage of the building was renovated?

- That's kinda tough to answer. For most projects, they measure in a percentage of the total floor space or square footage of the building. We did no work on the inside of the building however we rehabilitated the entire roof and mansard and a good portion of the tower façade. I guess you can say we renovated approximately 40 percent of the total building envelope (inclusive of the north and south wings that were added to the building circa 1890)

- During repointing I heard that you found hollow masonry walls how did you deal with this and what exactly did you find?

- The "hollow masonry walls were discovered during the investigation of the project. Further investigation revealed that they are not hollow masonry walls, but more like hollow masonry columns that double as the portions of the walls between the buildings.

- In your professional opinion how would these hollow masonry walls affect the structure of Washburn?

  As noted above, the hollow walls *are* the main structural component of the building.

- What work was done on the tower?

The brick corners of the tower were reconstructed from the ground up, in order to tie then together where there is a change in direction from one plane to the next. This helps to provide a little more rigidity to the overall structure.

In addition, the attachment of the belfry to the building was reinforced to ensure it is not damaged in a windstorm.

All slate was replaced as well as all wood trim and the copper belfry roof was replaced. The weathervane was also restored.

- Were there guidelines for the tower too?
- The masonry guidelines for the tower are the same as for the rest of the building as well as the slate replacement and woodwork. I've attached the slate and carpentry specifications for you.

- The bricks were cut to match the existing washburn bricks. Do you know the size that the bricks were cut to?
- The height of the bricks were cut to match the existing. I do not have the exact dimensions of the brick however I believe they are roughly 7-3/4" X 2-1/8" x 3-1/2"
- Is the mortar thickness the same as specifications given by ASTM or were these also altered to mimic washburns existing mortar joints?

- The mortar joints were specified to match the existing joints in order to maintain the historic characteristics of the building.
- Do you have the structural information about the timber roof structure. For example information about the layout of the timber beams and they type of timber etc used in washburn?
- Unfortunately since we did no work on the roof structure of the building, we do not much information. All I really know is that the existing roof deck is comprised of 2 inch thick tounge in groove boards and they are supported by heavy timbers spaced at 8' on.

7.8.5 BSCES and SEAMass Joint Presentation

Presentation: Massachusetts Building Code, 8th Edition Chapter 34: Existing Structures Incorporating the 2009 International Existing Building Code

- Presentation were given on the following topics
  - Background, Chapter 34 and Massachusetts Amendments
  - The Architects Perspective
  - Appendix A.1
  - Seismic Perspective
  - Sample Problems
- Chapter 34: Existing Buildings
  - Intent of Code: building official can't expect a lot of building upgrades
  - Owner/designer determines compliance path and the building official can't require a particular path
  - Almost every project uses prescriptive method
  - 101.5.4.0: Investigation and Evaluation is a Massachusetts specific amendment
  - Masonry wall amendment still covers all existing buildings
  - Appendix A.1 may require masonry testing
- Architects Perspective
  - Renovations require certain codes to come into effect, depending on the renovation size
    - <$100,000: only current work has to comply
    - >$100,000 but less than 30% of building value: current work and public access must apply
    - >$100,000 and more than 30% of building value: entire building must comply
    - Substantial Renovation requires update of sprinklers (substantial=updating fire protection system > 15% of total renovation cost)
- Appendix A.1
  - Life of building increasing = Risk of building increases
  - Initial assessment to see if building will support loads
  - Requirements of bearing walls and frames are listed in this appendix
  - Appendix equations allows engineer to do simple testing without producing much of the design work
- Seismic Design:
  - Chapter 21 details requirements for masonry structures
  - Extensive revisions have been made for seismic requirements in existing building
  - Some new requirements have been made retroactive and apply to existing buildings
  - Recently the building codes have been made more stringent

7.9 Proposal

Note to Reader: The appendices of this proposal were excluded from this appendix to avoid repeating information in this report. The appendices submitted with this proposal were the rough drafts of the information presented in the appendices of this reports; no information was excluded from this report that was previously in the proposal appendices.

GFS 1201
LDA 1204

Study of Washburn Tower Renovations

A Major Qualifying Project Proposal
Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the
Degree of Bachelor of Science
in Civil Engineering
by

____
Amanda Bowden

____
Paige Hanson

____
Alexandra Marokhovsky

Date: October 13, 2011

Approved:

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Professor L. D. Albano

____
Professor G. S. Salazar

Abstract

Washburn Shops, built in 1867, was one of the first buildings constructed on Worcester Polytechnic Institute's campus and is still in use today. Since Washburn is so old, many renovations and changes have been made to the structure resulting in dated, inaccurate drawings. The long life of Washburn also results in dated code compliance. If the building was to be renovated today, parts of the building would have to be brought up to compliance with the current Massachusetts State Building Code. This project will focus on the need to update Washburn's structural and fire engineering systems to ensure code compliance. Using Building Information Modeling (BIM), the team will create a model of Washburn that includes current drawings, renovation histories, areas that are not in compliance with the seismic and fire codes and design options for solving the code compliance issues. In the future, the facilities department at WPI will have access to this model for reference in upcoming renovations.

Capstone Design Experience

Included in the Major Qualifying Project is the capstone design experience, consisting of three components. First is a description of the design problem. Next is the approach to this design problem and finally a discussion on how the ABET General Criterion's realistic constraints are addressed. This section will discuss each component and its relation to fulfilling the requirements of this MQP.

Design Problem

Washburn Shops, one of the two original historic buildings on the Worcester Polytechnic Institute Campus, has recently been found to have structural and documentation issues. During the renovation project this year, these issues were called to the attention of WPI Facilities. The contractors, who were performing exterior masonry work, discovered the exterior walls of Washburn to be hollow except supporting columns between each of the windows of the original building. Fixing this problem requires an innovative design and in fixing it, the building may have to be brought partially or entirely into compliance with the *Massachusetts State Building Code*. The university and facilities office did not know the makeup of the walls until this project and other details of the building because sufficient documentation does not exist.

Approach

To approach this problem, the project team will first document the current condition of Washburn visually, structurally, historically and in regards to the *Massachusetts State Building Code* (MSBC). Building Information Modeling will then be utilized to design the building and document the most recent renovation project. After this model has been created, the team will investigate options to design a solution to the structural issue and to the areas of non-compliance in accordance to the MSBC. Through an iterative process these issues will be examined and solutions will be delivered to WPI Facilities.

Realistic Constraints

According to the ABET General Criterion, there are realistic constraints that should be considered in a major design experience to incorporate engineering standards. The following sections detail the five constraints that are address by this MQP.

Economic

In suggesting future designs, economic constraints will be considered. Some solutions to the structural and code violation issues may not be economically feasible to be judged an appropriate solution. When developing the BIM model of Washburn's current status, the economic factors of the most recent renovation will be considered and documented.

Manufacturability

The manufacturability of the proposed solutions must be considered. If it is not a feasible design to produce, then it is not feasible suggestion. Alternative designs will be proposed to avoid a manufacturability or constructability limitation. The materials of design and resources during construction will be considered. In the future BIM will allow an ease in manufacturability and constructability when working on Washburn because all information will be combined in one comprehensive model generated from this project.

Health and Safety

Health and safety is a significant consideration in any construction project, as it will be in the suggested designs. The designs proposed that will address the areas of non-compliance will also address health and safety. Building codes account for the health and safety of its occupants. In reaching these codes, Washburn will be safer for its users.

Social

Any changes on the WPI campus would have social implications. The extent of the designs and the affect the construction would have on the study body will be considered. The proposed designs implications to the campus will be considered from all sides, the student, the faculty, and the school.

Political

Washburn is a historical and high-valued sentimental building in the minds of students, alumni, faculty and staff. It represents the inception of the university that many have strong ties to. Construction and alterations involving this building will have a political implication within the WPI community. The team will consider the reaction and standpoint of WPI officials when selecting the most appropriate design solutions.

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1.0 Introduction

Washburn Shops is one of WPI's two original founding buildings. Built in 1867, the original purpose was space for machine shops and classrooms. Over the past 145 years, the building has been renovated many times to keep up with the needs of WPI.

Through these many changes, centralized and current information regarding Washburn shops is not readily available. The long life of the building presents code compliance issues. Considering the building was built over a century ago, the codes have changed drastically.

Present drawings of Washburn do not accurately depict the structure or dimensions of Washburn. Without accurate drawings, renovations may unknowingly cause damage to the structure. Also, these renovations may warrant updating the building to code. In particular, the seismic and fire codes are of great concern because they control the safety of the building.

This project will create a Building Information Model (BIM) of Washburn shops to depict current drawings, renovation histories, areas with seismic and fire code compliance issues, and design possibilities for solving these code issues. The completed model will provide WPI's facilities department with a reference to use in future renovations of Washburn.

2.0 Background

This chapter covers the five main areas of this project. First, a summary of Washburn's history portrays the changes the building has endured over the past 125 years. Second, a description of the current construction describes the recent renovation and discusses potential structural problems. The next section expresses the importance of project documentation for future construction and the lack thereof for Washburn (seen in Figure 1). A section over viewing BIM (Building Information Modeling) explains how this technology can be of practical use to a project in documenting Washburn's drawings and code compliance. Lastly, a summary of building codes presents the applicable codes that would bring a building such as Washburn up to standard. The five sections clarify the documentation issues with Washburn and some of the future areas of concern.

Figure 1. Washburn Shops

2.1 Washburn History

To fully understand why inaccurate and code compliance issues exist, the history of Washburn must be explained. This history will give a recap on how Washburn became the building it is today, including both its importance to the school and the challenges involved in keeping it safe.

2.1.1 Building Washburn

The first proposal for the construction of Washburn Shops was submitted to the Board of Trustees on December 2nd, 1865. Ichabod Washburn was, at first, the sole supporter of


Figure 2. Washburn Tower

building Washburn Shops. Ichabod materialized his idea of a machine shop by supporting Stephen Salisbury and Emory Washburn's proposal of a school for Mechanics. Ichabod donated money from his business, Washburn Wires, in order to fund building and equipping a machine shop. The basis of the WPI's curriculum, theory and practice, originate from this decision (Tymeson, 1965). The building was finally accepted by the trustees in March of 1866 (Taylor, 1937). During the construction, Ichabod suffered from a paralyzing stroke and was unable to continue his work on the project. Considering the walls of the shop were only halfway up, the project could have collapsed. However, Ichabod's superintendent at the wire mill, Charles H. Morgan, took over to see the project through completion (Tymeson, 1965). Figure 2 depicts Washburn's Tower.

The entire building cost was between $12,000 and $15,000 and consisted of a main shop and a wing. The main shop footprint was 102 ft by 44 ft and three stories high. The wing was 65 ft by 25 ft and contained the engine room, boiler room and blacksmith shop. Figure 3 illustrates this layout. Within these rooms were two 20 H.P. boilers and a 20 H.P. steam engine. Iron and wood working were also housed within this wing, and the first class of apprentices started on February 20, 1872 (Taylor, 1937).

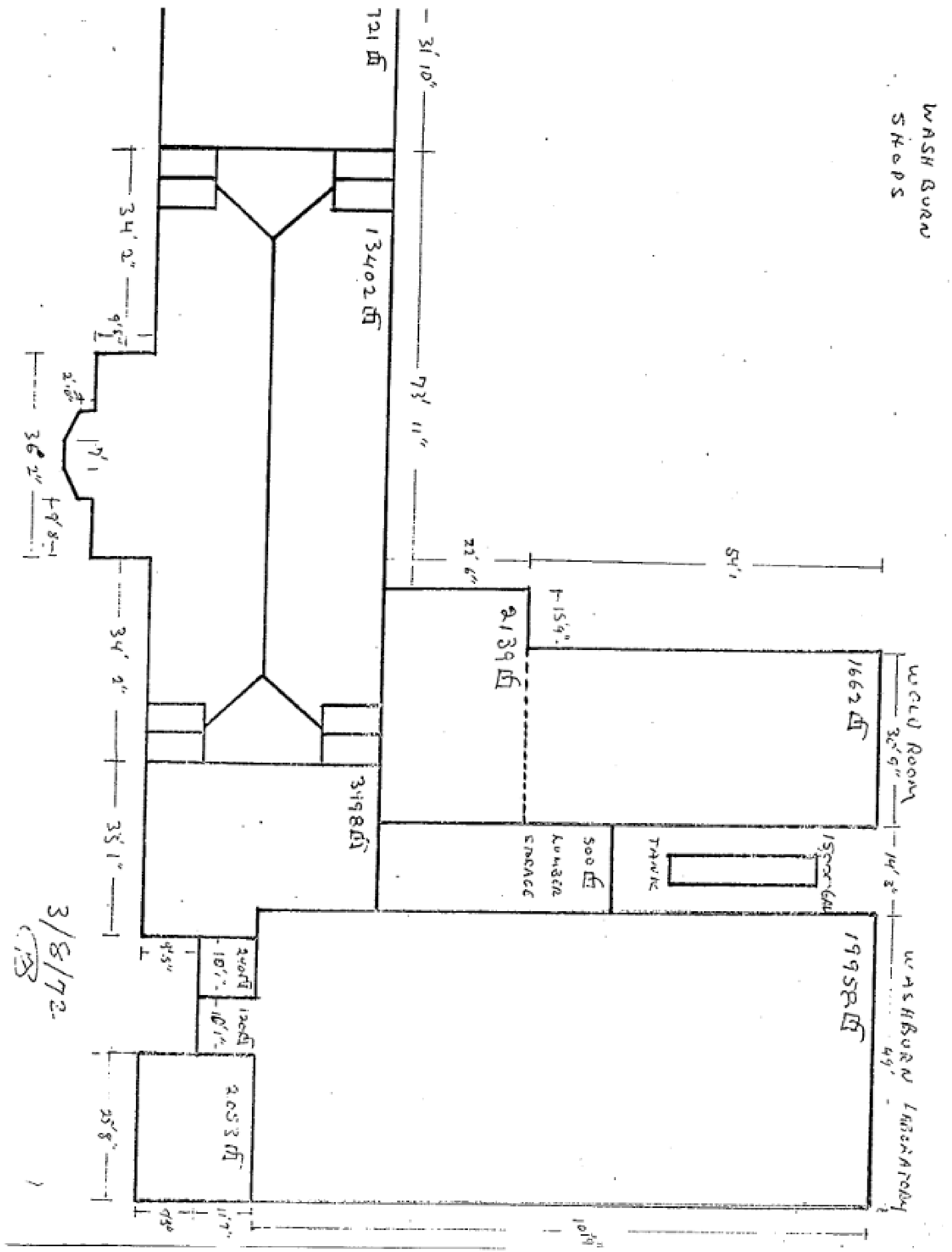


Figure 3. Layout of Washburn Shops 1972 (Pierce, 1972)

2.1.2 Renovating Washburn

In 1881, the Washburn Laboratory addition supplemented two wings on either side of the Shop. The south side, close to Boynton Hall, added a two story wing with 2,721 ft^2. The north wing included two stories and a basement of 3,998 ft^2 (Pierce, 1972). These two additions gave more room to the expanding school for classroom and machine space.

2.1.3 Longevity of Washburn

A report was given to the George Hazzard, WPI's President at the time, by the Director of Planning in 1972 analyzing the future of Washburn Shops. Over the past 100 years of Washburn's life, the building has been suffering from the wear and tear from the machinery. It was discovered that the main building and south addition only had a crawl space underneath the floor and needed to be reinforced in order to continue handling the machinery loads. It was also determined that all the woodwork including the window frames, towers and flooring needed to be repaired. The conclusion of the report was a recommendation by the Director of Planning that Washburn should be completely rebuilt. This reconstruction was projected to cost the school $532,800 and decrease the available floor area by 7,000 ft^2 (Pierce, 1972). This proposal was rejected based on the historical value of the building but illustrates the importance of understanding how Washburn is structurally supported and maintained.

2.2 Current Construction

Construction on Washburn Shops started in the summer of 2011 to renovate the roof along with select windows and masonry along the top portions of the building. This current project is planned to be completed for October 10th, 2011. The architect, Hoffman Architects

Inc. from Hamden CT, is working with the construction manager, Cutler Associates Inc. from Worcester MA, on this approximately $1.6 million project (Figure 4).

The renovation scope of work slightly changed from the original plans but is still on schedule. When the site work was being done before the renovation, workers discovered no insulation between the exterior and interior brick walls (Salter, 2011). The most concerning questions that arise from this situation are thermal and seismic stability. The tower walls were the only ones to be reinforced with bracing and these did not see any added insulation. Currently, the masonry walls of the original building only have a supporting column between each window and the addition's masonry walls are completely hollow between the windows (Guertin, 2011). A cross-section of the tower's masonry walls are shown in Figure 5.

Figure 4. Sign Announcing Renovation

Figure 5. Washburn Tower Masonry Wall Cross-Sections

The majority of the renovation work made changes to the upper portions of Washburn. The roof was entirely re-slatted, the top row of windows were replaced but kept the "divided light" style, and 31 window eaves were rebuilt with zinc coated copper. The before and after conditions of the windows is illustrated in Figure 6 and Figure 7.

Figure 6. Pre-renovation Window Conditions

Figure 7. Window Renovation Work

Five of the arches along the top of the building had to be completely rebuilt during the renovation because of extreme cracking and age. More will most likely need to be replaced in the future. The wood roof structure itself was deemed to be strong however one beam in the tower was replaced due to rotting. The mansard roof also had rotting sections and falling concrete that were refurbished. The tower needed to be reinforced, and bracing was installed along the inside framing. Figure 8 details the new bracing as well as the old (Guertin, 2011).

Figure 8. Views of Tower Bracing

This restoration fixed many of Washburn's structural problems however there are still many that need to be addressed. During this project, workers discovered that the loading dock foundation was disturbed due to the repetition of machines traveling through the area. Almost all the brick exterior walls are not reinforced for seismic loading and insulating the walls has not been addressed. The brick walls have the original mortar, a thin layer of lime and sand, holding them together (Salter, 2011). The combination of these issues will require innovative design solutions and renovation work in the future.

2.3 Project Documentation

Building plans, specifications, and other supporting documents all are a part of construction project documentation. A complete set of construction documents includes a couple of different components. Building plans or drawings are the principal construction documents. They are composed of several different plans, from floor plans to site plans to foundation designs. Figure 9 shows the floor plan for Washburn's second floor. The main

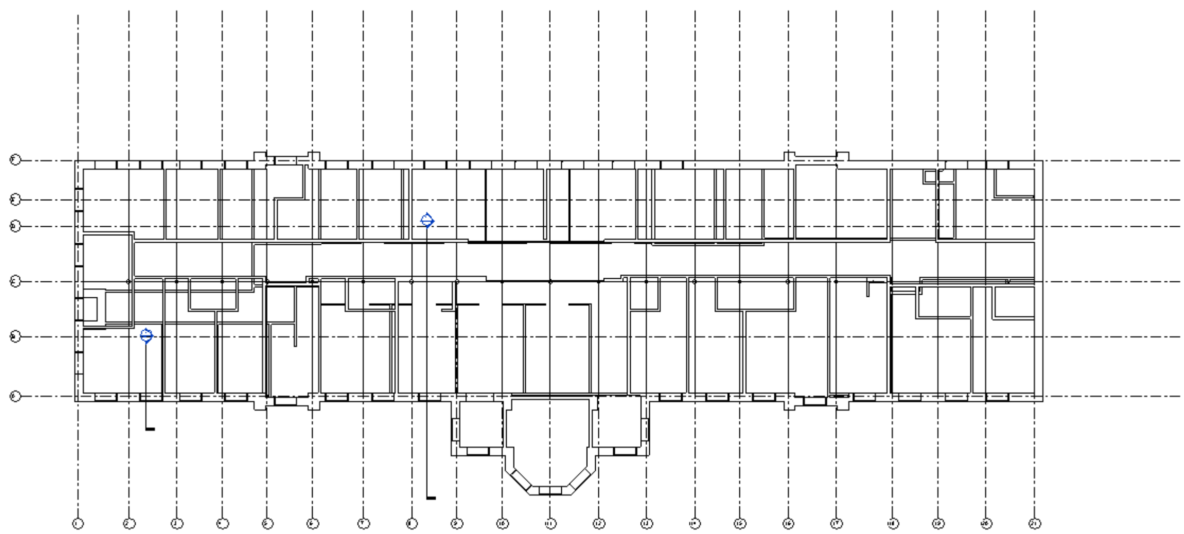


Figure 9. Floor Plan for Washburn's Second Floor

sections of drawings are broken down into architectural drawings, elevations, structural drawings, mechanical drawings and electrical drawings (Turner, 2011). Figure 10 is the front elevation of Washburn Shops, recreated in Autodesk Revit. Construction documents also include specifications or the "spec book." This is a reference that specifies the different materials and techniques used in order to construct the project. In addition there are other supporting documents like supplemental instructions that also make up construction project documentation (Turner, 2011). The processes in which these construction documents have been recorded have changed over the years however their importance has always been apparent.

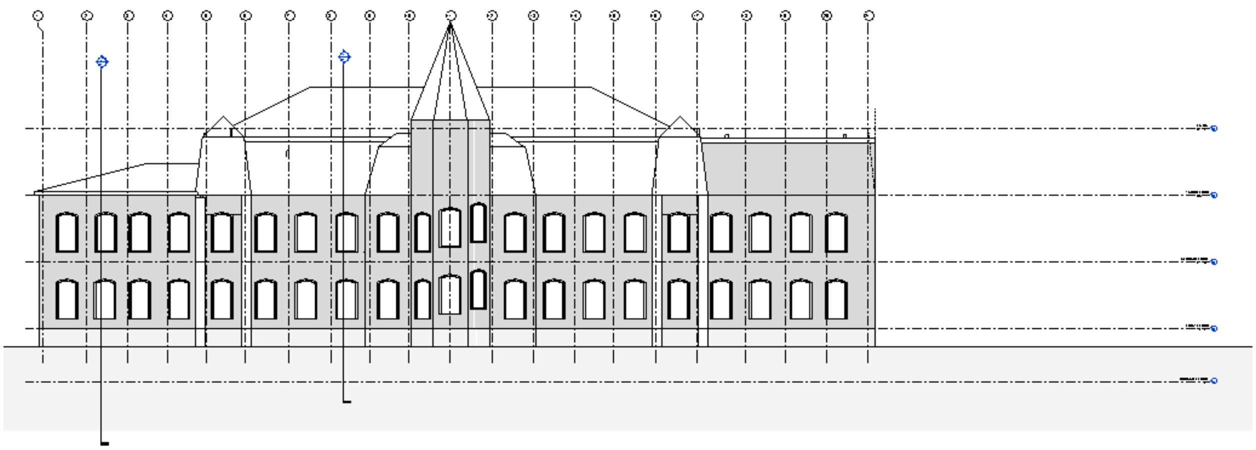


Figure 10. Front Elevation of Washburn

2.3.1 The Importance of Project Documentation

Documentation of a project is important throughout the lifecycle of the building, from before construction to maintenance and renovations. These documents have multiple purposes. One of these is to provide instructions to the contractors on how to build the structures (Turner, 2011). These drawings help to make sure all members of the team have the same understanding on what is being constructed, what it is being constructed of, where and when. Another objective of these documents is to leave the owner with the drawings of the building to help maintain the building and map out what was done. In addition it provides a starting point for building renovations in the future (Turner, 2011). However if documented incorrectly these can cause misunderstandings among construction companies and can cause future renovations to be more costly (Kymmell, 2008). Incorrect construction documents or lack of papers can hinder future construction leading to misjudgments, extraneous effort and additional costs.

Washburn Shops is an example of a building that lacks construction project documents. No record of Washburn's structural makeup currently exists in addition the only original drawings that WPI facilities have are of Washburn after its first renovation in 1881. In the year 2011 these documents were referenced for another renovation, however the incomplete documents did not assist contractors much. For example when renovation began on Washburn in the summer of 2011, it was realized that the bricks being taken out and replaced in the exterior wall were in fact holding the building together. Work had to be stopped for the construction team to reassess what could be done to the building that wouldn't alter its structural integrity. This caused a delay in project schedule and a raise in construction costs. In addition, when trying to recreate the building's drawings the details were found to be inaccurate. For example the stairways on the floor plans did not matching up when placed together in a 3D model (Salter, 2011). Because of the inaccuracies the drawings and the altogether lack of drawings the 2011 renovations were delayed and the costs increased, showing the importance of project documentation for future building renovations.

2.3.2 History of Project Documentation

Even in the 1800's the importance of project documentation was known. At this time the building layouts had to be hand drawn and traced to make copies for the different workers. In addition to the drawings documents describing the structures also had to be hand-written and hand copied in order to share among workers (Burr, 2002). These early drawings were made up of "thin, uniformly inked ruled lines" and were usually drawn on a small scale and with very little detail (Burr, 2002). For example many drawings did not have dimensions or descriptions of materials used. At this time the architect was known as the "master mason" and he was the supervisor of construction (Burr, 2002). Furthermore, small decisions like window trims were made through "informal consultation" during construction (Burr, 2002). However as the architectural profession grew the separation of design and construction became more apparent and new documentations practices were introduced (Burr, 2002).

In the early and mid-1900's drawings would be documented on "light translucent media" and by blueprinting could be recreated with greater ease (Burr, 2002). These were at first white lines on blue background paper but eventually changed to blue lines on white paper when the Diazo process was introduced. In the 1970's however, a new project documentation process was introduced that advanced how construction drawings and documents were produced (Burr, 2002).

In 1950 the *United States air defense system* created the electronic graphic system and in 1960 *McDonnell Douglas Automation Company*, which would later assist in introducing *Computer-Aided Design* (CAD), was founded. In 1969 *Computervision* sold the first commercial CAD system and this new technical advancement changed construction project documentation forever (Burr, 2002). CAD electronically produced drawings with electronic qualifications that have improved the construction project documentation process by "minimizing many mistakes involving human error and maximizing the use of time" (Burr, 2002).

As CAD softwares became more developed and were updated they went from two-dimensional representations to three-dimensional. There were many companies creating new CAD programs and upgrading existing ones. *Autodesk* was founded in 1982 and produced

AutoCAD, a CAD program that could run on a PC. In the years preceding this *Autodesk* upgraded their *AutoCAD* program as well as created add-ons like *AutoSolid* and in 1991 it created *ArcCAD* to start its emergence into the Architectural field (Bozdoc 2003).

Autodesk Revit Architecture was the next major milestone in project documentation. Revit was created by Revit Technology Corporation in 1997, it focused on not only the model concepts but also incorporated 3D concepts. Autodesk acquired Revit Technology Corporation in 2002 and added Revit to its already successful AutoCAD products (History of Revit, 2011). Autodesk and other companies have continued to create new software to better project documentation and Building Information Modeling (BIM) is currently the newest solution to project documentation with its ability to integrate 3D modeling concepts with databases of information (Kymmell, 2008).

Washburn shops was built in the 1800’s so it has seen all forms of project documentation. Its original documents were hand drawn representations of the building. They were later compiled to AutoCAD and Autodesk Revit depictions in order to allow WPI to have electronic copies. Figure 11 depicts the *Autodesk Revit* rendition of Washburn. The drawings of the building were further elaborated in this software for the preliminary stages of BIM. Figure 12 shows the current BIM Model WPI facilities has of Washburn.

Figure 11. Autodesk Revit representation of Washburn

Figure 12. BIM Representation of Washburn (Wang, 2010)

2.4 Building Information Modeling (BIM)

Building Information Modeling (BIM) is an innovative new concept emerging in the design and construction industry. A building information model integrates 3D modeling components with a database of information relating to the project (Kymmell, 2008). With this technology a project's physical and functional characteristics can be detailed and organized

(Buckley, 2007). A BIM model can be used to view a building in three dimensions, track information associated to specific items and also to produce two dimensional drawings to serve as as-builts.

2.4.1 Defining BIM

The phrase BIM was coined by Autodesk in 2002, but the growth of this technology has been happening for some time (Eastman, 2008). With the use of computer programs such as Revit Architecture, Revit Structures (Figure 13) and AutoCAD, a construction project can be simulated in a "virtual environment". "Virtual building implies that it is possible to practice construction, to experiment, and to make adjustments in the project before it is actualized" (Kymmell, 2008). BIM utilizes not only 3D modeling but parametric data attached to items to distinguish them and give a complete picture of the project. All facets of a project can be scheduled, estimated and visualized in one interactive model. "The building information model is a project as well as a process simulation" (Kymmell, 2008). Planning and building a project virtually allows all aspects to be considered and communicated before anything needs to be finalized. "After all, if there is only one opportunity to do it right, it makes a lot of sense to prepare well for that single occasion virtually, and

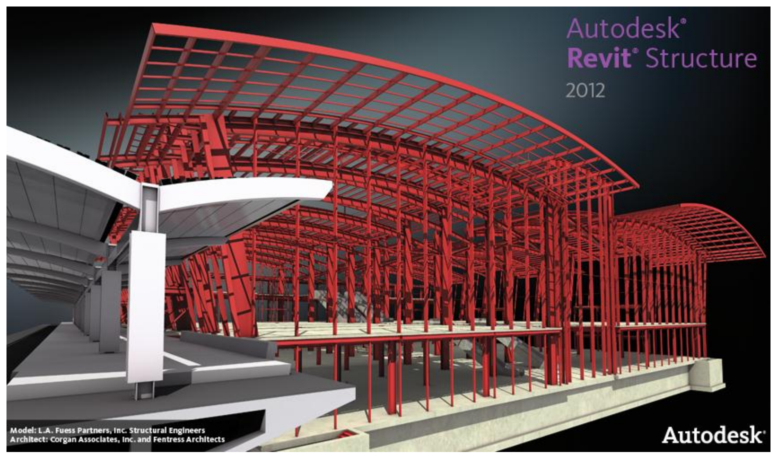


Figure 13. Autodesk Revit Structure

thereby reduce the inherent risks and improve the chances for success and efficiency" (Kymmell, 2008). Figure 14 is an example of a BIM 3D Model.

Figure 14. Example of BIM 3D Model (Reid, 2011)

BIM allows and encourages "integration among all the trades during design and construction phases". This pre-coordination brings everyone "together on a project to ensure compliance" (Murphy, 2009). By reviewing the model and running clash detection, conflicts that can increase project cost and length are able to be rectified immediately. In one example presented by Reid, during virtual coordination meetings, a design team "spotted more than 7,200 potential mechanical and plumbing systems conflicts, whereas only one of those conflicts would have been discovered through a conventional review of 2D paper documents". An additional "250 constructability issues were discovered via the model-based approach compared with six through the 2D process" (Reid, 2011). Discovering these issues prior to construction saved approximately $1.7 million, saving not only money but time. "Building information modeling software can produce significant time savings, smooth project logistics and facilitate communication with both clients and subcontractors" (Rollins, 2008).

2.4.2 The BIM Advantage

Both contractors and owners are seeing the benefits of BIM. It has been shown to "reduce the number of change orders and requests for information that impede projects and increase their costs; improving the coordination between the architectural, structural, and mechanical systems designs to avoid conflicts, optimizing spatial allocations; and streamlining the material estimating processes" (Reid, 2011). BIM improves communication and fosters collaboration and "the best design processes are collaborative ones" (Behrens, 2009).

Building information modeling is not only a tool that can be optimized today but greater utilized in the future. "If all subcontractors aren't using BIM now, that day is fast approaching as they realize the impact it can have on their work… It is clear that BIM is a transformational technology that will be reshaping the field for years to come" (Rollins, 2008). BIM has a tremendous amount of potential that can continue to improve the design and construction field.

2.4.3 AIA Level of Detail

Drawings and building information models can be created with all different attributes and at different amounts of detail. The AIA (American Institute of Architects) has set standards on the level of detail (LOD) when completing a BIM model which are dictated in the E202 document. Five levels have been defined from LOD 100 to LOD 500. LOD 100 to 300 follow the traditional two dimensional project delivery while LOD 400 to 500 are BIM specific (Kal-Blue, 2011).

The LOD 100 level is considered appropriate for conceptual design including overall building massing and whole building analysis. LOD 200 models consist of "generalized systems including approximate quantities, size, shape, location and orientation". It is the schematic design or development. The LOD 300 level is equivalent to "traditional construction documents and shop drawings" (Kal-Blue, 2011).

Detail higher than the 300 level incorporates BIM. LOD 400 is suitable for fabrication and assembly, and is most likely to be used by specialty trades. The final level, LOD 500, represents the project "as it has been constructed including as-builts". These models include completed parameters and attributes (Kal-Blue, 2011). Figure 15 displays and describes each level of detail.

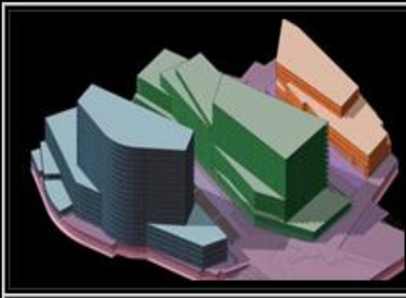
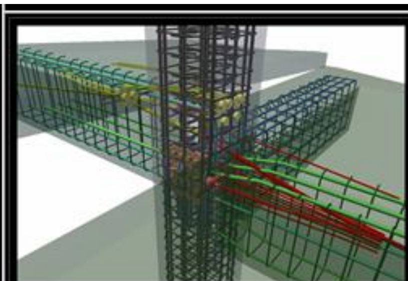
	LOD 100 - Essentially the equivalent of **conceptual design**, the model would consist of overall building massing and the downstream users are authorized to perform whole building types of analysis (volume, building orientation, cost per square foot, etc.)
	LOD 200 - Similar to **schematic design** or **design development**, the model would consist of "generalized systems or assemblies with approximate quantities, size, shape, location and orientation." Authorized uses would include "analysis of selected systems by application of generalized performance criteria."
	LOD 300 - Model elements are suitable for the generation of traditional **construction documents** and shop drawings. As such, analysis and simulation is authorized for detailed elements and systems.
 *Image courtesy of Mortenson Construction*	LOD 400 - This level of development is considered to be suitable for fabrication and assembly. The MEA for this LOD is most likely to be the trade contractor or fabricator as it is usually outside the scope of the architect's or engineer's services or would constitute severe risk exposure if such parties are not adequately insured.
	LOD 500 - The final level of development represents the project as it has been constructed - the as-built conditions. The model is suitable for maintenance and operations of the facility.

Figure 15. Outline of LOD (Van, 2008)

To define the level of detail the AIA provides Model Element Tables as shown in Figure 16 below. The parties responsible for developing the model content are Model Element Authors (MEAs) and per the AIA fill out such tables to document the work and appropriate level of detail (Van, 2008).

§ 4.3 Model Element Table

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

Model Elements Utilizing CSI UniFormat™				100 % SCHEMATIC DESIGN		DESIGN DEVELOPMENT		CONSTRUCTION DOCUMENTS		O & M			
				LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	M
A SUBSTRUCTURE	A10 Foundations	A1010	Standard Foundations	100	SOM	200	WSP	300	WSP	500	TC		
		A1020	Special Foundations	-	-	-	-	-	-	-	-		
		A1030	Slab on Grade	100	SOM	200	WSP	300	WSP	500	TC		
	A20 Basement Construction	A2010	Basement Excavation										
		A2020	Basement Walls	100	SOM	300	SOM	300	SOM	500	TC		
B SHELL	B10 Superstructure	B1010	Floor Construction	200	SOM	300	SOM	400	SOM	500	TC		
		B1020	Roof Construction					400	SOM	500	TC		
	B20 Exterior Enclosure	B2010	Exterior Walls										
		B2020	Exterior Windows										
		B2030	Exterior Doors										

Figure 16. Sample Model Element Table (Van, 2008)

2.5 Building Codes

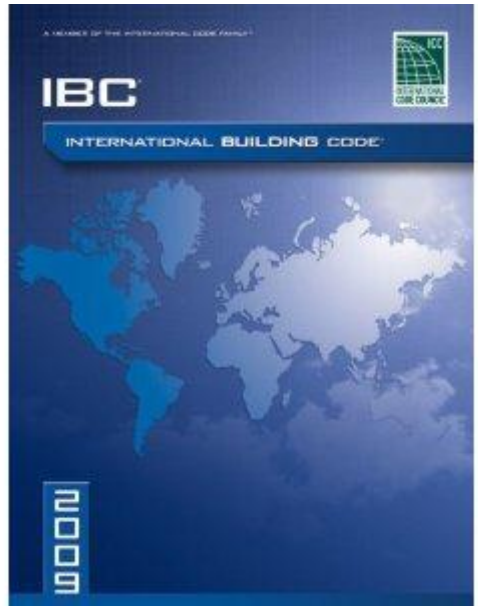


Figure 17. International Building Code

The purpose of building codes is to regulate facilities in order to protect the public's safety and general welfare. The Massachusetts State Building Code is controlled by the *Board of Building Regulations and Standards* (BBRS) (Massachusetts Department of Public Safety, 2011). The first edition of the Massachusetts State Building Code was developed in 1975 and has been edited over time to the current 8th edition (Guigli, 2011). This edition is based on the *2009 International Building Code* (IBC) which includes *International Mechanical Code* (IMC), *International Existing Building Code* (IEBC), *International Fire Code* (IFC) and the *International Energy Conservation Code* (IECC). Figure 17 shows the *2009 International Building Code*. The 8th edition also includes amendments to the IBC to coincide with "Massachusetts laws and regulations and unique requirements" (Executive Office of Public Safety and Security, 2011). The 8th edition is comprised of different chapters relating to various types of buildings construction and regulations. If general requirements and specific requirements of the different chapters do not agree with each other, then the most restrictive requirement is used (Executive Office of Public Safety and Security, 2011). In addition, any existing structures on the date the 8th edition is adopted shall remain unchanged unless defined in the new edition or judged by the building official to need to change (Executive Office of Public Safety and Security, 2011).

Chapter 34 of the Massachusetts State Building Code applies to existing building regulations and is based off of IEBC 2009 and MA amendments. This chapter of the 8th edition will relate the most to Washburn's analysis because it is an existing masonry structure (Guigli, 2011).

2.5.1 Massachusetts State Building Code Chapter 34

There are three compliance methods for existing buildings according to the IEBC: the prescriptive method, work area compliance method and performance method. The compliance method used is up to the owner's discretion (Guigli, 2011). The level of compliance of existing buildings is based on the cost of work and the construction performed. If work costs less than $100,000, then only the construction being done on the building must follow the regulations set by the 8th edition (Woodworth, 2011). If the scope of work costs more than $100,000 but less than 30% of "full and fair cash value of existing building," then only certain regulations are applied (Woodworth, 2011). If the cost of work is 30% or more of the "full and fair cash value of the existing building" then the entire building must adhere to the codes (Woodworth, 2011). As stated in the Code for any proposed work, with the issuance of a building permit, the building's compliance with the Code shall be evaluated. This evaluation usually includes the "evaluation of design gravity loads, lateral load capacity, egress capacity, fire protection systems, fire resistant construction, interior environment, hazardous materials, and energy conservation" (Executive Office of Public Safety and Security, 2011).

2.5.2 Seismic Codes for Existing Structures

In the past, earthquakes have not been major factors for structural designs in New England, unlike in California or along fault lines. However, recently earthquake magnitudes and frequency have increased, resulting in the Building Seismic Safety Council (BSSC) increasing seismic code regulations (Seismology and Structural Standards Committee, 2005). The BSSC created standards to ensure that building stay standing during a seismic event and also the building does not deteriorate rapidly afterwards. The following table, Table 1, represents the different seismic force resisting systems along with their R, Ω_0, and C_d values that help building officials analyze the structures and determine if they comply with codes (State Board of Building Regulations and Standards, 2011). R is the Seismic response Modification. This factor helps to simplify the design process so only the linear elastic static analysis is needed to design the building (SEAOC Seismology Committee, 2008). Ω_0 is the seismic force amplification factor or the structural overstrength factor. It is used to calculate the realistic seismic force in a member from the elastic design seismic forces (SEAOC Seismology Committee, 2008). C_d is the deflection amplification factor. This factor helps to determine the maximum deformations that can be expected from design seismic forces (SEAOC Seismology Committee, 2008). These factors will help to determine the Washburn Shops' compliance to the Massachusetts State Building Seismic Codes.

Table 1. Seismic Force Resisting (State Board of Building Regulations and Standards, 2011)

BASIC SEISMIC-FORCE-RESISTING SYSTEM	R	Ω_0	C_d
Bearing Wall Systems			
Steel concentrically braced frame (CBF) with diagonal [3] or X-bracing			
CBF per 6th Edition SBC[2] except for Section 9.5 of 1992 AISC Seismic Provisions	3.5	2	3.5
Otherwise[4]	3	3	3
Steel CBF with V, Inverted V or K bracing			
V or Inverted V bracing per 6th Edition SBC[2]	3	3	3
V or Inverted V bracing, otherwise[4]	3	3	3
K bracing	1.25	1.25	1.25
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition	5	2.5	5
Reinforced concrete shear walls with reinforcing steel less than required by, or with spacing greater than permitted by Section 11.9.9 of ACI 318-08	1.5	1.5	1.5
Unreinforced concrete shear walls	1.25	1.25	1.25
Reinforced masonry shear walls			
Class A[5]	4.5	2.5	3.5
Class B[6]	2.25	2.25	2.25
Class C[7]	1.25	1.25	1.25
Unreinforced masonry shear walls	1.25	1.25	1.25
Light-framed walls sheathed with wood structural panels or diagonal sheathing	4	2.5	3
Other light-framed walls[10]	2	2	2
Building Frame Systems			
Steel concentrically braced frame (CBF) with diagonal [3] or X-bracing			
CBF per 6th Edition SBC[2] except for Section 9.5 of 1992 AISC Seismic Provisions	4	2	3.5
Otherwise[4]	3	3	3
Steel CBF with V, Inverted V or K bracing			
V or Inverted V bracing per 6th Edition SBC[2]	3	3	3
V or Inverted V bracing, otherwise[4]	3	3	3
K bracing	1.5	1.5	1.5
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition	6	2.5	5
Reinforced concrete shear walls with reinforcing steel less than required by, or with spacing greater than permitted by Section 11.9.9 of ACI 318-08	1.5	1.5	1.5
Unreinforced concrete shear walls	1.5	1.5	1.5
Reinforced masonry shear walls			
Class A[5]	5	2.5	4
Class B[6]	2.25	2.25	2.25
Class C[7]	1.5	1.5	1.5
Unreinforced masonry shear walls	1.5	1.5	1.5
Light-framed walls sheathed with wood structural panels or diagonal sheathing	4	2.5	3
Other light-framed walls[10]	2.5	2.5	2.5

Moment Resisting Frame Systems			
Steel moment frames			
Special Moment Frame per 6th Edition SBC[2]	8	3	5.5
Ordinary Moment Frame per 6th Edition SBC[2]	3.5	3.5	3.5
Moment frame, otherwise[4]	3	3	3
Reinforced concrete moment frames			
Class A[8]	5	3	4.5
Class B[9]	2.5	2.5	2.5
Dual Systems (See ASCE 7, Section 12.2.5.1)			
Steel concentrically braced frame (CBF) with steel moment frames (MF)			
CBF and Special Moment Frame, per 6th Edition SBC[2]	5	2.5	4.5
CBF and Moment Frame per 1st through 5th Editions SBC[2], except V, Inverted V or K Braced Frames	3.5	2.5	3.5
CBF and Moment Frame per 1st through 5th Editions SBC[2], with V, Inverted V or K Braced Frames	3	2.5	3
Otherwise	1.5	1.5	1.5
Reinforced concrete shear walls with boundary elements and without coupling beams, in accordance with 780 CMR 1113.5.1.4a, 5th Edition, with reinforced concrete moment frames, Class A[8]	6	2.5	5
Ordinary reinforced concrete shear walls, as defined in 8th Edition SBC, with reinforced concrete moment frames, Class A[8]	5.5	2.5	4.5

Notes:

1. Systems of previous editions of the State Building Code that meet the ductility requirements of the 8th Edition of the Code are not included in this table.
2. SBC refers to 780 CMR Commonwealth of Massachusetts State Building Code.
3. A diagonal brace is one that frames from a beam-to-column connection diagonally to another beam-to-column connection or to a column at its base plate.
4. The seismic resistance of the frame shall be based on its seismic connections being subject to two times the computed forces and moments resulting from seismic load.
5. Class A reinforced masonry shear walls have a minimum total area of reinforcement in the vertical and horizontal direction at least 0.0020 times the gross cross-sectional area of the wall, with a minimum area in each direction at least 0.0007 times the gross cross-sectional area of the wall. Maximum spacing of reinforcing steel bars in grouted cells or bond courses is 6'-0" in one direction and 4'-0" in the other direction, but not more than 1/3 of the length or height of the wall, whichever is less, in each direction. Class A walls satisfy other requirements for reinforced masonry of the base code.
6. Class B reinforced masonry shear walls satisfy all requirements for Class A walls, except that spacing limits for reinforcing steel bars are exceeded.
7. Class C reinforced masonry shear walls satisfy all requirements for reinforced masonry of the base code.
8. Class A reinforced concrete moment frames satisfy requirements of Sections 1113.5.1, 1113.5.1.1, 1113.5.1.2 and 1113.5.1.3 of 780 CMR 5th Edition and Sections 11.12.1.1 and 11.12.1.2 of ACI 318-83 for reinforcing of beam to column joints.
9. Class B reinforced concrete moment frames do not satisfy requirements for Class A reinforced concrete moment frames.
10. Wood siding over horizontal or diagonal boards, plaster on wood or metal lath, and stucco on metal lath may be used to resist in-plane shear, where the walls are anchored to floors and to the floor or roof construction above such that they can transfer the shear between floors and to the foundation. Gypsum sheathing, lath, wall board, drywall, fiberboard and particle board are not permitted to resist in-plane shear unless originally designed in accordance with 780 CMR for that purpose.

2.5.3 Massachusetts State Building Code Chapter 34 Appendix A

Appendix A1 of Chapter 34 was written to "reduce the risk of death or injury that may result from the effects of earthquakes on existing, unreinforced, masonry walls" (Cowen, 2011). The codes state that all masonry walls must comply with Appendix A1 if work area is more than 50% of the building; occupancy increases more than 25%, if there is a change of occupancy to a relative hazard category of 1 or 2 and/or if there is a level 2 alteration (Mariani, 2011). In order to determine whether a building is up to code, initial tests are done to assess the strength of materials. The minimum values are:

f'm= 300 psi

Em= 550,000 psi

f'sp= 0 psi (tensile splitting strength)

Vm= 20 psi (running bond)

Vm= 20 psi (fully grouted)

Vm= 10 psi (partially grouted, ungrouted, no running bond)

The masonry and the mortar must be tested separately in order to determine code compliance. Section A106.3.3 refers to masonry testing including minimum qualities of mortar and masonry as well as testing procedures and other testing regulations. The code states that the qualities shall be determined by in-place shear tests unless this will cause the masonry unit to fail. In the case that in-place shear tests cannot be used, drilled core tests or hollow unit masonry tests should be used instead (International Code Council, 2007). Figure 18 shows an in-place shear test. Section A106.3.3.5 specifies the minimum quality of mortar; the data from the testing is used to determine the quality. The minimum quality of mortar shall be determined by the equation:

$$v_{to} = (V_{test}/A_b) - p_{D+L}$$

If v_{to} is less than 30 pounds per square inch or 207kPa, then the mortar shall be re-pointed and retested (International Code Council 2007). Section A106.3.3.6 regulates the minimum quality of masonry and states that f_{sp} shall be a minimum of 50 psi (Cowen, 2011).

Figure 18. In-place Shear Test

2.5.4 Fire Codes for Existing Structures

Fire building codes for existing structures must follow the 527 CMR regulations and the International Fire Codes. The code states that “every school, college and university laboratory newly constructed or renovated, or any room used for similar purposes wherein corrosives or flammable liquids are handled or where open flame devices are used, shall be equipped with one or more Emergency Wash Systems” (Board of Fire Prevention Regulations, 2010). Figure 19 shows an example of an emergency wash system. The codes also state that there should be no obstacles in the direct path to an exit and doors and windows must be kept clear at all times. In addition buildings must be sprinkled throughout when conducting “substantial renovation,” or “when the work performed facilitates the installation of sprinkler” and/or work done on the building affects more than 33% of its gross square footage or the total cost of work is greater than or equal to 33% of the buildings value (Woodworth, 2011).

Figure 19. Emergency Wash System (Board of Fire Prevention Regulations, 2010)

2.5.6 Wind Codes for Existing Structures

Buildings are often damaged by hurricanes, thunderstorms, and other high speed wind storms. The Massachusetts 8^{th} edition follows the wind design provisions set in place by the IBC. The IBC states that all roof decks must be designed to withstand the wind pressures according to *ASCE 7* and the basic wind speeds in their area (International Code Council, 2007). Table 2 shows the different basic wind speeds in Massachusetts; Worcester is underlined (State Board of Building Regulations and Standards, 2009). According to the Massachusetts 8^{th} edition building codes for existing structures, roof diaphragms will have to be re-evaluated if more than 50% of roofing materials are removed where the basic wind speed is greater than 90mph or in a special wind region. If the wind loads specified in the IBC do not comply with those of the building being evaluated, then the diaphragms and connections will have to be strengthened or replaced (Bonowitz, 2010).

Table 2. Massachusetts Basic Wind Speeds (State Board of Building Regulations and Standards, 2009)

TABLE 5301.2(4) MASSACHUSETTS BASIC WIND SPEEDS

<90 MPH	90 MPH		100 MPH		110 MPH
Adams	Acton	New Braintree	Abington	Middleton	Acushnet
Alford	Agawam	New Marlborough	Amesbury	Milford	Aquinnah
Ashfield	Amherst	New Salem	Andover	Millis	Barnstable
Becket	Ashburnham	North Brookfield	Arlington	Millville	Bourne
Bernardston	Ashby	Northampton	Ashland	Milton	Brewster
Buckland	Athol	Northborough	Attleboro	Nahant	Carver
Cheshire	Auburn	Northfield	Avon	Natick	Chatham
Clarksburg	Ayer	Oakham	Bedford	Needham	Chilmark
Colrain	Barre	Orange	Bellingham	Newbury	Dartmouth
Cummington	Belchertown	Otis	Belmont	Newburyport	Dennis
Dalton	Berlin	Palmer	Berkley	Newton	Duxbury
Egremont	Blandford	Paxton	Beverly	Norfolk	Eastham
Florida	Bolton	Pelham	Billerica	North Andover	Edgartown
Great Barrington	Boxborough	Pepperell	Blackstone	North Attleborough	Fairhaven
Greenfield	Boylston	Petersham	Boston	North Reading	Fall River
Hancock	Brimfield	Phillipston	Boxford	Northbridge	Falmouth
Hawley	Brookfield	Princeton	Braintree	Norton	Freetown
Heath	Carlisle	Royalston	Bridgewater	Norwell	Gay Head
Hinsdale	Charlton	Russell	Brockton	Norwood	Gosnold
Lanesborough	Chelmsford	Rutland	Brookline	Oxford	Halifax
Lee	Chester	Sandisfield	Burlington	Peabody	Harwich
Lenox	Chesterfield	Shirley	Cambridge	Plainville	Kingston
Leyden	Chicopee	Shrewsbury	Canton	Quincy	Lakeville
Middlefield	Clinton	Shutesbury	Chelsea	Randolph	Marion
Monroe	Conway	South Hadley	Cohasset	Raynham	Marshfield
Monterey	Deerfield	Southampton	Concord	Reading	Mashpee
Mount Washington	Dracut	Southbridge	Danvers	Rehoboth	Mattapoisett
New Ashford	Dunstable	Southwick	Dedham	Revere	Middleborough
North Adams	East Brookfield	Spencer	Dighton	Rockland	Nantucket
Peru	East Longmeadow	Springfield	Douglas	Rockport	New Bedford
Pittsfield	Easthampton	Sterling	Dover	Rowley	Oak Bluffs
Plainfield	Erving	Stow	Dudley	Salem	Orleans
Richmond	Fitchburg	Sturbridge	East Bridgewater	Salisbury	Pembroke
Rowe	Gardner	Sunderland	Easton	Saugus	Plymouth
Savoy	Gill	Templeton	Essex	Seekonk	Plympton
Sheffield	Goshen	Tolland	Everett	Sharon	Provincetown
Shelburne	Granby	Townsend	Foxborough	Sherborn	Rochester
Stockbridge	Granville	Tyngsborough	Framingham	Somerville	Sandwich
Tyringham	Groton	Wales	Franklin	Southborough	Scituate
Washington	Hadley	Ware	Georgetown	Stoneham	Somerset
West Stockbridge	Hampden	Warren	Gloucester	Stoughton	Swansea
Williamstown	Hardwick	Warwick	Grafton	Sudbury	Tisbury
Windsor	Hatfield	Wendell	Groveland	Sutton	Truro
Worthington	Harvard	West Boylston	Hamilton	Swampscott	Wareham
	Holden	West Brookfield	Hanover	Taunton	Wellfleet
	Holland	West Springfield	Hanson	Tewksbury	West Tisbury
	Holyoke	Westfield	Haverhill	Topsfield	Westport
	Hubbardston	Westford	Hingham	Upton	Yarmouth
	Hudson	Westhampton	Holbrook	Uxbridge	
	Huntington	Westminster	Holliston	Wakefield	
	Lancaster	Whately	mm	Walpole	
	Lawrence	Wilbraham	Hopkinton	Waltham	
	Leicester	Williamsburg	Hull	Watertown	
	Leominster	Winchendon	Ipswich	Wayland	
	Leverett	Worcester	Lexington	Webster	
	Littleton		Lincoln	Wellesley	
	Longmeadow		Lynn	Wenham	
	Lowell		Lynnfield	West Bridgewater	
	Ludlow		Malden	West Newbury	
	Lunenburg		Manchester	Westborough	
	Maynard		Mansfield	Weston	
	Methuen		Marblehead	Westwood	
	Millbury		Marlborough	Weymouth	
	Monson		Medfield	Whitman	
	Montague		Medford	Wilmington	
	Montgomery		Medway	Winchester	
			Melrose	Winthrop	
			Mendon	Woburn	
			Merrimac	Wrentham	

3.0 Methodology

The following chapter describes the methods to be taken in this project to accomplish the objectives in order to solve the problems expressed by WPI Facilities. The objectives of this project are:

1. Assess and document the current condition of the building through a study of the building codes and creating a Building Information Model.
2. Make suggestions for the future design of the building and use of BIM.

3.1 Scope of Work

This MQP project consists of two phases of work concerning WPI's Washburn Shops. The first phase assesses the current conditions to create a comprehensive picture of the building. After the study of Washburn has been completed, the second phase will involve outlining future options for design solutions and the use of the created model. The following methodology will be set in place in order to provide WPI facilities with the appropriate recommendations and deliverables.

3.2 Building Assessment

In order to produce the most suitable designs and solutions, the current state of Washburn after the most recent renovations must be categorized. A study of the building provisions applicable to this structure and a building information model will produce an all-inclusive image of Washburn Shops.

3.2.1 Building Codes Study

The *Massachusetts State Building Code* will be reviewed with attention to renovations of existing buildings. The criteria that apply to the building of interest will be noted and a checklist will be created. This checklist will be used to determine which areas of Washburn are and are not in compliance with the most recent code. The areas of non-compliance will be defined based on current and predicted future uses of the building. The predicted uses of the building will be determined through interviews with WPI facilities as to what their goal for Washburn will be. Team members will evaluate the building through walkthroughs, plan reviewing and discussions with facility personnel.

Once the areas of non-compliance have been clearly defined, options will be explored to achieve compliance and to improve the safety and use of Washburn. Attention will be paid to different levels of non-compliance. The team will adopt a risk management approach to suggest certain options as a priority over others in regards to ease of compliance and potential significance of non-compliance.

3.2.2 Current Drawings/Model

An integral part of this project is the computer-based documentation of Washburn. The team will first investigate the drawings that others have created in the past. These drawings will be reviewed to determine if they are up to date and what inaccuracies exist. WPI Facilities Management has simple architectural and structural drawings, but requires a more detailed and precise capture of the building. Figure 20, Figure 21 and Figure 22 show the drawings that currently exist. These drawings and the three dimensional drawing created from them will be corrected and expanded upon. The roof level of the building will be added and components will be updated to reflect the materials and details of Washburn.

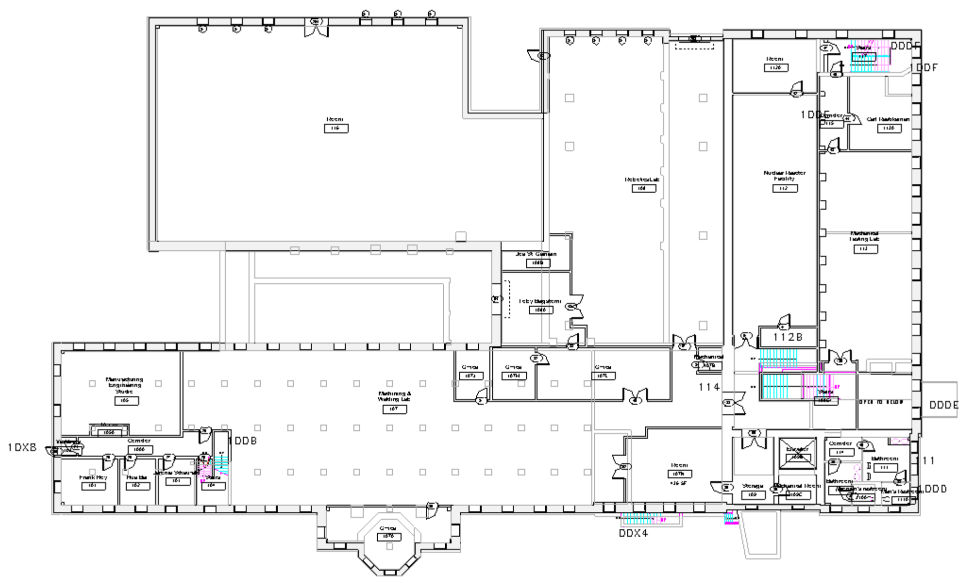


Figure 20. 2D First Floorplan

Figure 21. Current 3D Washburn Model

Figure 22. Floor View from 3D Model

Revit will be used to create and improve the body of drawings. Building information modeling will be utilized to create a comprehensive model of Washburn. The 3D model will be completed to show the building at its current state after the most recent exterior renovation project most likely to an LOD 400. This model will categorize the changes made to the building to provide updated drawings without the inaccuracies of the previous plans. A focus will be placed on the structural and masonry sections of the building. Information and pictures will be attached to items to distinguish them and to detail the renovation work. For example, a window that was replaced will have the date of replacement and picture of existing window attached to that component of the building as part of the database in Revit. The data required to document the 2011 renovation project will be gathered from site visits, construction meetings and interviews with construction and design staff. Areas of compliance and future compliance will also be tagged throughout the model from data collected in the study of the Code, outlined in 3.2.1. This BIM model will also be used to created two dimensional drawings to function as the as-builts for WPI Facilities Management

3.3 Future Options

Once the current state of Washburn is defined and documented, future options will be suggested for the building and for the use of the BIM model. Designs will be considered to solve any compliance and structural issues and the value of the team's BIM model will be emphasized.

3.3.1 Building Future Solutions

The areas of non-compliance highlighted in the study as a priority will be analyzed for possible design solutions. If a major renovation were to happen, solutions would be suggested to improve the building structurally. Washburn's unique structural issues will be investigated by suggesting several options to solve this problem while also meeting *Massachusetts State Building Codes*. Drawings will be created to display these suggested designs.

Washburn will be used as a case study to create designs for renovating unreinforced masonry buildings. When looking at MSBC two issues will be specifically analyzed. Designs will be created for a seismic and fire code upgrade. The non-compliance areas discovered in 3.2.1 that relate to these categories will be highlighted and specific solutions will be designed to solve the Code violations in a future renovation.

3.3.2 BIM Future

The BIM model created by the project team will have extensive future applications. The team will make suggestions to WPI Facilities Management on how to use and benefit from this technology. This model's future uses will be outlined specifically for Washburn. The different applications will be described and the most beneficial uses will be highly suggested. The great value building information modeling has can be brought to future projects involving Washburn. This value will be highlighted and detailed to WPI officials. The level of detail and attributes of the model will be described for ease of use in the future. This section of the project will help future contractors, designers or others to work with and gain advantages from the comprehensive model created. By having all the building information along with the 2011 renovation details in one program, future projects will be more time and cost effective.

At the completion of the project methodology, the project team will have satisfied the documentation and specific compliance needs of WPI Facilities Management, providing an interactive BIM model with a study of the present and future of Washburn.

3.4 Tasks

Table 3 below displays the tasks included in the project methodology and respectively how each task will be completed with what resources.

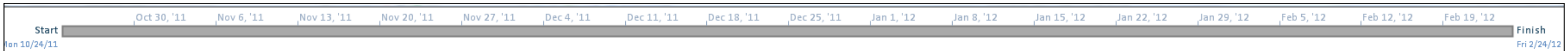
Table 3. Summary of Methodology Tasks

Task	Strategy	Resources
Building Assessment		
Building Codes Study		
Review Codes	Research documents with attention to renovations of existing buildings	Mass Building Codes SEAMass Codes Conference
Create Checklist	Extract applicable code provisions from research and organize in thoughtful manner	Mass Building Codes SEAMass Example Worksheets and Checklists
Apply Checklist	Walk through building, review drawings and meet with personnel	Drawings, Project Staff and WPI Facilities Office
Outline Areas of Non-Compliance	Review checklist and extract areas that failed review	Checklist, Mass Building Codes Example Buildings
Explore Compliance Options	Categorize non-compliance by severity and ease of solution and list possible resolutions	Mass Building Codes Example Case Studies and Buildings from SEAMass
Suggest Codes and Changes	Analyze and prioritize issues based on rational preferred outcome	Mass Building Codes
Current Drawings/Model		
Review Drawings by Others	Collect and organize files, outline traits and attributes	Drawings from architect and WPI archives, model from pervious students
Determine Accuracy	Compare drawings to each other and to observations from building walk-throughs	AutoCAD, Revit Drawings and notes
Make Corrections	With computer programs re-draw or make additions to rectify	AutoCAD, Revit List of Inaccuracies
Complete 3D Model	Add the missing components to the model, roof etc	Revit, Observations Two-dimensional drawings
Gather Data for BIM	Compile notes and documentation Meet with project staff	Cutler project manager Project meetings, photos and documentation
Organize Data	Outline information gathered by item and organize with photos	Project notes Meeting notes
Attach Data to Items	Within Revit attach item information and photographs	Revit, BIM
Tag Code Compliances	Within Revit tag items suggested to reach compliance	Building Code Study and analysis of results

Task	Strategy	Resources
Future Options		
Building Future Solutions		
Analyze Seismic and Fire Code Issues	Highlight areas of non-compliance from study that apply to seismic and fire violations	Mass Building Codes Code Study
Research Possible Designs for Seismic Upgrade	Look at standards, examples and similar upgrades	Mass Building Codes Example Buildings
Design Seismic Solutions	Calculate and plan solution to non-compliance	Calculations, Standards Past Upgrade Projects
Research Possible Designs for Fire Upgrade	Look at standards, examples and similar upgrades	Mass Building Codes Example Buildings
Design Fire Solutions	Calculate and plan solution to non-compliance	Calculations, Standards Past Upgrade Projects
Generate Drawings of Designs	Create suggested designs in computer programs to display graphically	AutoCAD Revit
BIM Future		
Outline Future Uses	Research uses of BIM and apply to building of study	Articles, Journals, Books Educational Background
Detail Value of Model	Highlight helpful attributes of model and value of BIM	Research Generated BIM Model
Describe Level of Detail	Apply AIA standards to model created to document LOD	AIA E202 Standards Generated BIM Model
Complete Final Report		
Create Detailed Outline	Review required sections and work completed and compile into outline	Past MQPs Advisor Instructions
Write Sections	Distribute sections evenly to be written throughout the project	Work completed References and research
Final Editing and Review	Rotate sections between members for editing and final review together	Team Members Advisors

3.5 Schedule

Figure 23, Figure 24 and Figure 25 illustrate the project team's schedule for both B and C term. Each step to the methodology is include and given a tentative time frame to be completed.



Task Name	Duration	Start	Finish
Building Assesment	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Building Codes Study	**25 days**	**Mon 10/24/11**	**Fri 11/25/11**
Review Codes	5 days	Mon 10/24/11	Fri 10/28/11
Create Checklist	4 days	Fri 10/28/11	Wed 11/2/11
Apply Checklist	8 days	Wed 11/2/11	Fri 11/11/11
Outline Areas of Non-Compliance	6 days	Fri 11/11/11	Fri 11/18/11
Explore Compliance Options	6 days	Wed 11/16/11	Wed 11/23/11
Suggest Codes and Changes	5 days	Mon 11/21/11	Fri 11/25/11
Current Drawings/Model	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Review Others Drawings	8 days	Mon 10/24/11	Wed 11/2/11
Determine Accuracy	6 days	Mon 10/31/11	Mon 11/7/11
Make Corrections	8 days	Mon 11/7/11	Wed 11/16/11
Complete 3D Model	9 days	Wed 11/16/11	Mon 11/28/11
Gather Data for BIM	6 days	Mon 11/28/11	Mon 12/5/11
Organize Data	5 days	Mon 12/5/11	Fri 12/9/11
Attach Data to Items	6 days	Fri 12/9/11	Fri 12/16/11
Tag Code Compliances	5 days	Mon 12/12/11	Fri 12/16/11
Future Options	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Building Future Solutions	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Analyze Seismic and Fire Code Issues	9 days	Fri 11/25/11	Wed 12/7/11
Research Possible Designs for Seismic Upgrade	8 days	Wed 12/7/11	Fri 12/16/11
Design Seismic Solutions	16 days	Fri 12/16/11	Fri 1/6/12
Research Possible Designs for Fire Upgrade	8 days	Wed 12/7/11	Fri 12/16/11
Design Fire Solutions	16 days	Fri 12/16/11	Fri 1/6/12
Generate Drawings of Designs	10 days	Tue 1/3/12	Mon 1/16/12
BIM Future	**22 days**	**Fri 12/16/11**	**Mon 1/16/12**
Outline Future Uses	11 days	Fri 12/16/11	Fri 12/30/11
Detail Value of Model	6 days	Mon 1/2/12	Mon 1/9/12
Descibe Level of Detail	6 days	Mon 1/9/12	Mon 1/16/12
Report Writing	**85 days**	**Mon 10/31/11**	**Fri 2/24/12**
Create Detailed Outline	11 days	Mon 10/31/11	Mon 11/14/11
Update Background	35 days	Mon 10/31/11	Fri 12/16/11
Write Section on Building Code Study	15 days	Mon 11/14/11	Fri 12/2/11
Write Section on BIM Model	15 days	Mon 11/28/11	Fri 12/16/11
Write Section on Building Future	15 days	Mon 1/16/12	Fri 2/3/12
Write Section on BIM Future	15 days	Mon 1/16/12	Fri 2/3/12
Update and Expand Methodology	16 days	Mon 1/23/12	Mon 2/13/12
Update Introduction	11 days	Mon 1/30/12	Mon 2/13/12
Update Conclusion	11 days	Mon 1/30/12	Mon 2/13/12
Final Editing and Review	10 days	Mon 2/13/12	Fri 2/24/12

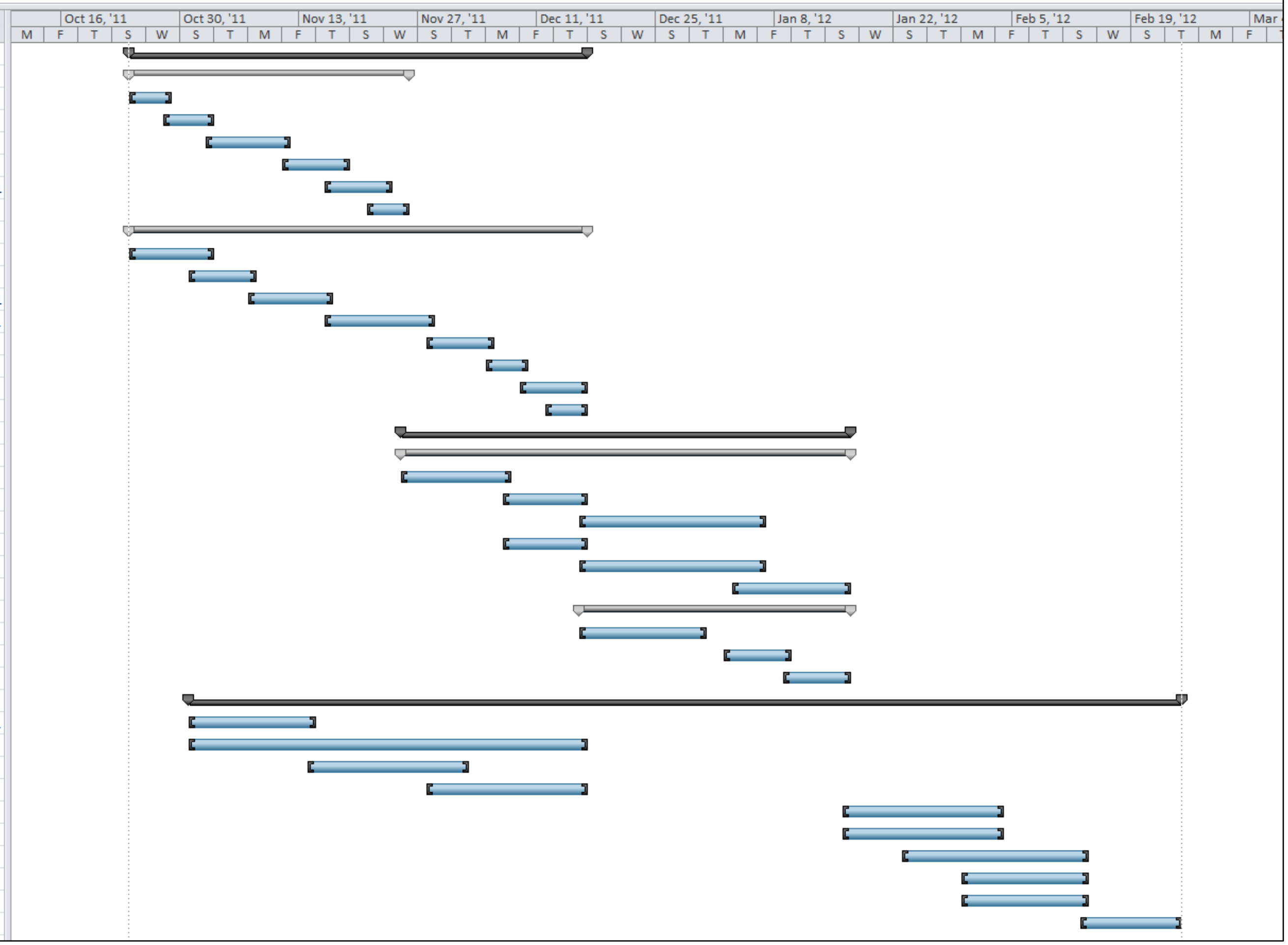


Figure 23. Gantt Chart of Entire Project Schedule

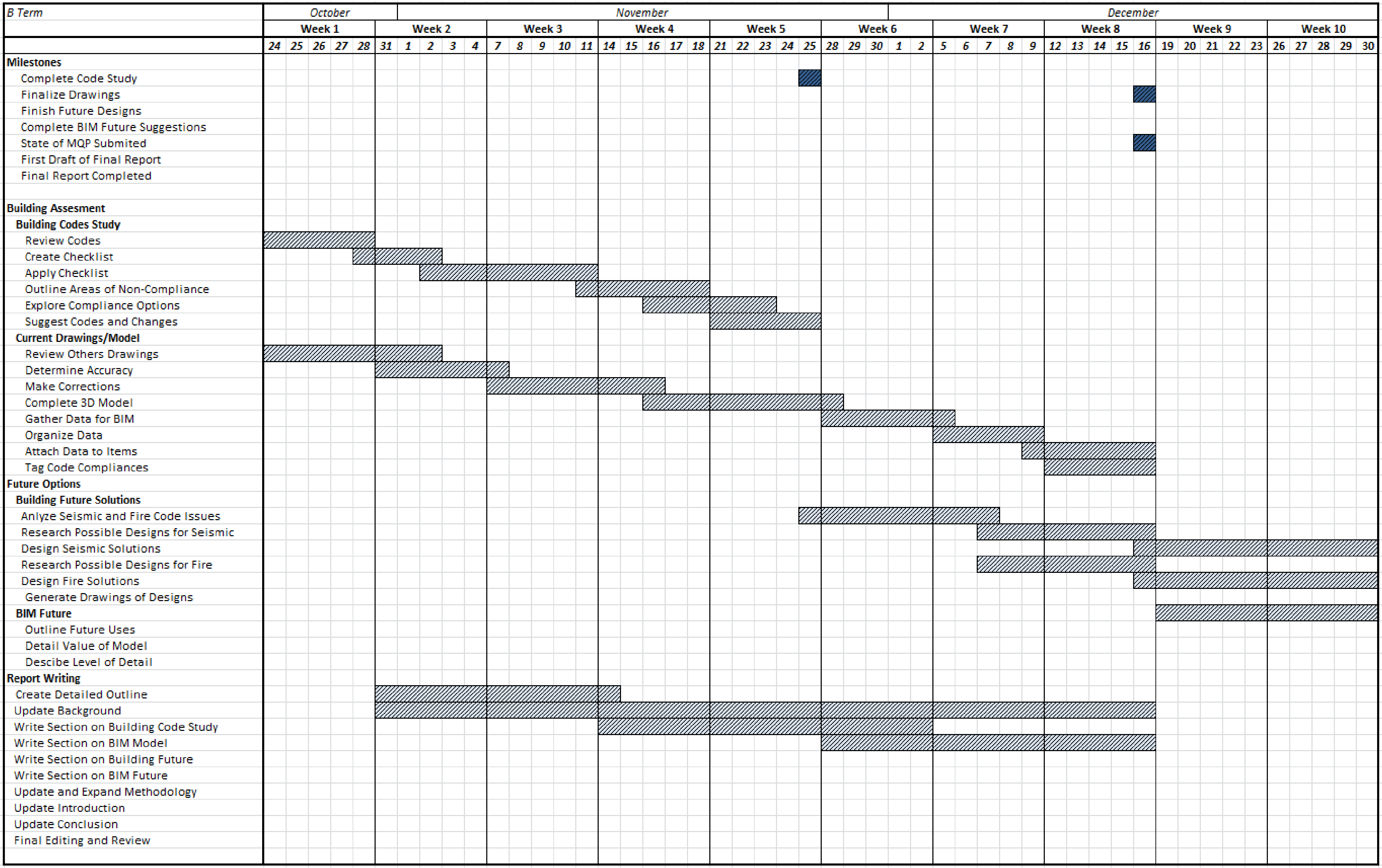


Figure 24. B Term Detail Schedule

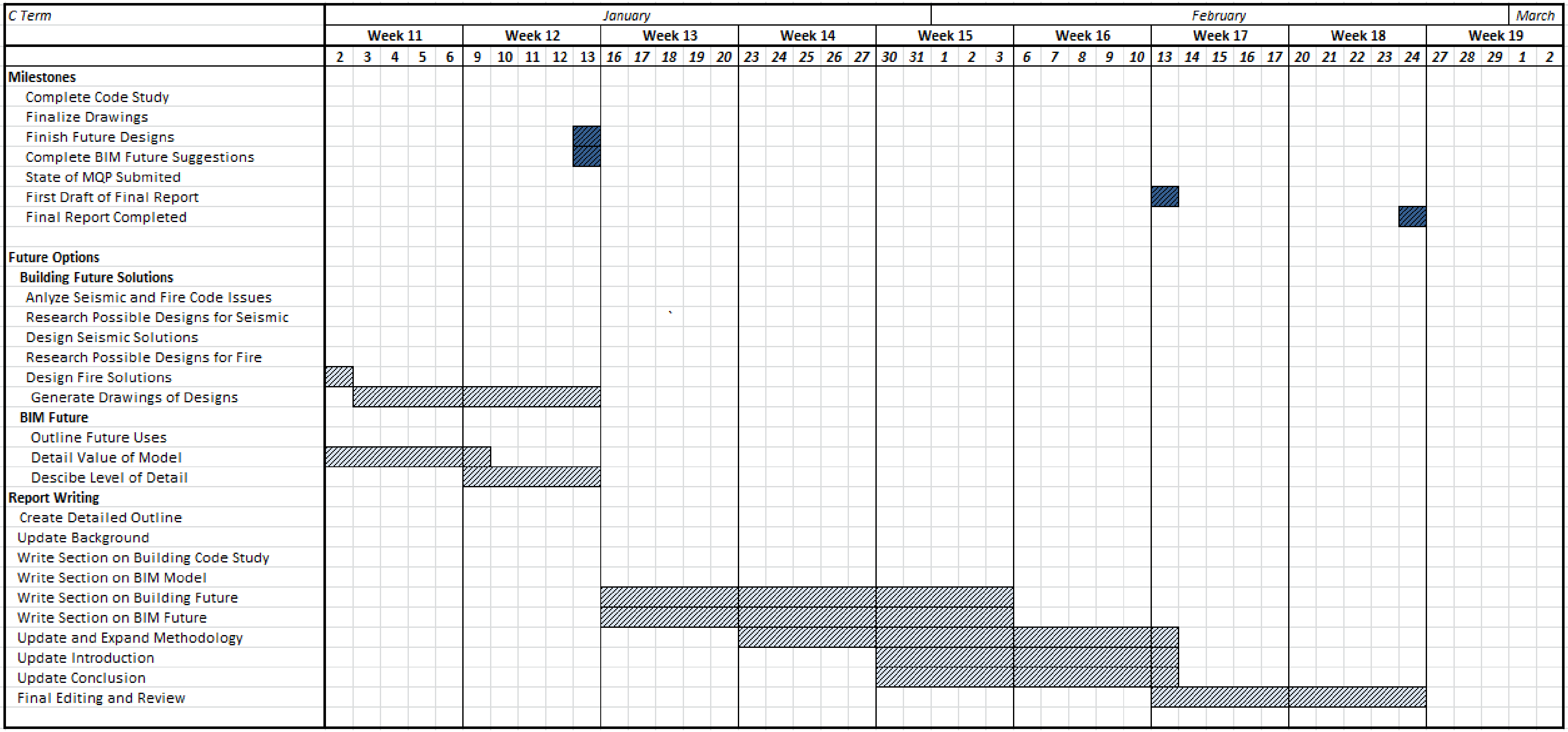


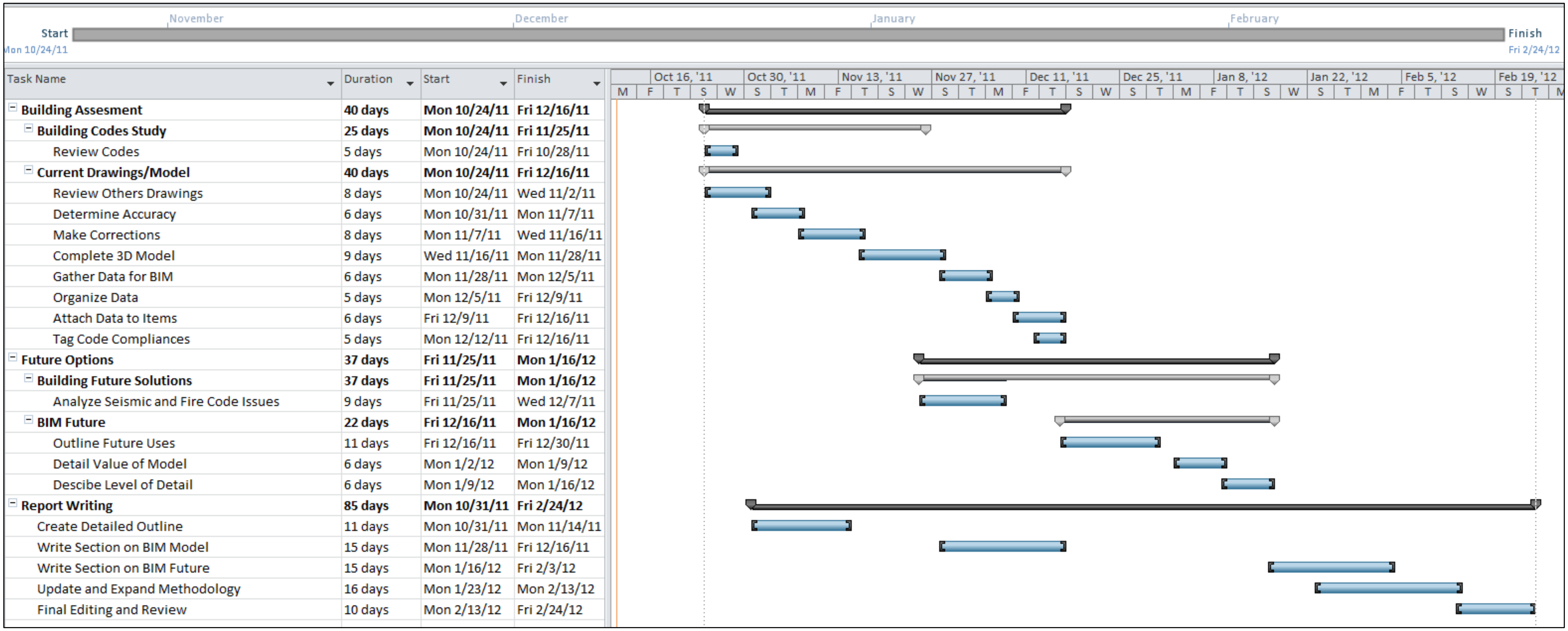
Figure 25. C Term Detail Schedule

3.6 Division of Responsibilities

Table 4 that follows details the delegation of the tasks for the MQP. Each member's responsibilities are outlined and individual schedules are provided in Figure 26,Figure 27 and Figure 28.

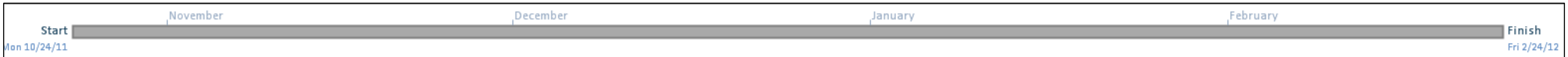
Table 4. Division of Tasks

Task	Responsible Team Members
Building Assessment	
Building Codes Study	
Review Codes	Amanda, Sasha, Paige
Create Checklist	Sasha, Paige
Apply Checklist	Sasha, Paige
Outline Areas of Non-Compliance	Sasha, Paige
Explore Compliance Options	Sasha, Paige
Suggest Codes and Changes	Sasha, Paige
Current Drawings/Model	
Review Drawings by Others	Amanda, Sasha, Paige
Determine Accuracy	Amanda, Sasha, Paige
Make Corrections	Amanda
Complete 3D Model	Amanda
Gather Data for BIM	Amanda, Sasha, Paige
Organize Data	Amanda, Sasha, Paige
Attach Data to Items	Amanda
Tag Code Compliances	Amanda
Future Options	
Building Future Solutions	
Analyze Seismic and Fire Code Issues	Amanda, Sasha, Paige
Research Possible Designs for Seismic Upgrade	Sasha
Design Seismic Solutions	Sasha
Research Possible Designs for Fire Upgrade	Paige
Design Fire Solutions	Paige
Generate Drawings of Designs	Sasha, Paige
BIM Future	
Outline Future Uses	Amanda, Sasha, Paige
Detail Value of Model	Amanda
Describe Level of Detail	Amanda
Complete Final Report	
Create Detailed Outline	Amanda, Sasha, Paige
Update Background	Sasha, Paige
Write Section on Building Code Study	Sasha, Paige
Write Section on BIM Model	Amanda
Write Section on Building Future	Paige, Sasha
Write Section on BIM Future	Amanda, Sasha, Paige
Update and Expand Methodology	Amanda, Sasha, Paige
Update Introduction	Sasha
Update Conclusion	Paige
Final Editing and Review	Amanda, Sasha, Paige



Task Name	Duration	Start	Finish
Building Assesment	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Building Codes Study	**25 days**	**Mon 10/24/11**	**Fri 11/25/11**
Review Codes	5 days	Mon 10/24/11	Fri 10/28/11
Current Drawings/Model	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Review Others Drawings	8 days	Mon 10/24/11	Wed 11/2/11
Determine Accuracy	6 days	Mon 10/31/11	Mon 11/7/11
Make Corrections	8 days	Mon 11/7/11	Wed 11/16/11
Complete 3D Model	9 days	Wed 11/16/11	Mon 11/28/11
Gather Data for BIM	6 days	Mon 11/28/11	Mon 12/5/11
Organize Data	5 days	Mon 12/5/11	Fri 12/9/11
Attach Data to Items	6 days	Fri 12/9/11	Fri 12/16/11
Tag Code Compliances	5 days	Mon 12/12/11	Fri 12/16/11
Future Options	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Building Future Solutions	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Analyze Seismic and Fire Code Issues	9 days	Fri 11/25/11	Wed 12/7/11
BIM Future	**22 days**	**Fri 12/16/11**	**Mon 1/16/12**
Outline Future Uses	11 days	Fri 12/16/11	Fri 12/30/11
Detail Value of Model	6 days	Mon 1/2/12	Mon 1/9/12
Descibe Level of Detail	6 days	Mon 1/9/12	Mon 1/16/12
Report Writing	**85 days**	**Mon 10/31/11**	**Fri 2/24/12**
Create Detailed Outline	11 days	Mon 10/31/11	Mon 11/14/11
Write Section on BIM Model	15 days	Mon 11/28/11	Fri 12/16/11
Write Section on BIM Future	15 days	Mon 1/16/12	Fri 2/3/12
Update and Expand Methodology	16 days	Mon 1/23/12	Mon 2/13/12
Final Editing and Review	10 days	Mon 2/13/12	Fri 2/24/12

Figure 26. Amanda's Project Schedule



Task Name	Duration	Start	Finish
Building Assesment	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Building Codes Study	**25 days**	**Mon 10/24/11**	**Fri 11/25/11**
Review Codes	5 days	Mon 10/24/11	Fri 10/28/11
Create Checklist	4 days	Fri 10/28/11	Wed 11/2/11
Apply Checklist	8 days	Wed 11/2/11	Fri 11/11/11
Outline Areas of Non-Compliance	6 days	Fri 11/11/11	Fri 11/18/11
Explore Compliance Options	6 days	Wed 11/16/11	Wed 11/23/11
Suggest Codes and Changes	5 days	Mon 11/21/11	Fri 11/25/11
Current Drawings/Model	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Review Others Drawings	8 days	Mon 10/24/11	Wed 11/2/11
Determine Accuracy	6 days	Mon 10/31/11	Mon 11/7/11
Gather Data for BIM	6 days	Mon 11/28/11	Mon 12/5/11
Organize Data	5 days	Mon 12/5/11	Fri 12/9/11
Future Options	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Building Future Solutions	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Analyze Seismic and Fire Code Issues	9 days	Fri 11/25/11	Wed 12/7/11
Research Possible Designs for Seismic Upgrade	8 days	Wed 12/7/11	Fri 12/16/11
Design Seismic Solutions	16 days	Fri 12/16/11	Fri 1/6/12
Generate Drawings of Designs	10 days	Tue 1/3/12	Mon 1/16/12
BIM Future	**22 days**	**Fri 12/16/11**	**Mon 1/16/12**
Outline Future Uses	11 days	Fri 12/16/11	Fri 12/30/11
Report Writing	**85 days**	**Mon 10/31/11**	**Fri 2/24/12**
Create Detailed Outline	11 days	Mon 10/31/11	Mon 11/14/11
Update Background	35 days	Mon 10/31/11	Fri 12/16/11
Write Section on Building Code Study	15 days	Mon 11/14/11	Fri 12/2/11
Write Section on Building Future	15 days	Mon 1/16/12	Fri 2/3/12
Write Section on BIM Future	15 days	Mon 1/16/12	Fri 2/3/12
Update and Expand Methodology	16 days	Mon 1/23/12	Mon 2/13/12
Update Introduction	11 days	Mon 1/30/12	Mon 2/13/12
Final Editing and Review	10 days	Mon 2/13/12	Fri 2/24/12

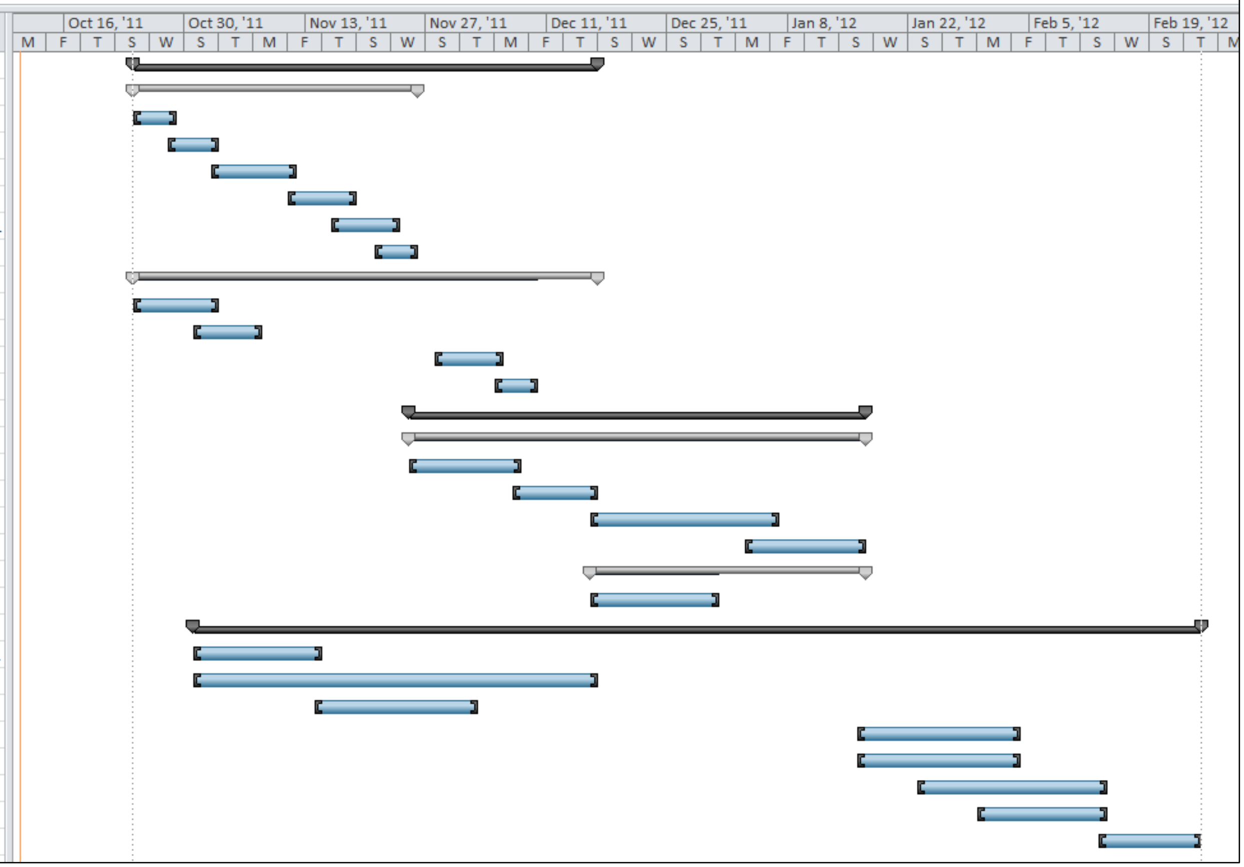


Figure 27. Sasha's Project Schedule

November December January February

Start Mon 10/24/11 — Finish Fri 2/24/12

Task Name	Duration	Start	Finish
Building Assesment	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Building Codes Study	**25 days**	**Mon 10/24/11**	**Fri 11/25/11**
Review Codes	5 days	Mon 10/24/11	Fri 10/28/11
Create Checklist	4 days	Fri 10/28/11	Wed 11/2/11
Apply Checklist	8 days	Wed 11/2/11	Fri 11/11/11
Outline Areas of Non-Compliance	6 days	Fri 11/11/11	Fri 11/18/11
Explore Compliance Options	6 days	Wed 11/16/11	Wed 11/23/11
Suggest Codes and Changes	5 days	Mon 11/21/11	Fri 11/25/11
Current Drawings/Model	**40 days**	**Mon 10/24/11**	**Fri 12/16/11**
Review Others Drawings	8 days	Mon 10/24/11	Wed 11/2/11
Determine Accuracy	6 days	Mon 10/31/11	Mon 11/7/11
Gather Data for BIM	6 days	Mon 11/28/11	Mon 12/5/11
Organize Data	5 days	Mon 12/5/11	Fri 12/9/11
Future Options	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Building Future Solutions	**37 days**	**Fri 11/25/11**	**Mon 1/16/12**
Analyze Seismic and Fire Code Issues	9 days	Fri 11/25/11	Wed 12/7/11
Research Possible Designs for Fire Upgrade	8 days	Wed 12/7/11	Fri 12/16/11
Design Fire Solutions	16 days	Fri 12/16/11	Fri 1/6/12
Generate Drawings of Designs	10 days	Tue 1/3/12	Mon 1/16/12
BIM Future	**22 days**	**Fri 12/16/11**	**Mon 1/16/12**
Outline Future Uses	11 days	Fri 12/16/11	Fri 12/30/11
Report Writing	**85 days**	**Mon 10/31/11**	**Fri 2/24/12**
Create Detailed Outline	11 days	Mon 10/31/11	Mon 11/14/11
Update Background	35 days	Mon 10/31/11	Fri 12/16/11
Write Section on Building Code Study	15 days	Mon 11/14/11	Fri 12/2/11
Write Section on Building Future	15 days	Mon 1/16/12	Fri 2/3/12
Write Section on BIM Future	15 days	Mon 1/16/12	Fri 2/3/12
Update and Expand Methodology	16 days	Mon 1/23/12	Mon 2/13/12
Update Conclusion	11 days	Mon 1/30/12	Mon 2/13/12
Final Editing and Review	10 days	Mon 2/13/12	Fri 2/24/12

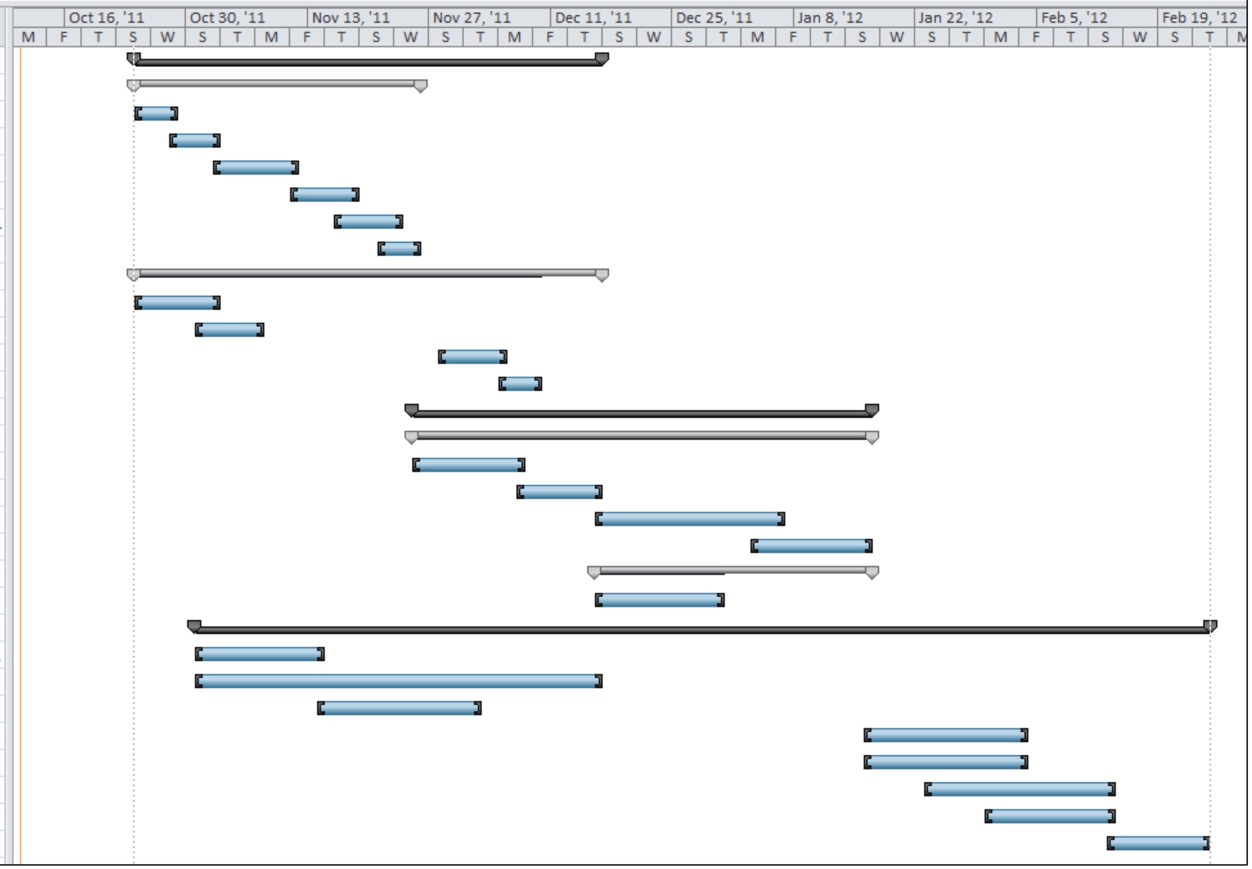


Figure 28. Paige's Project Schedule

3.7 Project Organization

The project team will use several resources for project organization. It is critical for the team to organize all documents and communication throughout the MQP experience to provide stronger collaboration and a better working relationship.

A myWPI page has been created to exchange and organize files. This site allows the team to compile and integrate each member's individual work. MyWPI will also be used to post all notes and minutes. Meeting agendas and minutes will be easily accessible, making the project more efficient.

Refworks will continue to be used to track the resources the team has used in their research and writing. This online tool compiles the references in an organized manner that allows easy sharing of information.

Through these computer resources and a cohesive team relationship, the project will be completed in an organized and effective manner taking full advantage of each member's abilities.

4.0 Deliverables

After the research has been completed and the building has been analyzed the project team will develop 3D models from which drawings and information will be represented that document Washburn's current condition along with solutions and recommendations to bring the building up to Massachusetts State Building Codes.

4.1 Drawings and Model

AutoCAD, *Revit* and BIM computer software will be used to produce documents representing Washburn after construction along with our suggested designs. These drawings of Washburn after construction will serve as the as-builts providing the accurate documentation of Washburn Shops that WPI is currently lacking. In future construction work or renovations these drawings can be utilized and help projects run more smoothly. The BIM model will complete the picture of the building, detailing the most recent renovation work and areas of non-compliance where the suggested designs can be applied. The drawings included in the BIM model will contain site plans, floor plans, elevations, in addition to structural drawings and other drawings. Through these drawings, Washburn will be more easily understood by others in the future.

4.2 Detailed Information and Recommendations

Along with drawings, detailed information will be represented in BIM along with design suggestion specifications on how to bring the building up to Massachusetts 8th Edition State Building Codes. The information in BIM will include all the areas Washburn does not comply with the current Codes. In addition the suggestions represented in BIM will outline the most significant code violations as well as renovation plans to bring the building up to these Codes.

The designs created to resolve these code issues and structural problems that have been discovered will need specifications of materials and methods of construction. These specifications will also be included in the BIM representation. The detailed information, suggestions and specification will allow every detail of Washburn to be known and will allow the improvement and preservation of this historical building.

5.0 Conclusions

The listed deliverables will be achieved through the drafted methodology explained in Chapter 3 and the background research presented in Chapter 2. The project team is aware that changes will have to be made to plan because unexpected dilemmas will arise and some tasks may be more simple than anticipated but this general outline will be followed to complete the project. This proposal will be used as a guide to eventually present WPI Department of Facilities with one complete document explaining Washburn's history, renovations, areas of concern and potential future upgrades.

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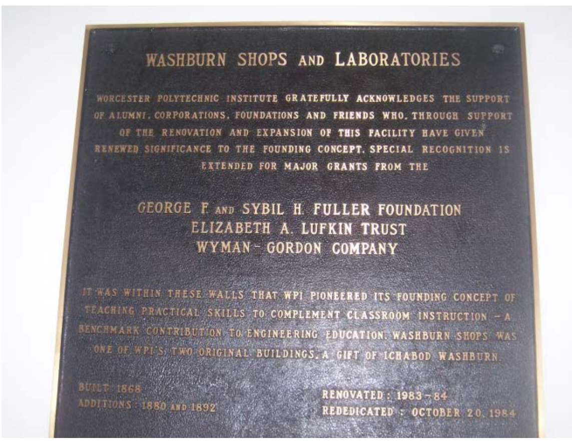
7.10 Site Photographs

Washburn Construction Sign

Washburn Shops Entrance



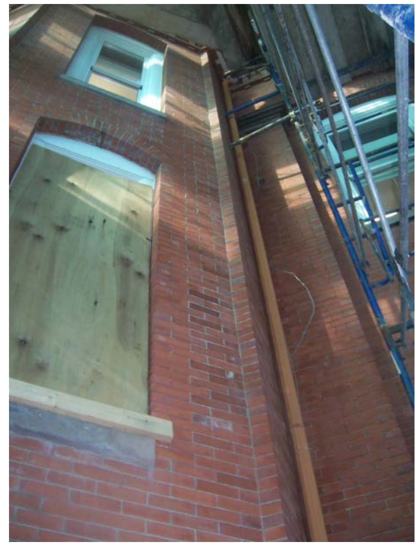
Washburn Dedication Sign

Washburn Letters on Exterior of Building

Alley Scaffolding

Alley Scaffolding 2


Scaffolding on Front of Building


Replaced Bricks on Front Tower


Soldering on Window


New Window at Roof Level


Windows with New Slate


Tower Exterior


Tower and Roofing


New Window on Tower

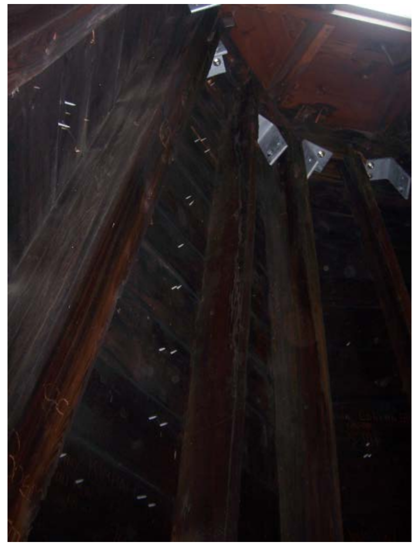

Working on Roofing


Laying Slate on Roof


Worker Soldering


Top Windows and Roof

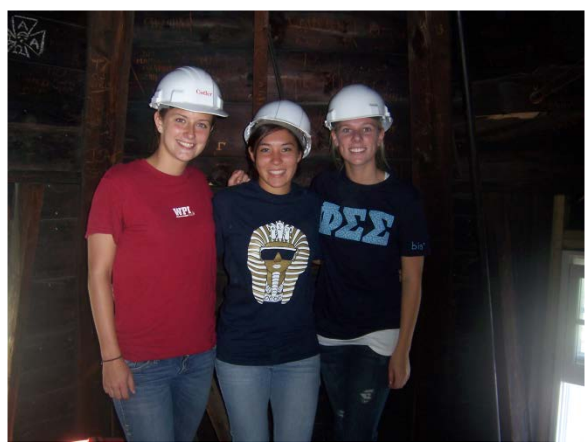
Top of Tower


Interior of Tower with New Brackets


New Exterior Tower Bracket


Old Exterior Tower Bracket

Roof from Top of Tower



Group in Tower