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WPI GATEWAY II PHOTONICS Lab RENOVATION: Design and Construction Process Analysis Using 5-D Building Information Modeling (BIM)

Submitted to the Faculty of the
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science
In Civil and Environmental Engineering

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Abstract.

This project develops a 5-D Building Information Model (BIM) to visually display the gradual progress of the construction and its associated cost in the renovation of the third and fourth floors of the WPI Gateway II building, which is intended to advance healthcare technologies and launch new medical cyber-physical systems. The 5-D BIM model information is then evaluated using Earned Value Analysis to assess the project progress and performance. This project also includes the design and constructability analysis of an alternative staircase linking the two floors involved in the renovation project.

Authorship.

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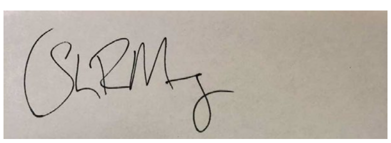
<u>The signatures below indicate equal contribution from each author to the contents of this report listed above:</u>



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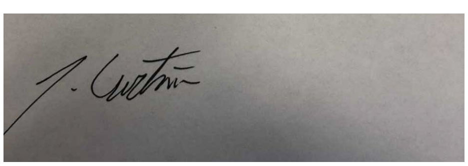

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Capstone Design Statement.

This Major Qualifying Project (MQP) proposes a Building Information Model (BIM) that incorporates and analyzes the spending associated with the gradual construction of the Gateway II 3rd and 4th floor renovation, and predominantly focuses on Phase I of the renovation due to time constraints. The MQP also includes Earned Value Analysis of the design and construction of Phase I of this renovation, which is supported by the 5D BIM model that displays the 3D views of the gradual construction process associated with corresponding costs. The project also includes a detailed proposal for a staircase between the 3rd and 4th floors that was considered in the preliminary design of the renovation and could be implemented in a future renovation of the Gateway II building. This MQP has a varied and integrated capstone design plan as the BIM model incorporates design, budget, and schedule, while the staircase proposal includes detailed structural analysis, cost estimating, and scheduling.

Economic

Economic restraints are one of the biggest obstacles to overcome in any construction project. Project estimates and budgets are made by parties involved with the project to keep construction cost in check but are often underestimated and surpassed in the field. Renovations, like this project, can be specifically economically challenging as there is commonly challenges when working with a previously built building that was not designed for the renovations purpose. In the case of the Gateway II renovation, the project is being delivered under a fast-track schedule, making the design and construction processes more complex because decisions are constantly being made under financial constraints as the project moves forward. Through the use of BIM technologies, this report investigates the relationship between the project schedule and budget to evaluate the efficiency of construction. The project schedule was analyzed in conjunction with project spending to assess construction performance and identify how schedule and cost is impacted throughout construction. Changes in schedule and spending were also tracked to determine their overall effect on the project. Additionally, value engineering will be assessed as construction progresses to show how the design and construction management teams minimized costs.

Constructability

In construction, the design and construction management teams work together to meet project budget and requirements. In the early proposed structural drawings of the Gateway II Project, the design team included a staircase between the 3rd and 4th floors that would enhance the egress routes. However, due to financial constraints, this staircase was cut from the project to reduce overall project cost. This MQP, will include a proposal for the omitted staircase. The staircase proposal will include a structural analysis. The staircase proposal could be used in a future renovation and would enhance construction speed and efficiency. If the staircase proposal was ever implemented in a future renovation project, the serviceability the Gateway II building would only be enhanced. The staircase would make the building safer and more secure as it would link the 3rd and 4th floors and create another means of egress.

Social

This project is involved with the Gateway II 3rd and 4th floor renovation, which will eventually house an integrated photonics laboratory, a PracticePoint medical laboratory, Magnetic Resonance Imaging (MRI) technology; as well as other valuable laboratory, research, and office spaces. These spaces will be used in conjunction by the WPI community and esteemed research-oriented companies. When completed, the 3rd and 4th floors of the Gateway II building will provide state-of-the-art technologies, laboratories, research spaces, and office spaces that will enhance WPI's academic opportunity and advance research in various cutting-edge medical technologies. The renovation will also promote and generate relationships between WPI and various companies. This statement is true in any construction project. But due to the construction management plan of the Gateway II renovation being fast tracked the communication between all groups involved in the project occurs much more and requires extensive elaboration between each group. Another social situation that arises in the Gateway II renovation is appealing to the groups who reside in the occupied areas of the building. Due to the fact that the Gateway II building is not being entirely renovated the project team must consistently make adjustments to their daily construction routines in order to keep the tenants working in the second and first floors happy.

Safety

On every construction project there are always safety concerns involved. This is due to the increase of ethics involved in construction and the increasing costs that occur when a safety issue arises. The Gateway II renovation is no different. In fact, there are much more safety concerns. For example, the Magnetic Resonance Imaging (MRI) systems being installed raise a lot of safety concerns. Due to the strength of the magnets any ferrous materials are not allowed within the MRI rooms. If a metal material is brought inside the magnet room it will be sucked directly into the magnet possibly damaging the expensive equipment or injuring anyone in the room. Safety on-site was very important to the project team since it can cause delays and eat away at spending cost; depending on who controls the insurance policy. Throughout the duration of our MQP there were no lost time injuries, which occur when there's an injury onsite that affects the schedule of the project.

Serviceability

As with every construction project, maintaining the serviceability of the building is essential. Maintaining the serviceability of the building means not only that it is structurally sound but also the building does not fail serviceability factors such as excessive deflection and vibrations. An example of this on the project is the reinforcements of the beams under the MRI machines to ensure the beams do not deflect too much and keeping the floor structurally sound. Serviceability of a project also has to do with the functionality of the project at completion and in the future, which in the case of the Gateway II project involves a motion lab, medical equipment, and office space. To be serviceable each of these new spaces must be fully and effectively functional for the intender users. One way this MQP set out to increase the serviceability of the renovation is by proposing a staircase design. The proposed staircase connects the third and fourth floor, which would increase the accessibility to the equipment, labs, and offices. Additionally, the staircase offers an alternative means of egress, therefore making the building not only more serviceable but also safer.

Ethics

Throughout the duration of this project, all parties involved in planning, design, and construction maintained the highest level of construction and business ethics. Each party-maintained respect, professionalism and honesty throughout the project. The group was generously shared information relating to the project. Information from the general contractor's firm Procore system such as design drawings, construction drawings, and project estimates were shared with the group. The group followed the confidentiality agreement signed at the start of the project.

Professional Licensure Statement.

In many areas of the Civil Engineering field it is essential to obtain a Professional Engineer's license (PE). A PE license gives an engineer the ability to approve documents based on the fact that the engineer is knowledgeable and versed in the field of Civil Engineering. A PE license is specifically important in the design fields of Civil Engineering, such as structural engineering. By approving a document an engineer becomes liable for any problems that may arise in the future, meaning approval should not be given if the engineer is not in full agreement with the document in question.

The Fundamentals of Engineering (FE) Exam.

The FE exam is the first step in the process of becoming a professional licensed engineer (PE). The exam is designed for recent engineering graduates and students who are close to finishing an undergraduate engineering program at an ABET accredited university or program. Passing this exam allows you to become an engineer in training, who then needs to spend five years working under a Professional Engineer.

The Principles and Practice of Engineering (PE) Exam.

The PE exam is required to become a Professional Engineer (PE) in the United States. Many jobs require the review and stamp of a professional engineer for any work to be performed and the job to be insured. The Professional Engineer is taken by engineers in training who have passed the FE Exam and worked under the supervision of a licensed PE for five years. Upon passing the PE Exam, the engineer in training receives their Professional Engineering (PE) License. In the engineering field, PE licensure is highest standard of competence, and the mark of a professional. It is a standard recognized and respected by employers, clients, and the public that assures quality, skill, and dedication. Receiving the distinction of the PE allows an engineer to stamp drawings for public review.

Acknowledgements.

We would like to thank all the individuals who were involved in the Gateway II Photonics Lab renovation. We would like to thank WPI and the various faculty and staff members who assisted us throughout our project. We would like to thank KVAssociates for giving us insight into the collaboration and construction process of the Gateway II project, as well as allowing us to observe and learn from their extensive knowledge in the construction project management field. We would like to thank Consigli Construction for giving us access to their Procore information for the Gateway II project, as well as allowing us to attend weekly owner's meetings in the Gateway II building. Finally, we would like to Isgenuity for giving us insight into the design aspects of this project as well as allowing us to observe and learn from their professional work and knowledge. Without each mentioned party this project would not have been possible.

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1.0 Introduction.

In 2010, Worcester Polytechnic Institute (WPI) added Gateway Park to the campus infrastructure. Gateway Park is a multi-building development that extends the WPI campus out to the edge of Interstate 290. Originally, it began as a venture between WPI and the Worcester Business Development Corporation to transform the previously unused area into a state of the art academic, research, and commercial facility. Today, the development consists of three facilities that house departments and programs such as: Robotics Engineering, a Biomanufacturing Education and Training Center, the Fire Protection Engineering Research Lab, the Foisie Business School, and the Life Sciences and Bioengineering Center (WPI, 2015). Each building in the Gateway Park development houses important graduate research and is essential to various academic departments at WPI. Along with graduate research, the Gateway Park houses local commercial life science companies. This project focuses solely on the second development in Gateway Park.

The second development to Gateway Park, the Gateway II building at 50 Prescott Street, was built in 2013. The original intent of the Gateway II development was to have the bottom two floors of the four-story building serve as space for a few different WPI academic departments, while the third and fourth floors were to be rented out to Siemens Metal Technologies (WPI, 2016). However, in 2018, Siemens Metal Technologies left the third and fourth floors of the Gateway II building vacant. WPI is renovating these two floor spaces of 35,000 vacant square feet to better utilize the vacant area and create a space dedicated to medical research and cutting-edge technologies, such as photonics and PracticePoint. PracticePoint is a membership-based research, development, and commercialization alliance founded to advance healthcare technologies, with focus on modern medical devices interact with the physical world to improve patient care. This renovation will enhance WPI's academic opportunity as well as develop valuable relationships between the WPI community and esteemed companies in the medical and manufacturing fields. To make this project reality, WPI hired KVAssociates Inc. (KVA) to serve as the Owner's Project Manager (OPM) throughout the duration of the project. With consultation from KVA, WPI then hired Isgenuity LLC as the Architect and Consigli Construction Co. as the General Contractor/Construction Manager (J. Lussier and D. Sullivan, personal communication, September 28, 2018). Each party involved in this project faced various unique challenges throughout the duration of design and construction that depended on collaboration to resolve. Two main challenges the project has presented are the project was developed under a fast-track schedule and the first two floors of the building were occupied during construction.

This Major Qualifying Project (MQP) tracked the development of the design completion and the construction progress and efficiency associated with the Gateway II renovation. The renovation schedule and costs are analyzed using earned value analysis and visually displayed through the use of 5-D Building Information Modeling (BIM). BIM is a cutting-edge construction technology and is an effective way of showing the physical and functional aspects of a construction project. A 5-D BIM incorporates the design, schedule, and cost of the project into a visual 3-D graphic. The report first analyzes the project organization among the different parties involved in the design and construction process. The next part of the report goes into detail about the effects Building Information Modeling (BIM) has on the project while also providing a model using Earned Value Analysis that incorporates and analyzes the cost and schedule of the construction process. The last part of the report presents a design for an alternative staircase linking the two floors involved in this renovation project.

2.0 Background.

The renovation of Gateway II at 50 Prescott Street presents various unique challenges to the design and construction management teams. The project requirements and contract-type are largely responsible for such challenges, but there is also a tenant that will remain in the building and occupy space on the third floor during construction while the first and second floors will remain occupied throughout the entire project. The project requirements and construction include the creation of academic, medical, and research spaces that require previous experience from each responsible party to successfully satisfy the owner and meet project requirements. Additionally, the project is under a fast-track contract, which is a project delivery method intended to shorten the project duration by starting construction before the design is complete. To effectively analyze this project, it is important to understand the purpose and logistics of each part of construction, from start to finish.

2.1: 50 Prescott Street (Gateway II).

In 2013, WPI added the second building to the Gateway Park complex, Gateway II. Originally, the Gateway II building was designed because WPI wanted to support its programs with a facility that would attract companies in the life sciences and biotech industries. At completion, Gateway II housed tenants such as the Biomanufacturing Education and Training Center, the Massachusetts Biomedical Initiatives, the Fire Protection Engineering department at WPI, and the WPI School of Business. The Gateway II building offers valuable office, laboratory, and research space that is essential to WPI's commitment to scientific research and advancement.

2.2 O'Connell Development Group.

As Gateway Park was built, WPI formed a relationship with the O'Connell Development Group. O'Connell is a real-estate development firm out of Holyoke, Massachusetts that assists in financial objectives and real estate development. O'Connell partnered with WPI as the designated developer of the Gateway II building. Under the agreement, WPI ground-leases one of Gateway Park's four remaining pad-ready sites to O'Connell. A ground lease is an agreement in which a tenant is permitted to develop a piece of property during a specified lease period, after which the land and all improvements are turned over to the property owner. Typically, ground leasing involves a lease period for 50 to 99 years and allows the landlord to assume all improvements once the lease term expires, so the landlord may sell the property at a higher rate. Accordingly, the O'Connell Development Group owns the Gateway II building as the company financed, developed, and constructed the building. The ground lease agreement between WPI and O'Connell regarding the Gateway II building lasts 50 years, after which the property will be fully owned by WPI.

2.3 Gateway II Renovation.

In January of 2018, WPI received some very exciting news. The Massachusetts Lt. Governor Karyn Polito announced a four-million-dollar state funded grant to WPI and Quinsigamond Community College (Baker-Polito Administration, 2018). The grant was given to the two schools to support the launch of the American Institute for Manufacturing Integrated Photonics (AIM Photonics) Lab for Education & Application Prototypes' (LEAP). At WPI, the grant went towards a new facility that will work collaboratively with AIM Photonics, the AIM Photonics Academy based at MIT, and other academic, industrial, and government organizations linked with the integrated photonics to help drive business in the emerging manufacturing sector (Photonics Media, 2018). Along with the LEAP area, WPI plans on building a PracticePoint facility. The purpose of the PracticePoint facility is to advance healthcare technologies and launch new medical cyber-physical systems.

After receiving the LEAP grant, WPI decided to use the space left vacant by Siemens Metal Technologies in the Gateway II building to house the photonics and PracticePoint laboratories and research spaces. The proposed plans for this project can be seen in Figures 1 & 2. The project scope includes the use of the majority of the third floor and the entire fourth floor of the Gateway II building. On the third floor (See Figure 1 below), the scope includes a Magnetic Recognition Imaging (MRI) magnet and procedure space, a neuroscience motion laboratory and observation suite, a patient care area, a manufacturing and 3D printing area, and office space. Originally, there were plans for an additional smaller MRI magnet on the third floor, but due to schedule and logistical constraints the plans for the smaller MRI were cut from the scope of this project. The third floor also houses a tenant called LakePharma, which is a biologic service provider that specializes in antibody and protein engineering. LakePharma will occupy their space on the third floor throughout the duration of the project, which poses additional challenges throughout construction. On the fourth floor (See Figure 2), the project scope includes the PracticePoint photonics laboratory, a photonics clean room, and photonics office space. The fourth floor is dedicated predominantly to photonics research, while the third floor is a more integrated space. As shown in the project plans, much of the work in the Gateway II renovation is related to medical and research spaces.

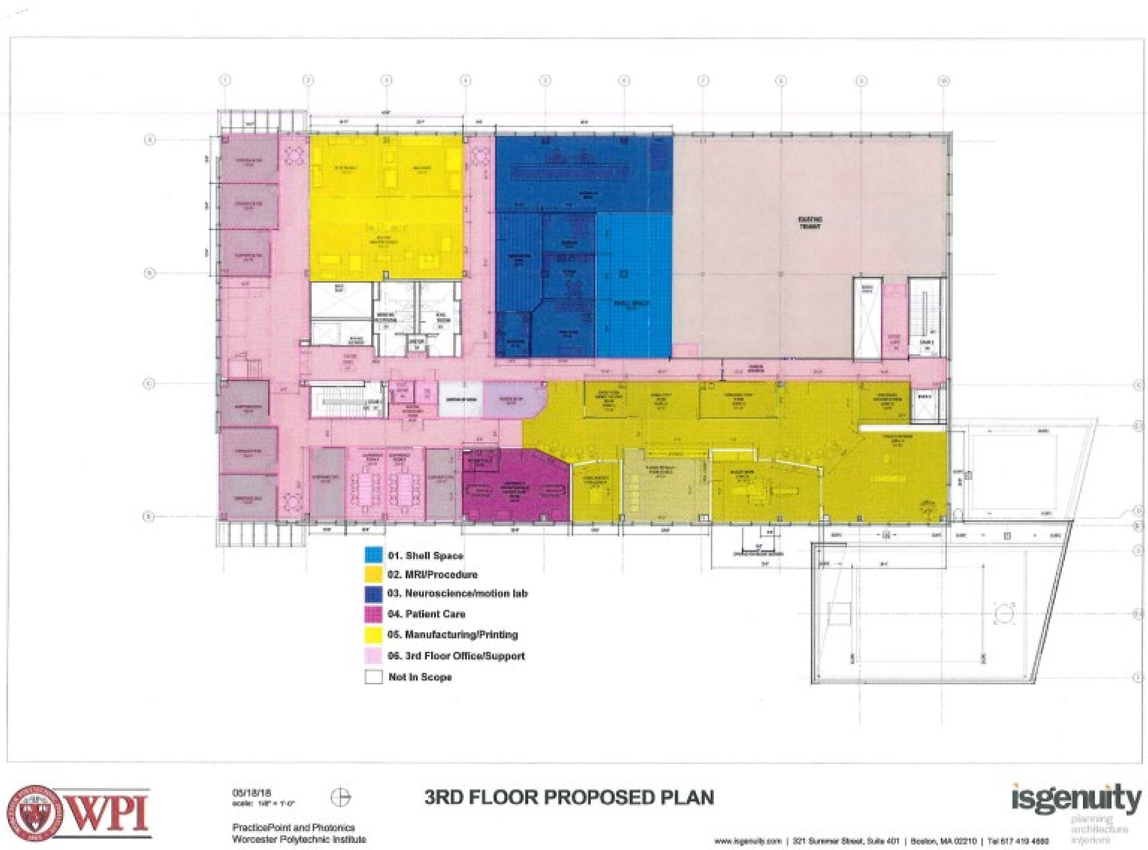

Figure 1: 3rd Floor Proposed Plan

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Figure 2: 4th Floor Proposed Plan

2.3.1 Photonics Lab.

According to the AIM Photonics Academy, photonics is the science of creating, moving and detecting photons. A sub-category of photonics, which the WPI photonics lab will be focusing on, is integrated photonics. Because of past research, integrated photonics has led to complex photonic circuits that can process transmit light in similar ways to in which electronic integrated circuits process and transmit electrical signals. Integrated electronic circuits, or microchips, is an assembly of electronic components in which capacitor, resistors, transistors, and diodes are built up on a thin semiconductor material (typically silicon). The resulting circuit can control the flow of electrons and perform electrical operations (Saint & Saint, 2018). Integrated photonic circuits are trying to do the same thing as an electric circuit with electrons, except with photons. A photon is defined as a particle representing a quantum light or other electromagnetic radiation (Marburger III, 1996). In the new photonic circuits, photons are sent through at the speed of light, allowing many pieces of information to be sent at once. Electrons, used by electrical circuits, are sluggish and interactive with one another and the copper wire. This characteristic limits the amount of information that can be transmitted at once. "Integrating more photonic devices in micron-scale proximity on a computer chip will enable more of its components, transistors, memory, modulators, detectors- to work seamlessly together" (Aim Photonics Academy). The lab at WPI will support the manufacturing sector in central Massachusetts by:

1) Advancing integrated photonics research
2) Supporting growth of the integrated photonics industry along the I-90 corridor
3) Accelerating innovation from the lab to the marketplace
4) Educating and training the next generation of industry leaders

2.3.2 PracticePoint.

With the introduction of the PracticePoint area at Gateway II, WPI has created an alliance built to advance healthcare technologies and launch new cyber-physical systems. PracticePoint Communications is a medical education company that partners with academic medical centers to design and develop Certified-Continued Medical Education (CME)/Continued Education (CE) for healthcare providers. PracticePoint has teamed up with a variety of accrediting universities such as Johns Hopkins Medicine, NYU School of Medicine, University of Nebraska Medical Center, and more. WPI is the next university to create an alliance with PracticePoint (Practice Point Communications, 2018).

At WPI, members of the research, development, and commercialization alliance will work together to make advances in digital medical technologies, robotics, cloud computing, wireless technologies, and data science- for the benefit of patients, providers, and companies in the medical field. The PracticePoint facility will replicate point-of-practice environments that are integrated with advanced manufacturing and testing equipment. Another goal of the new labs will be to accelerate the translation of new discoveries from prototype to product. The PracticePoint facility at WPI will not only enhance on-campus research but will also contribute towards the advancement of important medical technology. Professor Gregory Fischer, part of the Mechanical Engineering Department at WPI, is the PracticePoint Director on campus, and is also the founding director of the AIM Laboratory. Professor Fischer's research and interests align with the Gateway II renovation directly, as his research focuses on medical robotics, MRI-compatible mechatronics, computer-assisted and image-guided surgery, sensors and actuator development, soft wearable devices, socially assistive robots, and robotics education.

2.3.3 Magnetic Resonance Imaging (MRI).

Magnetic resonance imaging (MRI) technology is a common procedure in the medical field throughout the world. MRI uses strong magnetic fields and radio waves to create detailed images of the organs and tissues within the body. MRI scanners contain two powerful magnets, which are the most powerful parts of the equipment. Accordingly, in this project there is a need for structural reinforcement below the MRI scanner due the magnets weight. There is also another construction consideration when dealing with MRI technology, which comes by way of radio-frequency shielding.

2.3.4 Radio-frequency (RF) Shielding.

MRI technology is undoubtedly powerful, but it is important to remember MRI machines are very sensitive. In many cases, any slight external interference can have a huge impact on the MRI's ability to produce diagnostically acceptable images. Consequently, MRI imaging rooms need radio-frequency (RF) shielding to ensure optimal MRI operation. RF shielding serves two important purposes:

1. RF shielding prevents external electromagnetic radiation from distorting diagnostic images.
2. RF shielding prevents the MRI's own electromagnetic radiation from disrupting external medical devices.

MRI machines have highly sensitive RF sensors that can pick up radio-frequency electromagnetic radiation (RF noise) coming from outside the MRI room. This interfering RF noise can come from a wide variety of devices, including transformers, computers, and motors. To prevent any distortion from RF noise, an RF shield completely encloses the MRI room with a system of interacting components that include, doors, windows, ceilings, floors, and walls. Additionally, items that pass through the RF shield, such as HVAC, plumbing, piping, etc., must pass through RF filters.

In order to design and create an effective RF shield, all components must feature appropriate conductive materials. When each component is assembled, the RF shield is a six-sided box with walls, a floor, and a ceiling, referred to as a "Faraday Cage". Some important considerations for the RF enclose design should include the following:

1. **RF Shield Walls** — RF shields often require three partitions, including the parent wall, the RF shield wall, and the interior finishing wall.
2. **RF Flooring** — Floors in MRI exam rooms often require a structural subfloor, RF shielding, a protective layer, and other finish materials.
3. **RF Door** — Common types of RF door systems include single swing, double swing, sliding, double sliding, acoustic, non-acoustic, automatic, and manual.
4. **RF Ceiling** — An RF shield ceiling is often suspended from the structural deck overhead. Any services that must pass above the MRI scanner room (power, piping, cabling, and ductwork, for example) should do so in the plenum above the RF shield ceiling.
5. **RF Windows** — The window between the magnet room and control or console room usually requires RF shielding, which is often two layers of copper screens or perforated sheets.
6. **RF Filters** — Items that penetrate the RF shield enclosure will require special fittings and materials to maintain shield integrity. RF filters and waveguides are common materials used at the shielding feed-through points.

One of the most common RF shielding design, which will be incorporated in the Gateway II renovation, uses solder seamed copper as the protective conductive material. An example of a typical copper RF shielding enclosure can be seen below in figure 3.

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Figure 3: Copper RF shielding in a planned MRI room

3.0 Design and Construction Planning.

This project is under a Reimbursable Cost with a Guaranteed Maximum Price (GMP) Single-Prime Contract with an $8 Million estimated cost of construction; meaning that if the project spending exceeds the price of $8 Million, the General Contractor (GC) Consigli Construction Co. will be required to cover the cost in the event of overspending. The project is "Fast-Tracked" meaning the design and construction of the project occur simultaneously. The project involves a 35,000 square foot renovation and has an estimated construction schedule of 8 months beginning on September 28th and estimated completion date of June 25th. The project scope includes over 25 labs, an MRI space, photonics and practice point labs, two living spaces, 15 offices, and updated mechanical and electrical work. Consequently, work includes interior demolition, new doors, frames, partitions, ceiling, flooring, millwork, raised flooring and architectural specialties. There is also a need for other groups such as: architectural engineers, structural engineers, and Mechanical Electrical Plumbing and Fire Protection (MEPFP) engineers due to the new equipment that is producing different structural loading. Demolition and reconstruction of portions of the exterior facade will also be necessary to install the MRI equipment. Additionally, there is a need for installation of radio-frequency (RF) shielding due to the MRI magnet.

The project is constructed in two phases. Phase 1 is about 5,000 square feet and consists of: a motion lab with a force plate and raised floor, a patient holding area equipped with a gantry system, and multiple office space. Phase 1 is only comprised of one area on the third floor and the two electrical rooms; one on the third floor and one of the fourth floor. Phase 2 encompasses the rest of the 30,000 square foot project scope. Phase 2 consists of: two MRI units, an animal holding center, multiple labs which will be rented by various health care companies, and a considerable amount of office space and collaboration areas. The extent of phase 2 covers the majority of the third floor and just about all the fourth floor, apart from one electrical room. Figure 4 displays the phasing plans for the third and fourth floors of the Gateway II renovation.

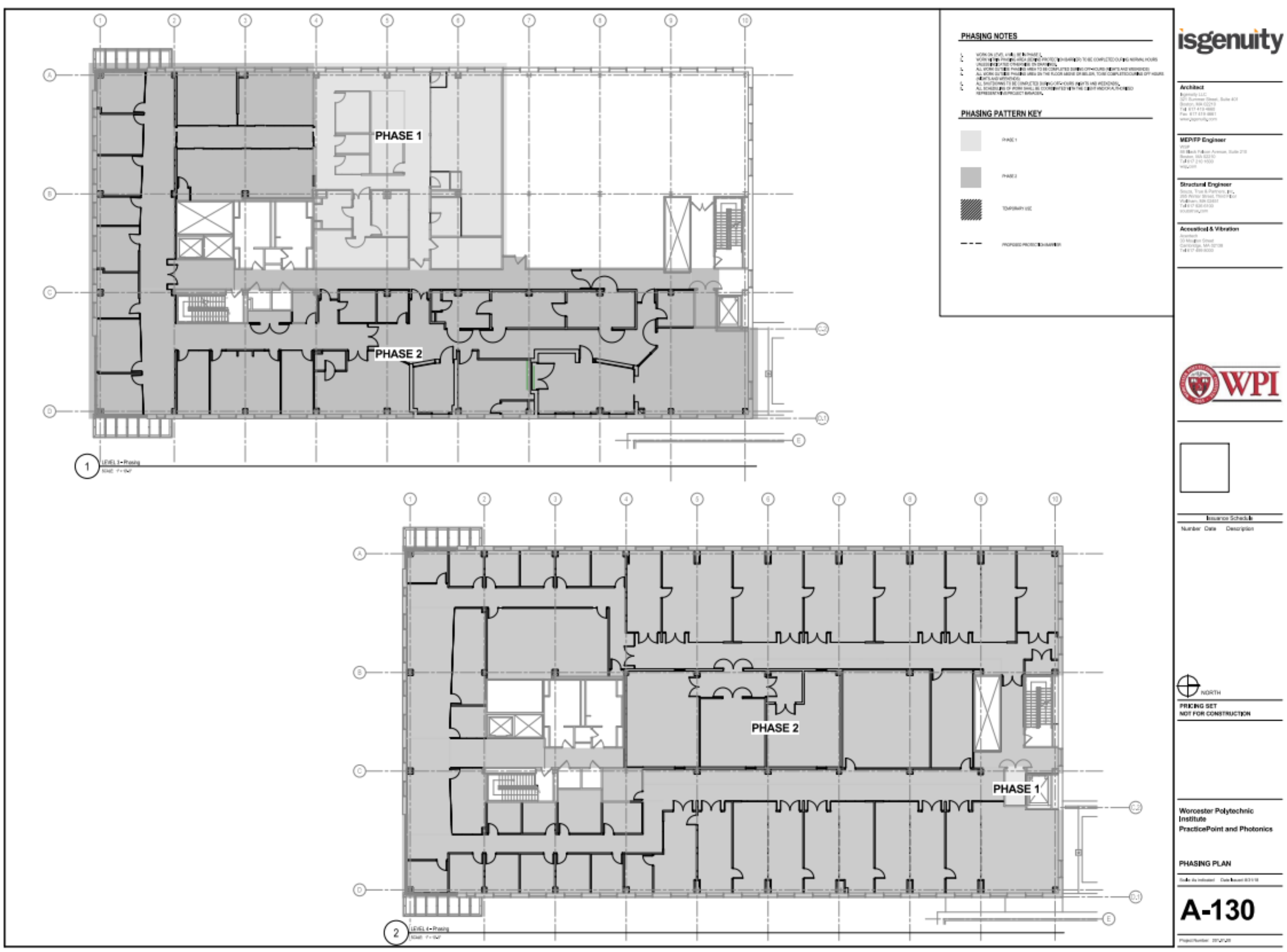

Figure 4: Phasing Plans for the third floor (top left) and the fourth floor (bottom right) of the Gateway II Renovation.

3.1 Bid Process.

The bid process for the Gateway II renovation involved various parties but depended first on decisions made by the WPI Campus Planning Facilities Team, led by Eric Beattie, and the WPI Design and Construction Team, led by Ronald O'Brien. First, WPI hired and contracted a third-party owner's project management team out of Boston called KVAssociates (KVA), with whom WPI has worked with on various previous projects, such as the Foisie Innovation Studio. In collaboration, WPI and KVA then developed a budget of about eight million dollars. Once the budget was identified Jeff Lussier, who is the head Owner's Project Manager (OPM) from KVA on the Gateway II renovation, developed a rough estimate based on extensive prior experience. From there, the design teams were bid out and Isgenuity LLC (Isgenuity), a design team out of Boston whose work focuses primarily on the academic and healthcare sectors, was chosen for the renovation project. KVA then sent out the invitation to bid for construction to 4 general contractors, three of which had a history with WPI and a background working on research and medical facilities; Bond Construction, Shawmut and Consigli Construction. The fourth contractor was a company affiliated with the O'Connell development group, which was taken out of contention early in the process due to their lack of experience with constructing research labs and medical spaces. After receiving bids back from the other three general contractors/construction managers, WPI and KVA interviewed each of the project teams from each contending firm. These interviews carry a lot of weight when deciding which general contractor will be awarded the contract. The interviews give the owner insight on things such as: the character of the team, how honest and communicative the group will be during the project development, and their prior experience with projects of similar scope. Once the interviews were completed WPI awarded the project to Consigli Construction, whose main offices are located in

Boston. The figure below shows the hierarchy of the projects that occur at WPI. At the top of the chain is the WPI board of trustees, who work closely with the Department of Campus Planning and Facilities Management to plan and get projects in motion. The Department of Campus Planning and Facilities Management also works closely with the Owners Project Manager (OPM), who is KVA Consultants on this project. As the OPM, KVA oversees managing the design team, Isgenuity, and the General Contractor, Consigli Construction. See Figure 5: Bid Process Flow Chart for detail.

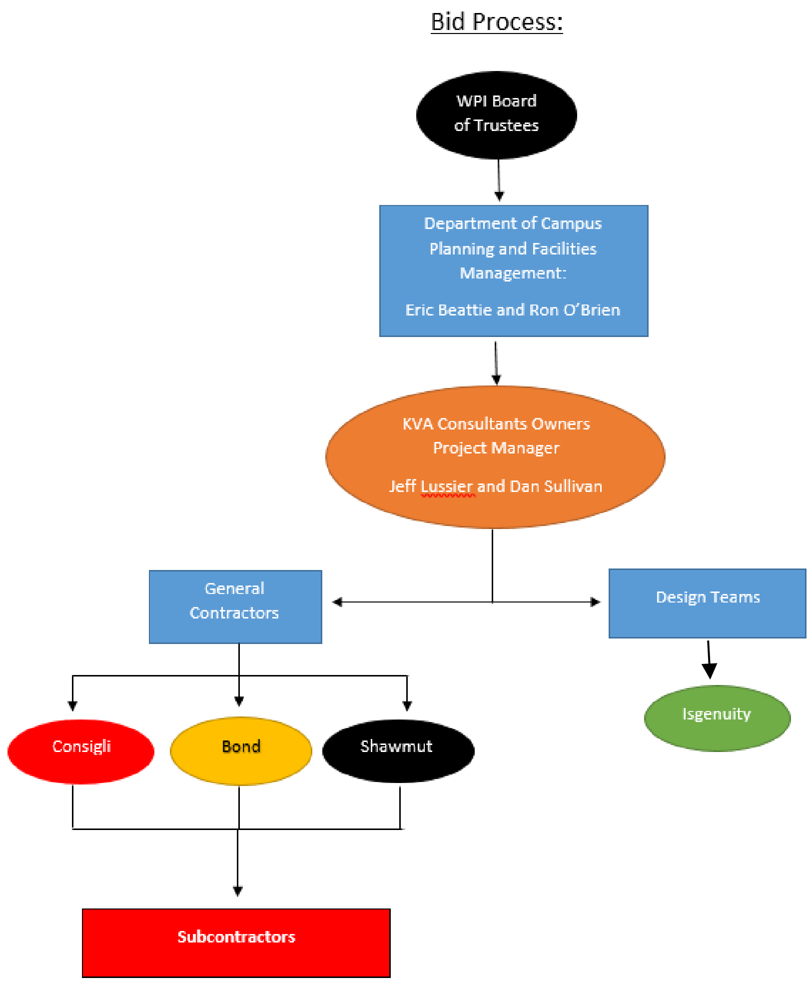

Figure 5: Bid process flow chart

3.2 KVAssociates Inc.

KVA is an owner's project management firm located out of Boston, MA. As the owner's project manager (OPM), KVA assists and serves as a consultant to the project's owner from the start to the very end. Although WPI has personnel responsible for managing on-campus construction projects within the departments of Campus Planning and Facilities Management, KVA is hired to assist in project management whenever a project's scope is large enough to require such assistance. The goal of KVA is essentially to provide experience, decision-making skills, and leadership throughout a project with intentions of maximizing project efficiency and performance, while minimizing costs. They complete this task by continually monitoring project progress, while also addressing and solving any budget or schedule constraints with creative solutions. It is not the role of KVA to design or build anything throughout the duration of a project, but there is often conflict between the parties responsible for the designing and building of a construction project. Consequently, KVA often acts a mediator between the design team and the general contractor that encourages efficient collaboration. In short, KVA is responsible for monitoring a project's budget, schedule, and quality while keeping in mind the project requirements and owner specifications. The KVA team on the Gateway II renovation consists of Jeff Lussier and Dan Sullivan. Jeff Lussier leads the KVA team as the head owner's project manager, while Dan Sullivan works closely in collaboration with Jeff as an associate owner's project manager. (See Figure 6: KVA Organizational Chart)

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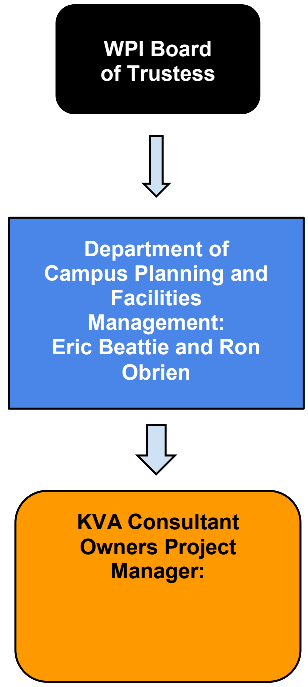

Figure 6: KVA Organizational Chart

3.3 Isgenuity, LLC.

The role of the designer on the project is to develop a design model for the customer that satisfies their needs aesthetically and practically. In this project, the Isgenuity design team prepared a bid for KVA and WPI to review, which was awarded the project. Due to the fast-track project delivery method of the Gateway II project, Isgenuity was still in the process of revising and completing design drawings during early stages of construction. Along with Consigli, Isgenuity is essential to project efficiency and effectiveness as they are responsible for all aspects related to design throughout the project.

Isgenuity was specifically chosen by KVA and WPI to complete this project for a number of reasons. Isgenuity is a Boston-based architecture and design practice with a primary focus in the academic and healthcare sectors that prides themselves on their ability to efficiently design complex and unique projects. In the past, Isgenuity has worked with a number of respected institutions, such as; Beth Israel Deaconess Medical Center, Boston Children's Hospital, Boston College, Boston University, and many more. Their valuable experience in the academic and healthcare fields proved Isgenuity to be a fitting choice for the design team in the Gateway II renovation, due to the complicated medical and academic spaces in the project scope.

In this project, Isgenuity was first hired in the summer of 2018 for a preliminary eight-week conceptual design phase, and then proceeded into detailed design after the bid was formally awarded to them. The conceptual design phase is the initial design phase that involves the design team developing a design based off of research and the customers wants and needs. Each design team may go about this phase slightly differently but the by the end, the team should;

1) Review the programs ideas of the client to ascertain the requirements of the project and arrive at a mutual understanding of such requirements with the Client.
2) Provide a preliminary evaluation of the Client's program, schedule, and construction budget requirements
3) Review with the Client alternative approaches to design and construction of the project.
4) Based on the mutually agreed-upon program, schedule and construction budget requirements, prepare for approval by the client, schematic design drawings consisting of preliminary drawings illustrating the project.

5) Prepare and submit to the Client a preliminary estimate of Construction cost based on current area, volume, or other unit costs.

During the conceptual design phase for the Gateway II renovation project, Isgenuity formed a team of three members: Dena Zyroff, Jennifer Vachon and Sarah Edwards. The team has been led by Dena Zyroff, who has over 18 years of experience as an architect. Dena is an associate principal at Isgenuity who has worked and contributed extensively on significant healthcare and laboratory projects for medical and academic centers. Jennifer Vachon, the second member of the Isgenuity team, is a senior associate at Isgenuity who plays a pivotal role in this project. Additionally, Sarah Edwards, an associate at Isgenuity, plays an important role in this project as she is responsible for maintaining most of the communication with other parties during the project. From the WPI standpoint, most of the contact with Isgenuity is primarily with Dena Zyroff, Jennifer Vachon, and Sarah Edwards. The fourth and final member of the team is Martin Batt, who is the President of Isgenuity. Mr. Batt was predominantly involved in the early stages of this project but continues to stay up to date on the project and lend assistance when necessary. Table 1 shows the Isgenuity hierarchy in the Gateway II project, while figure 7 shows the Isgenuity acquisition flow chart.

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Isgenuity Team Member:	**Project Team Position:**
Martin Batt	President
Dena Zyroff	Associate Principal, Architect
Jennifer Vachon	Senior Associate, Architect
Sarah Edwards	Associate

Table 1: Isgenuity Project Team Members and Roles

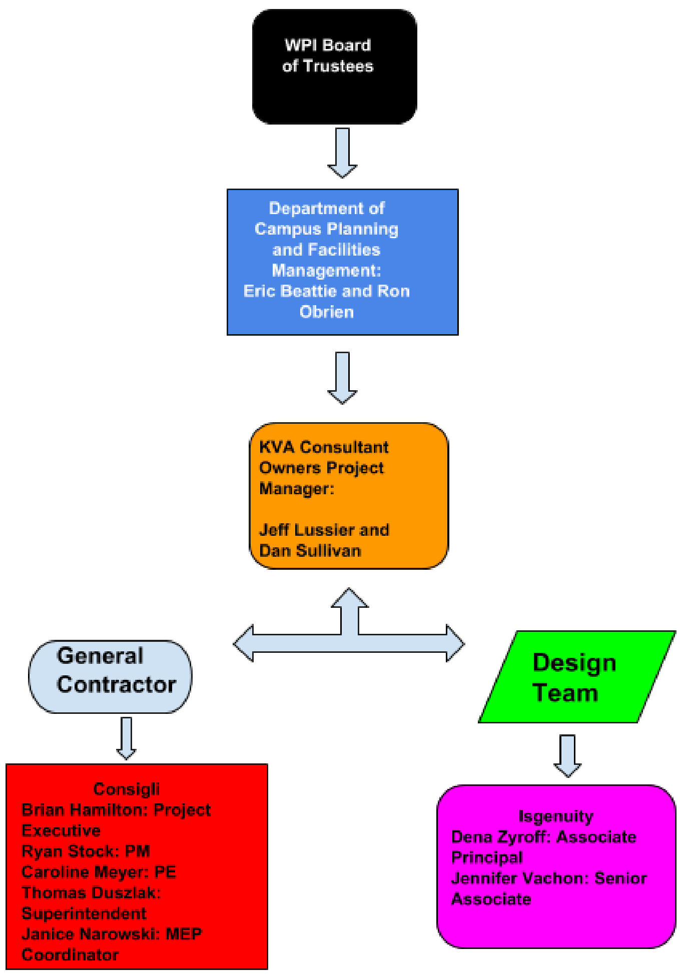

Figure 7: Isgenuity Acquisition Flow Chart

3.4 Consigli Construction Co., Inc.

Consigli is the General Contractor (GC) on the Gateway II renovation project. Consigli was founded in 1905 by Peter Consigli. The company started off as a small crew of masons that performed work around the Milford, MA area. Gradually the company evolved into a construction company that performed work such as: small commercial work, plowing, grave digging and restoration jobs. Today Consigli performs around $1 billion in annual construction volume. The role of Consigli, as a self-perform contractor, is not only to provide construction management services such as: scheduling, estimating, quality, safety etc., but also to provide the labor to perform the actual work through their own forces or through subcontractors.

Heading the project management aspects of the Gateway II renovation on the Consigli team are Ryan Stock and Caroline Meyer, both of whom are WPI graduates. Ryan Stock serves as the project manager and Caroline Meyer serves as the project engineer. The work the project management team performs changes at the different stages of the construction project but remains essential to project efficiency throughout the entire project. During the pre-construction phase, the group works to find the best subcontractors for the job at hand. During this process Ryan and Caroline review the bids from the various subcontractors to ensure that there is no work left out of the contract or no extra work listed that would potentially result in a change order. During construction, the project management team is tasked with reviewing Request for Information (RFI's), submittals, material delivery, processing change orders and communicating with the owners about the progress of the project and the challenges faced. See (Figure 8: Consigli Acquisition Flow Chart)

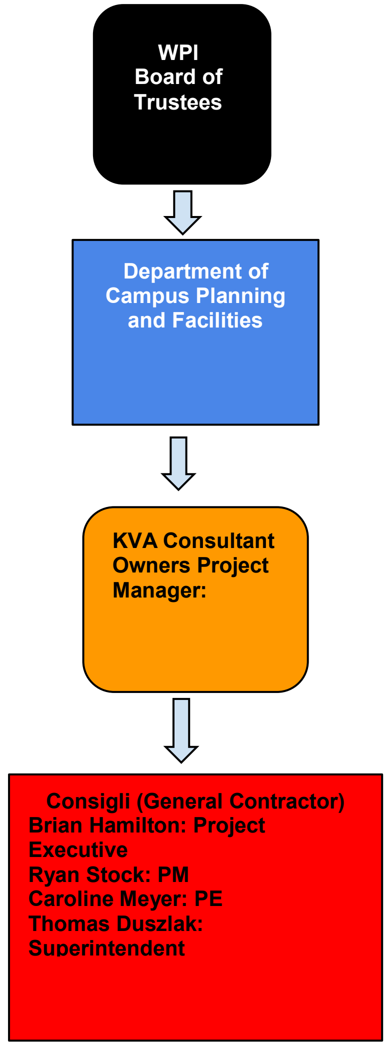

Figure 8: Consigli Acquisition Flow Chart

The other division of the project team is the field operations. The field operations team on the Gateway II project is led by Thomas Duszlak, who is the project superintendent and also a WPI graduate. Thomas' role is to coordinate the work being performed in collaboration with the project team, and also manage the subcontractors in the most efficient way possible. Thomas achieves these goals through tasks such as: developing site logistics plans, scheduling meetings with the subcontractors and finding creative solutions to the unique and unpredictable problems often faced in construction as they relate to planning and constructability. One of the most important roles of the superintendent on the construction site is safety and ensuring the site always remains safe. Most of the work performed by the project management team revolves around in-office work, while the work of the superintendent mainly involves being on the construction site. This role difference is what makes Thomas very instrumental in maintaining jobsite safety, efficiency, and productivity; because he is consistently monitoring the site and interacting with the laborers and foremen.

Another role within the Consigli project team is the MEP coordinator, Janice Narowski. The MEP coordinator is responsible for assisting with mechanical and electrical design as well as construction issues from pre-construction through construction. Typically, MEP coordinators are involved more heavily early on during pre-construction to help make informed engineering decisions prior to bidding and construction. The overarching goal of the MEP coordinator in any construction project is to make sure that the engineering design decisions and solutions meet the owner's project goals related to scope, budget, quality, and performance. Lastly, the top position on the project team consists of the role of Project Executive, for the Gateway II renovation Brian Hamilton assumed this role. The Project Executive serves almost as a business owner within Consigli. The Project Executive is given several projects they are assigned to and serve as the overwatch of the team and assist when needed. The Consigli team hierarchy for the Gateway II renovation can be seen in Table 2.

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Consigli Team Member:	Project Team Position:
Brian Hamilton	Project Executive
Ryan Stock	Project Manager
Caroline Meyer	Project Engineer
Thomas Duszlak	Superintendent
Janice Narowski	MEP Coordinator

Table 2: Consigli Project Team Members and Roles

3.5 Lean Construction on Gateway II.

According to the Lean Construction Institute, Lean Construction of Lean Project Delivery, is a project delivery method that seeks to develop and manage a project through relationships, shared knowledge and common goals ("What is Lean Design & Construction?", Lean Construction Institute, 2017). The traditional areas of knowledge, work and effort are broken down and reorganized for the advancement of the project rather than the individual parties involved on the project. In doing so projects are finished quicker, produce less waste, reduced safety hazards, and have more cost savings.

Lean Construction methods are becoming more common in the construction industry. According to the lean construction institute, the effectiveness of a labor hour has not improved in the last 50 years, while other industries have seen significant advancements. In other words, the construction industry has not improved its efficiency in 50 years which is causing the cost of building to increase. Currently, 70% of projects are over budget and delivered late ("What is Lean Design & Construction?", Lean Construction Institute, 2017).

Consigli decided to implement Lean construction on the Gateway II project in a few different ways. Based off a meeting with the Consigli project manager, Ryan Stock, and sitting in on a presentation from the Consigli team, it was determined that Consigli planned to use the following Lean construction methods:

- No materials "touch the ground"
- Meetings with the subcontractors on the site
- Job is a little too small to use pull planning, might do more harm than good.

The first method, no materials "touch the ground" can help make the project much safer and more efficient. This method consists of thorough material delivery scheduling. The point of this method is to have subcontractors only have materials delivered that they will be immediately using. This prevents materials cluttering the job site creating tripping and other safety hazards, and prevents materials from being damaged, saving money for the subcontractors and the owners.

The second method is meeting with the subcontractors on the site. This step is very important for keeping the project on time and on budget. These meetings often begin before construction even begins and occur throughout the life of the project. The purpose of these meetings is to have different trades and subcontractors collaborate to perform the tasks on hand in the most efficient and logical way. These meetings also help determine whether the project is on schedule, behind schedule, or ahead of schedule. Lastly, these meetings also help with the planning of the delivery of the materials.

The third method of Lean construction mentioned is “pull planning”. Pull planning is a technique that is used to develop a coordinated plan for one phase of a project. Making milestones for the project to meet, there collaborative approach between those who are directly responsible for supervising the work on the project to make these milestones. Often working backwards from the milestone scheduling daily and weekly tasks until everything is scheduled up to the beginning of the phase (“Pull Planning”, 2018). Consigli has decided that they are not performing pull planning sessions because of the size of the project. Consigli typically uses pull planning to finely tune the construction hand-offs and work. Due to the size and the specialized labs going into Gateway II, Consigli determined that the use of pull planning would be micromanaging the project too much and lead to more harm than good.

4.0 Project Management.

The project management portion of the Gateway II MQP depended on the progression of the construction process. As the project progressed, more aspects of construction could be analyzed, and therefore the project efficiency could also be tracked and evaluated. The team did this through observing weekly construction meetings with Consigli, KVA and Isgenuity to understand and record the progress of construction and any setbacks that occurred along the way. The team also attended a series of site walks with Consigli, Isgenuity and KVA. These walks presented the group with the opportunity to correlate the discussion from the weekly owner's meetings to the actual work being performed. The group also had access to Consigli's Procore files, which displays RFI's, changes in the design drawings, submittals and many other aspects of the construction process. It should be noted that the numbers the group attain through their studies are not exact due to the nature and complexity of the project.

4.1 Schedule.

Project schedule affects all parts of any construction project and can greatly impact the project budget. Accordingly, it is critical to consistently track project schedule throughout the duration of any construction project. The Gateway II project schedule was recorded and updated by Consigli Construction throughout the duration of the project using Primavera P6 software. The team was able to use the schedules as the job progressed to gain insight on how the project is going. In other words: if the project is behind schedule, ahead of schedule or if the schedule is on target. The first schedule, from 9-17-2018, was used to help develop the first cost estimate.

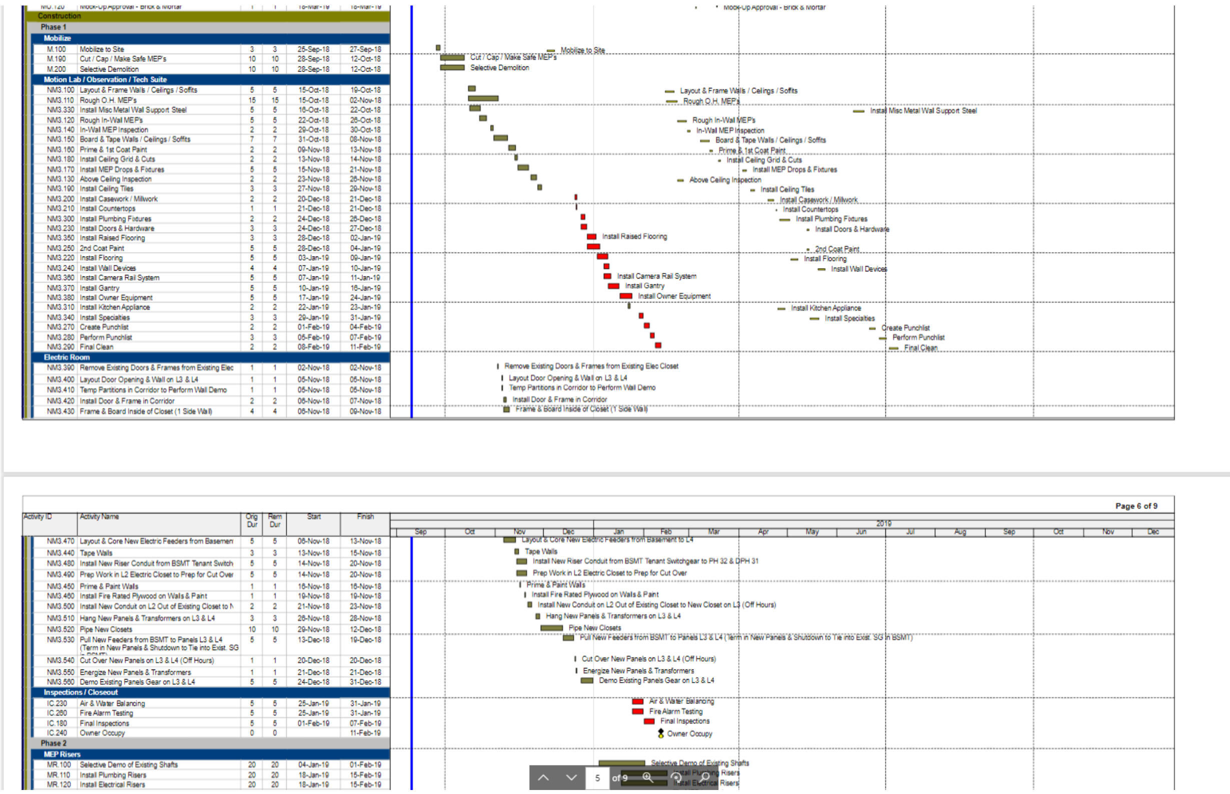

Figure 9: 9/17 Project Schedule

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The cost estimates are organized by trade cost and time. See example in Figure 10.

Total Demo Cost=	$411,863.00			
Phase 1	HVAC	3,758	45.35	$170,425.30
Phase 1	Electrical	3,758	34.37	$129,162.46
Phase 1	Drywall	3,758	25.33	$95,190.14
Phase 1	Painting	3,758	2.91	$10,935.78
Phase 1	Acoustical Ceiling	3,758	7.38	$27,734.04
Phase 1	Finish Carpentry	3,758	4.14	$15,558.12
Phase 1	Plumbing	3,758	31.26	$117,475.08
Phase 1	Doors/Frames/Hardware: Increaed Door Quantity, Increased Hardware pricing for WPI spec	3,758	7.89	$29,650.62
Phase 1	Flooring	3,758	11.8	$44,344.40
Phase 1	Metals:Removed Stair/Railings, Added steel Tubes in Type P Partition, Added Camera equipment rail	3,758	6.12	$22,998.96
Phase 1	Medical Equipment - Gantry	1		$30,000.00
Phase 1	Install Specialties	3,758	3.27	$12,288.66
Phase 1	Communications	3,758	2.57	$9,658.06
Phase 1	Access Control	3,758	2.73	$10,259.34

Figure 10: Cost by Phase cost sheet

The schedule was able to define when certain costs, represented in the Design Development Estimate, were spent. The multi-phase schedule helped develop the idea of project milestones that served as markers for analyzing the estimated construction progress to the actual construction progress. With use of the schedule, start and finish dates could be placed on every activity and phase. Figure 9 shows a screenshot of the construction schedule, and shows the entire Phase 1 schedule, which this MQP predominantly focuses on.

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4.2 Budgeting.

The budgeting portion of the MQP focuses on identifying the projected costs of the renovation and comparing them to the actual costs of the project. To do this, the first step was understanding what the spending of the project was and how that number came to be. The Gateway II project has a GMP of $8 Million. The first estimate provided from Consigli was their 9-17 Design Development (DD) Estimate. In this estimate Consigli assumes an area of 35,000 square feet as the construction site and associates a cost estimate to each of the construction divisions that are involved in the project. As seen in figure 11 below.

Variance Report Detail - Proposal Estimate to DD

CONSIGLI
Est. 1905

Revised 9/17/18

Division / Trade	DD Estimate	Proposal Estimate	Variance Value
01-50 - Trade General Requirements	$ 248,400	$ 197,500	$ 50,900
1 Added temp walls (corridor L3 wall shown to be removed)			
02-20 - Demo/MRI Opening EARLY DEMO	$ 212,000	$ 261,000	$ (49,000)
1 Removed Stair Demo			
2 Scope clarified in DD drawings			
05-12 - Metals	$ 214,284	$ 427,000	$ (212,716)
1 Removed Stair/Railings			
2 Added Steel Tubes in Type P Partition			
3 Added Camera Equipment Rail			
06-25 - Finish Carpentry	$ 144,750	$ 148,865	$ (4,115)
1			
07-50 - Roofing	$ 33,000	$ 28,000	$ 5,000
1			
07-81 - Fireproofing	$ 21,000	$ 84,000	$ (63,000)
1 Reduce Due to Removed Stair and Stiffening			
07-90 - Firestopping Existing Penetrations Allowance	$ -	$ 15,000	$ (15,000)
1 Moved to Trades			
08-10 - Doors/Frames/Hardware	$ 276,066	$ 147,812	$ 128,254
1 Increased Door Quantity - Shifted From Demountable			$ -
2 Increased HW Pricing For WPI Spec - Electrified Sets			
08-45 - Glass & Glazing	$ 52,000	$ 38,500	$ 13,500
1 Added Alum Framed All Glass Doors			$ -
09-21 - Drywall	$ 886,374	$ 847,365	$ 39,009
1 Scope clarified in DD drawings			
2 Solid Demountables Removed - Shifted to DW			
09-51 - Acoustical Ceiling	$ 258,290	$ 241,054	$ 17,236
1 Scope clarified in DD drawings			
09-65 - Flooring	$ 413,118	$ 261,418	$ 151,700
1 Added Ceramic Wall Tile			
2 Added Access flooring			
3 Corridors/offices assumed to be exposed concrete previously			

Figure 11: Consigli Design Development Estimate

This helped form the basis for the cost sheet. To start, the cost sheet was developed in a very broad manner. To further analyze the budget of the project, costs were broken into three major phases: Demolition, Phase 1 and Phase 2. The next step was listing each activity that occurs during the associated phase. In summary, the schedule was used to determine what construction activities and scopes occur in which phases. Then, the unit costs for each activity from the design development estimate were used to start to develop a general cost estimate. See Figure 12.

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				Earned Value Ana
Construction phase:	Scope:	Square feet:	Cost/sf	Cost:
Demo	Early Demo Demo and MRI opening	35,000	6.06	$212,100.00
Demo	Early Demo Plumbing	35,000	0.94	$33,000.00
Demo	Early Demo HVAC	35,000	2.51	$88,000.00
Demo	Early Demo Electrical	35,000	1.33	$46,538.00
Demo	Early Demo Fire Protection	35,000	0.92	$32,225.00
Total Demo Cost=	$411,863.00			
Phase 1	HVAC	3,758	45.35	$170,425.30
Phase 1	Electrical	3,758	34.37	$129,162.46
Phase 1	Drywall	3,758	25.33	$95,190.14
Phase 1	Painting	3,758	2.91	$10,935.78
Phase 1	Acoustical Ceiling	3,758	7.38	$27,734.04
Phase 1	Finish Carpentry	3,758	4.14	$15,558.12
Phase 1	Plumbing	3,758	31.26	$117,475.08
Phase 1	Doors/Frames/Hardware: Increaed Door Quantity, Increased Hardware pricing for WPI spec	3,758	7.89	$29,650.62
Phase 1	Flooring	3,758	11.8	$44,344.40
Phase 1	Metals:Removed Stair/Railings, Added steel Tubes in Type P Partition, Added Camera equipment rail	3,758	6.12	$22,998.96
Phase 1	Medical Equipment - Gantry	1		$30,000.00
Phase 1	Install Specialties	3,758	3.27	$12,288.66
Phase 1	Communications	3,758	2.57	$9,658.06
Phase 1	Access Control	3,758	2.73	$10,259.34
Total Phase 1 =	$426,093.20	Total sf Complete:	3,758	
Phase 2	Plumbing	31,481	31.26	$984,096.06
Phase 2	Electrical	31,481	34.47	$1,085,150.07
Phase 2	Level 2 Selective Demo	31,481		
Phase 2	Level 2 Steel	31,481	6.12	$192,663.72
Phase 2	Fire Proofing	31,481	0.6	$18,888.60
Phase 2	HVAC	31,481	45.35	$1,427,663.35
Phase 2	Drywall	31,481	25.33	$797,413.73
Phase 2	Painting	31,481	2.91	$91,609.71
Phase 2	Acoustical Cieling	31,481	7.38	$232,329.78
Phase 2	Finish Carpentry	31,481	4.14	$130,331.34
Phase 2	Install Demountable Partition	31,481	9.88	$311,032.28
Phase 2	Flooring	31,481	11.8	$371,475.80
Phase 2	Doors/ Frames and Hardware	31,481	7.89	$248,385.09
Phase 2	Glass & Glazing	31,481	1.48	$46,591.88
Phase 2	Shielding	31,481	7.74	$243,662.94
Phase 2	Install Specialties	31,481	3.27	$102,942.87
Phase 2	Security	31,481	2.73	$85,943.13
Phase 2	Membrane Roofing	31,481	0.94	$29,592.14
Phase 2	Landscaping	31,481	1.43	$45,017.83
Total Phase 2=	$6,444,790.32	Total sf Complete:	35,239	
Project Complete: (This is the number given in the DD Estimate	$8,687,107.00		Total:	$7,582,334.28

Figure 12: Phasing Cost Estimate

The Phasing Cost Estimate was not the only way the project cost was divided. To develop a more in-depth cost estimate we split the cost by phase a step further. Within each phase, we separated the estimate into the rooms that are constructed at different times according to the schedule, thus creating a cost by room estimate. The cost by room estimate shows the progression of the project at 10 different times, whereas the cost by phase would only create a 3-step progression of construction. Estimating by room gave more milestones to help track the construction progress. The cost by room estimate can be seen in Figure 13.

Demolition:						
Scope:	Square feet:	Cost/sf:	Total Cost:	Start Date:	Finish Date:	Duration:
Early Demo Demo and MRI opening			$212,100.00	9/28/18	10/12/2018	10
Early Demo Plumbing			$33,000.00	9/28/18	10/12/2018	10
Early Demo HVAC			$88,000.00	9/28/18	10/12/2018	10
Early Demo Electrical			$46,538.00	9/28/18	10/12/2018	10
Early Demo Fire Protection			$32,225.00	9/28/18	10/12/2018	10
		Total Demo Cost:	$411,863.00		Total Duation:	10

Phase 1:							
Room:	Scope:	Square feet:	Cost/sf:	Total Cost:	Start Date:	Finish Date:	Duration:
Motion Lab/ Observation/ Tech Suite:	HVAC	3023.52	45.35	$137,116.63	10/15/2018	11/2/2018	15
	Electrical	3023.52	34.37	$103,918.38	10/15/2018	11/2/2018	15
	Plumbing	3023.52	31.26	$94,515.24	10/15/2018	11/2/2018	15
	Drywall	3023.52	25.33	$76,585.76	10/31/2018	11/8/2018	7
	Paint	3023.52	2.91	$8,798.44	11/9/2018	1/4/2019	***
	Acoustical Ceiling	3023.52	7.38	$22,313.58	11/13/2018	11/29/2018	***
	Finish Carpentry	3023.52	4.14	$12,517.37	12/20/2018	12/21/2018	2
	Doors/Frames/Hardware: Increaed Door Quantity, Increased Hardware pricing for WPI spec	3023.52	7.89	$23,855.57	12/24/18	12/27/18	3
	Flooring	3023.52	11.8	$35,677.54	12/28/18	1/9/19	8
	Metals:Removed Stair/Railings, Added steel Tubes in Type P Partition, Added Camera equipment rail	3023.52	6.12	$18,503.94	1/7/19	1/11/19	5
	Medical Equipment - Gantry	3023.52	--	$30,000.00	1/10/2019	1/16/2019	5
	Install Specialties	3023.52	3.27	$9,886.91	1/17/2019	1/31/2019	***
	Communications	3023.52	2.57	$7,770.45			
	Access Control	3023.52	2.73	$8,254.21			
Total Motion Lab:			Total Cost:	$589,714.02			
Electric Room:	Electrical	143.3	34.37	$4,925.22			
	Drywall	143.3	25.33	$3,629.79			
	Doors and Hardware	143.3	7.89	$1,130.64			
	Paint	143.3	2.91	$417.00			
		143.3					
			Total Cost Electrical Room:	$10,102.65			
	Phase 1 Totals:	3166.82	Total Phase 1 Cost:	$599,816.67		Total Duration:	80

Phase 2:							
Room:	Scope:	Square feet:	Cost/sf:	Total Cost:	Start Date:	Finish Date:	Duration:
Level 2:	Demo:						
	Start:	3505					
	HVAC	3505	45.35	$158,951.75			
	Electrical	3505	34.37	$120,466.85			
	Plumbing	3505	31.26	$109,566.30			
	Drywall	3505	25.33	$88,781.65			
	Painting	3505	2.91	$10,199.55			
Level 4:							

Figure 13: Cost by Room Spreadsheet

Initially when the "Cost by Room" estimate was created there were a few issues: for example: the cost was too low and there was square footage unaccounted from the projected 35,000 sf estimate. The total square footage found in the cost by room estimate was around 17,000 sf. It was soon realized that the smaller than expected number was due to the missing square feet combined from the hallways and a few rooms. The total missing square footage was then calculated. Using Procore a visual could be created showing the missing square feet from each drawing. The hallways were assumed to have a more standard work schedule, consistent with a room such as a level 3 office room. Once the schedule of the areas was identified a cost estimate could be formed based on the cost/sf of the work that needed to be performed and the total area of work. See Figure 14 to show the finding of the missing square feet on the Level 3 South Phase 2 drawing.

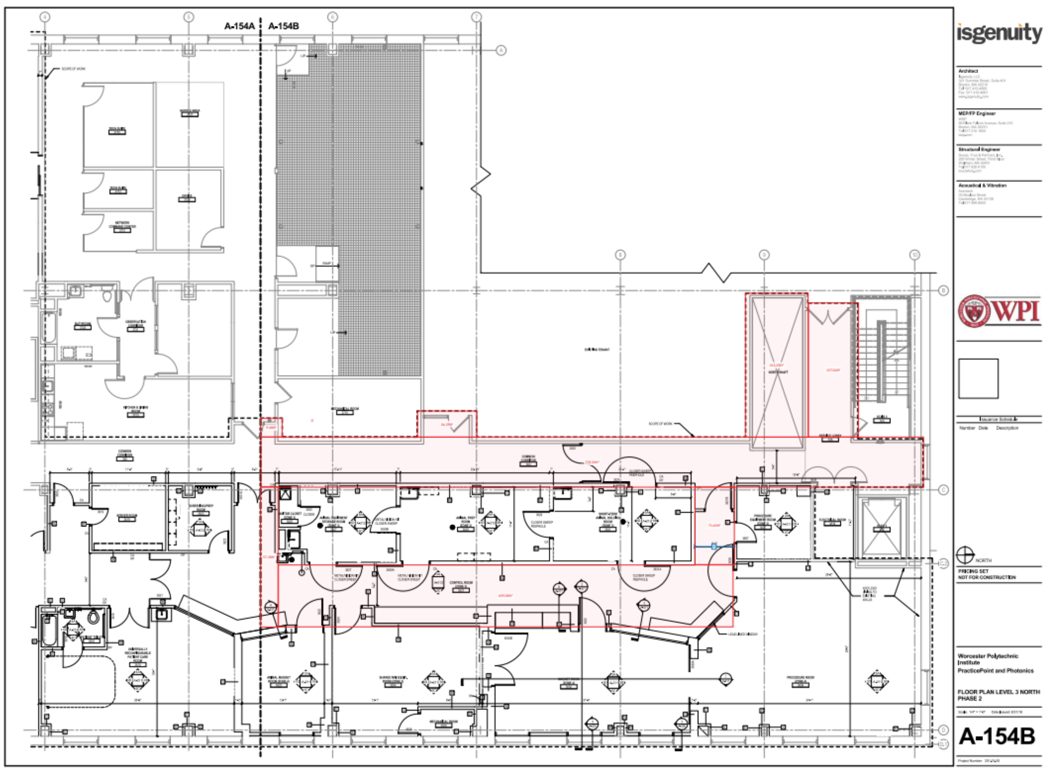

Figure 14: Missing Square Footage Tracking Drawing

The next step in the process of analyzing the cost is comparing the numbers obtained from the Design Development Estimate to the acquisitions developed by Consigli. The acquisitions are the documents that the construction project manager develops and presents to the owner based on the work performed. The requisitions are used to measure the work performed by Consigli and their subcontractors to get each party paid fairly. The most common way the construction project manager develops the requisition is walking through the jobsite and tracking the progress visually. After the superintendent and project manager come to an agreement on the amount of work they should bill the owner for, the requisition is sent in for approval by the owner.

4.3 Procore.

Procore is a Management Information System where Consigli stores and tracks information and documentation related to the management of the project. Within Procore Consigli can: send and receive submittals, produce Requests for Information (RFI's) for the design team, produce meeting minutes, store and update the drawing files, maintain daily manpower logs etc. Access to Procore aided in the understanding of the work being performed and the issues being faced on the construction project.

Procore was very instrumental in tracking the progress of the project. With procore we were able to get accurate square footages of each room and phase to help develop our cost estimates. This was accomplished using the markup tool in Procore. Once the markup tool is accessed, a calibration tool is displayed. By using the calibration tool to a known distance on the drawing, areas and distances can be measured directly from Procore. See Figure 15 for an example of how the square footages were compiled from Procore.

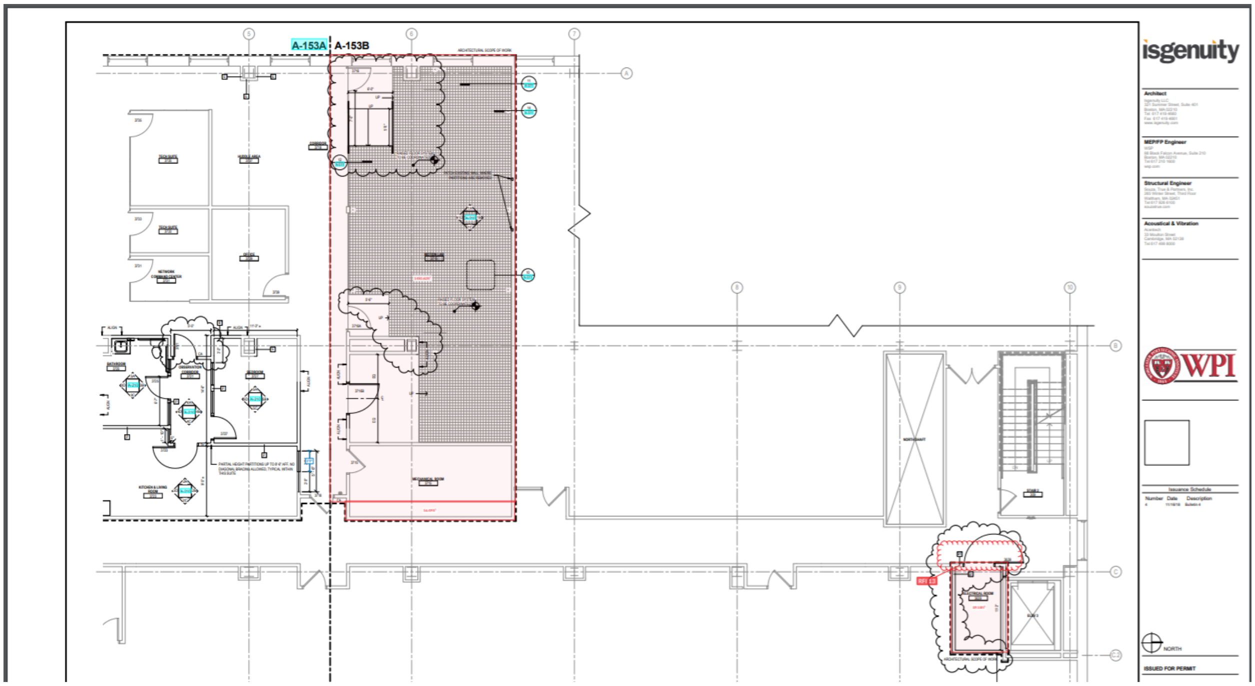

Figure 15: Level 3 North Phase 1 Square Footage Count from Procore

4.4 Earned Value Analysis (EVA).

The most important aspects of construction are staying on schedule and budget. One way to track a projects ability to perform these tasks is through earned value analysis. Earned value analysis (EVA) is "a method that allows the project manager to measure the amount of work actually performed on a project beyond the basic review of cost and schedule reports" (Reichel, C. W. 12/3/2018). The two main goals of earned value analysis are to calculate the Schedule Variance (SV) and the Cost Variance (CV). The Schedule Variance and Cost Variance are ratios that, in the case of the SV, determine whether the project is ahead of schedule, behind or on target, and in the case of the CV determine whether the project is on target, under or over budget. See Table 3.

Schedule Variance (SV):	
SV > 0	Ahead
SV = 0	On Target
SV < 0	Behind

Cost Variance (CV):	
CV > 0	Under
CV = 0	On Target
CV < 0	Over

Table 3: Schedule Variance (SV) and Cost Variance (CV) Tables

To calculate the schedule variance and cost variance there are a few other variables that must be analyzed, these are: The Budgeted Cost of the Work Scheduled (BCWS), the Budgeted Cost of the Work Performed (BCWP), and the Actual Cost of the Work Performed (ACWP). Each of these variables represented the intended cost of the project at different points of time. The Budgeted Cost of the Work Scheduled (BCWS) is the planned schedule of the project from the beginning. The Budgeted Cost of the Work Performed (BCWP) is represented as the progress that has been made on the construction site. Lastly, the Actual Cost of the Work Performed (ACWP) is represented by the actual costs and payment that has occurred during construction. On the Gateway II renovation the BCWS was taken from the Design Development estimate provided by Consigli, the BCWP was derived by analyzing progress pictures from procore and comparing them to the original schedule received and the ACWP was found in the requisitions that were provided by Consigli. After these variables were determined, the next step in the earned value analysis process was creating the lazy s-curve for the Gateway II project. Lazy S-curves are a very useful project management tool, as they provide a visual representation that tracks the progress of a project over time. Lazy S-curves allow project managers to easily analyze project growth and identify any potential problems that could negatively affect the project. In the case of the Gateway II project, the Lazy S-curve (figure 16) showed that the project is ahead of schedule. The curve shows that the ACWP value is lower than both the BCWS and the BCWP, however the BCWP is higher than the BCWS. When analyzing the Lazy

S-curve to determine if the project is on schedule, it is important to calculate schedule variance and cost variance. Schedule Variance (SV) is the difference between the cost of work performed and the cost of work scheduled, and can be calculated with the formula, SV = BCWP - BCWS. Cost Variance (CV) is the difference between the cost incurred on the project during construction and the budgeted cost, and can be calculated with the formula, CV = BCWP - ACWP. On the Gateway II project, the calculated SV value at December 31st was $410,349.94, which means the project is ahead of schedule. Additionally, the calculated CV at December 31st was $363,115.57, which means the project is under budget.

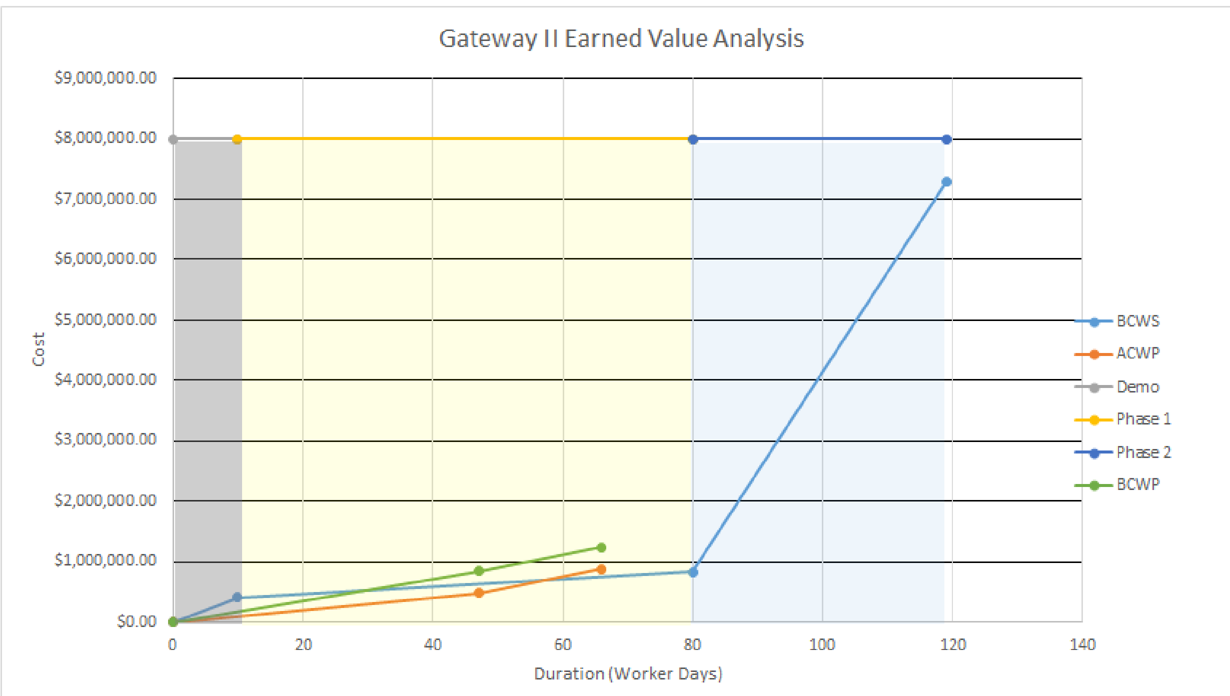

Figure 16: Complete Lazy-S Curve for Gateway II Project - Phase 1

Earned value analysis was used in the project by analyzing the groups' cost estimates and the schedule based on the documents obtained from Consigli at the beginning of the project and comparing them to the requisitions that are provided by Consigli throughout the project. The first requisition received was the November requisition. After receiving this document, the group compared the costs spent for each activity and the worker days used for each activity to the totals from the original schedule. Therefore, by associating the actual spending and the allocated spending from the budget we can tell if the cost of the project is: on target, behind schedule or ahead of schedule. Performing earned value analysis is essential to this project because it effectively analyzes project performance and progress and shows whether the project is on schedule and on budget.

4.5 Project Meetings/ Site Walks.

Throughout any construction project it is imperative to meet with all groups who have stake in the project and work together to identify challenges, solve problems, and complete tasks. During the Gateway II construction, Consigli, KVA, Isgenuity and many representatives from WPI met every Thursday. The MQP group regularly attended these meetings. During these meetings the project team had a consistent schedule they followed, which kept the meeting structured and on topic. The schedule usually went as follows: Schedule, safety and logistics, administration items, procurement/buyout status, RFI's and submittals, scope items and new business. The project meeting was normally around two hours but depended on the topics needed to be addressed each week. Typical project meeting notes and pictures the group took during a meeting can be found in Appendix 4. After a few project meetings, the group did a brief site walk through with Ryan Stock and/or Thomas Duszlak. During the site walks, the group visually observed project progress, asked questions about the construction and any notable challenges the team was facing. Pictures were taken during these walks to identify progress visually.

Figure 17: Site Walk Photo - Existing

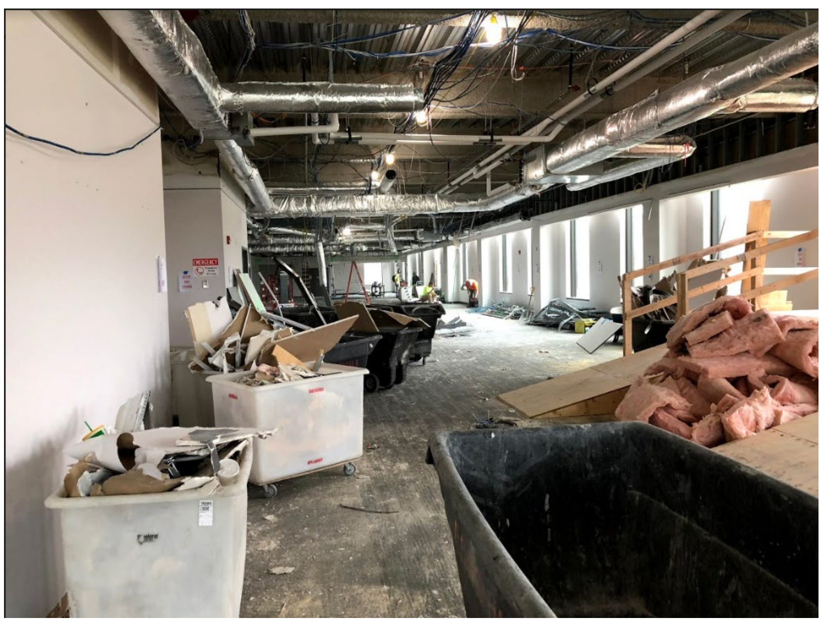

Figure 18: Site Walk Photo – Demolition

5.0 Building Information Modeling (BIM).

Throughout recent years, construction has started to integrate information technology in supporting the design and construction project management process. One of the major technologies increasingly adopted by the industry is Building Information Modeling (BIM). BIM is "an intelligent 3D model-based process that gives architecture, engineering and construction the insight and tools to more efficiently plan, design, construct and manage buildings and infrastructure" (Autodesk, 2018). BIM has many applications in a variety of different sectors of the construction process, some of these applications include: visualization, fabrication, reviewing code, cost estimation, construction sequencing, collision detection, potential failure detection and facilities management. These applications are just some of the reasons that the use of Building Information Modeling (BIM) has been so successful in finding problems with construction designs sooner and attaining solutions faster. The benefits from using BIM on a construction project are extensive. When utilizing BIM, a team can move information faster and more effectively because the information shared can be edited by anyone with access to it. Ultimately this leads to better designs, more project control, greater project quality and enhanced customer service. For example, BIM can detect a situation where two components of the design will collide or "clash" into one another. There are 3 different types of clashes BIM technology can detect: a physical clash, soft clash and logistical clashes. A physical clash occurs when two objects occupy the same position. A soft clash occurs when two objects close to one another are not touching, but BIM technology understands that there needs to be more space to adequately fit the other elements associated with the two objects. Lastly, a logistical clash occurs when an object is placed in an area where it would cause constructability concerns for the project. Technology like this has been very instrumental in the coordination of the Mechanical, Electrical, and Plumbing (MEP) functions for Gateway II. The labs that are going to be constructed have extensive MEP requirements. With technology like this becoming more and more utilized, construction projects will perform faster and be increasingly cost effective. On the Gateway II project both the general contractor, Consigli, and the Designer, Isgenuity, have developed BIM models. Although both companies have a model, the models are developed for different uses. Consigli's model is used primarily for MEP coordination. The model Consigli has can detect potential clashes of systems which helps ensure the design has complete constructability.

5.1 5D BIM Model.

A variety of Building information modeling (BIM) is used in our project to properly sequence and analyze the Gateway II construction project. The model created is a 5-Dimensional model, meaning it incorporates the design of the building, the schedule of the project and the cost. A visual representation explaining 5D BIM can be seen in figure 19. One of the platforms consistently used in Building Information Modeling (BIM) is Revit. Revit is a 3D software that allows the designer to develop a visual of the project as it will look when the construction process is complete. Due to the fast-track schedule of the project the GMP was not finalized initially and progressed overtime; therefore, the project schedule had a large impact on how the 5-D model was developed. In Revit, the project is broken up into phases, like the phases of the project schedule. The phases allow the elements of the model to be aware of time. Each phase represents a different area of project that was constructed at different times. The Gateway II Revit model was broken up into 4 phases: Existing, Demolition, finish phase 1 and phase 2 finish. The idea was that these different phases produce a visual of what the 3rd and 4th floors of Gateway II will look like throughout the project as construction and spending progresses.

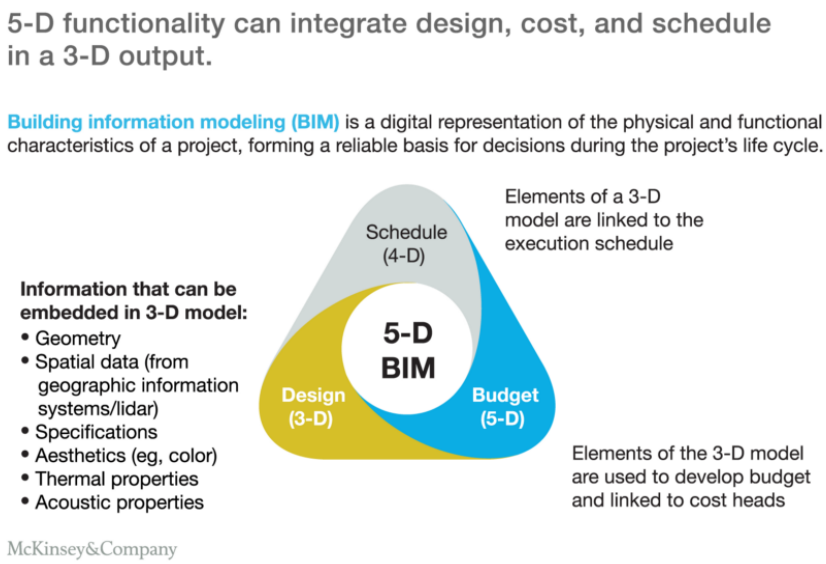

Figure 19: 5-D Visual Representation

After the project has been phased in Revit, the project was brought into Navisworks. Navisworks is a 5-Dimensional software that allows the user to develop a 3-D model and display the progress overtime. Within Navisworks the schedule can be associated with the model. Navisworks is instrumental in building information modeling due to its ability to import multiple models and information from multiple software and utilize them all at once. This was accomplished by linking the phases to the dates in which they begin and the dates they are completed. This created a visual that displays the construction progress of the Gateway II renovation overtime. After, the construction progression has been developed, the group created a "Lazy S" Curve of the construction spending. The Lazy S curve effectively developed an understanding of the use of resources over time and the accumulated cost overtime. By analyzing the construction costs from three different perspectives: The Actual Cost of Work

Performed (ACWP), Budgeted Cost of Work Performed (BCWP) and the Budgeted Cost of the Work Scheduled (BCWS).

5.2 Revit.

Throughout the project several different design tools were suggested; However, Revit seemed to be the best way to start the project. In the beginning of the BIM design phase we worked with Isgenuity to get access to their model. After working with the design team for a few weeks, attempting to gain access through various platforms we were not able to access the file on a school computer. Once we realized that we could not gain access to the design teams model we found an old model of the Gateway II project site. The older model was generated by the following MQP group (Na, Aaron Edwin, Lebedev, Artur, and Angulo, Joseph Augusto. *Gateway Building 2012: Alternative Designs and Use of Building Information Modeling)* seven years prior to our project. The model consisted of the shell of the building and a complete second and first floor. With the old model we created floors for the third and fourth levels and put in as-built walls on the third and fourth floors.

The next step was to phase the model. Phasing allows us to begin implementing the aspect of time into the model. The project has been broken up into 5 phases: existing, demolition, phase 1, phase 2 and complete. The existing phase shows the Gateway II building as it was before construction began on the site See figure 19. There was an underlay on the project for the third and fourth floors that was used to help frame the walls on the third and fourth floors for the existing phase. The demolition phase shows the destruction of the walls within the third and fourth floors of the gateway project site. Phase 1 shows the construction of the walls on the third floor and the electrical rooms See figure 20 below. To place the Phase 1 walls distances were taken from known points on the floor layout drawings in Procore. Phase 2 shows the construction that occurs on the third and fourth floors. The distances of the walls were also found in the drawings in Procore, whether they were given dimensions listed on the drawings or we had to use the tools in Procore to get an approximate dimension. Lastly, the complete phase is a rendition of what the project layout will mostly like when complete. Due to the complexity of the Gateway II renovation the Revit model could not accurately display what the renovation looks like when complete. This is because throughout the project the drawings are constantly modified to comply with the changes the design team must make to the project to fit the requirements of the project.

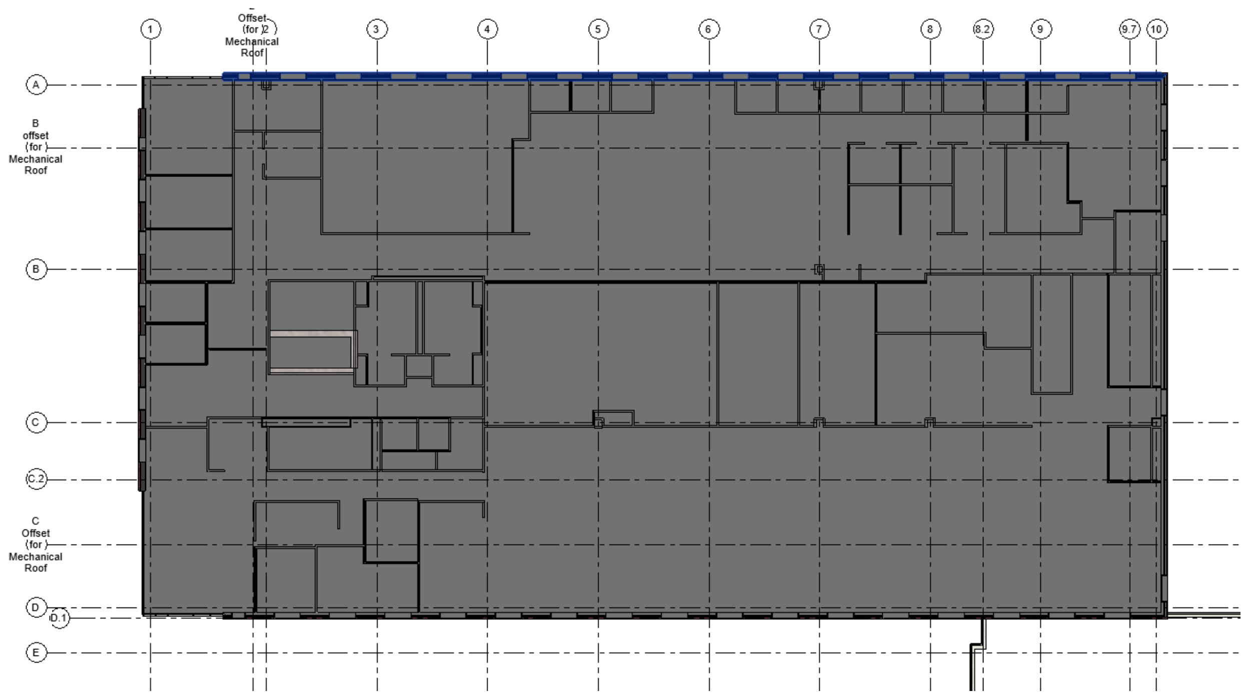

Figure 20: Level 3 Existing Phase

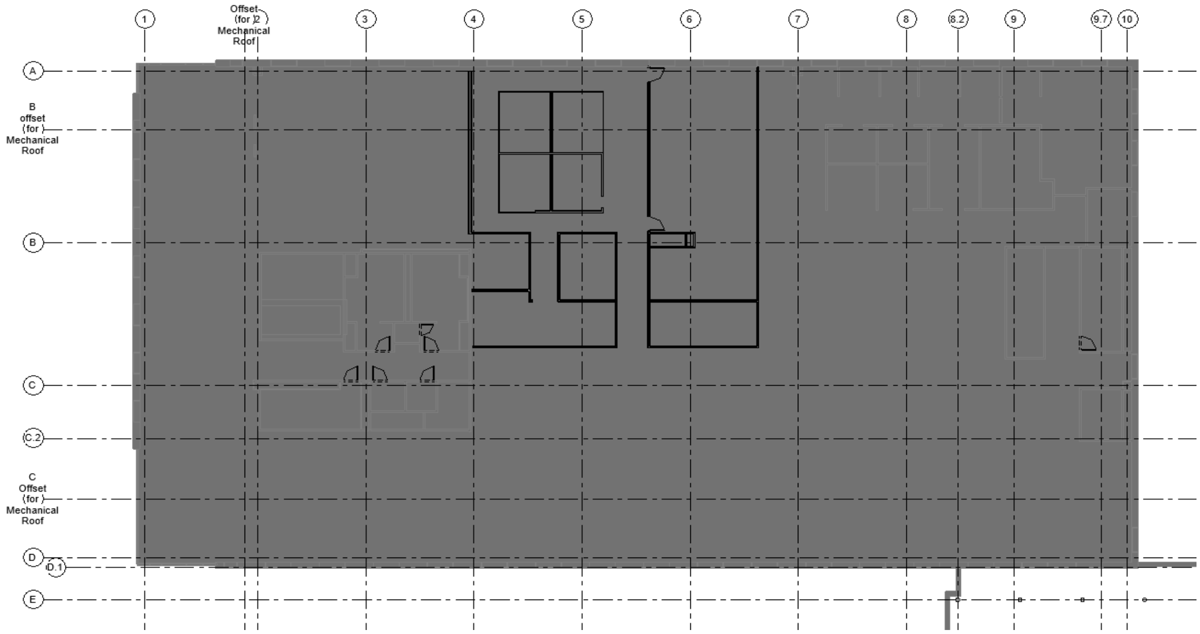

Figure 21: Level 3 Phase 1

The greatest challenge faced while developing the phased Revit model was working with the old Revit model. After the phases were created in Revit the whole model put itself into phase 1. See Figure 22: Phase 1 Revit 3-D View.

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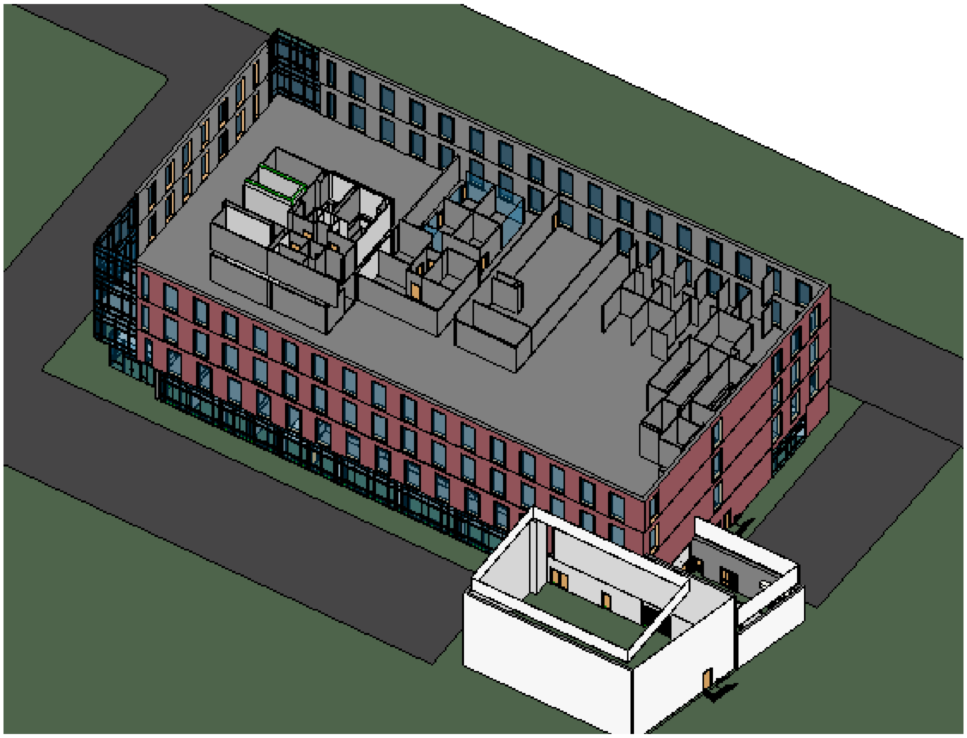

Figure 22: Phase 1 Revit 3-D View

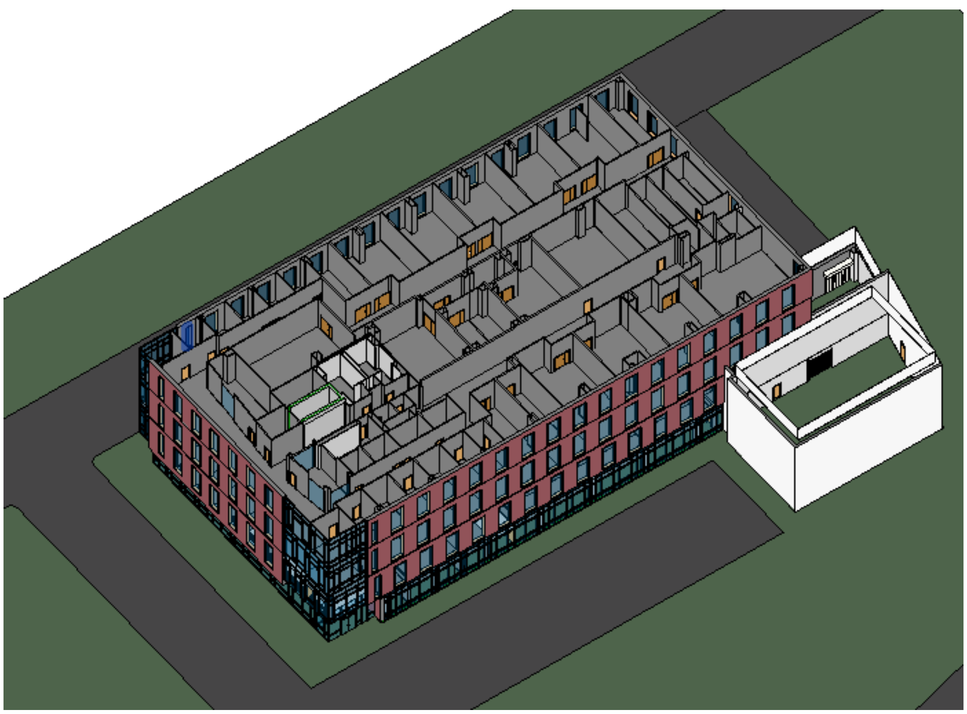

Figure 23: Phase 2 4th Floor Revit 3-D View

This presented the first challenge of using Revit; everything had to go from Phase 1 to existing. For the most part bringing the elements of the model back to the existing phase was easy, but when elements were in model groups we had to select every group member individually, ungroup the element then program it to the correct phase. This is the only way the group was able to identify to resolve the issue in Revit. Although Revit does allow for some 3-D components to be presented in the model it is difficult to show a time lapse of the project. Therefore, the next step of the 5-D BIM development phase is to upload the drawing to Navisworks.

5.3 NavisWorks.

Revit serves as an excellent tool for the modeling of the renovation; however, when creating a visual representation that implements time and cost with the project NavisWorks was used. In NavisWorks the Timeliner tool was utilized to piece the time frame of the project together. The first step in Navisworks was to upload the Revit file created. The interface for Navisworks is different than Revit, so when the file was uploaded it looked different than it did on Revit.

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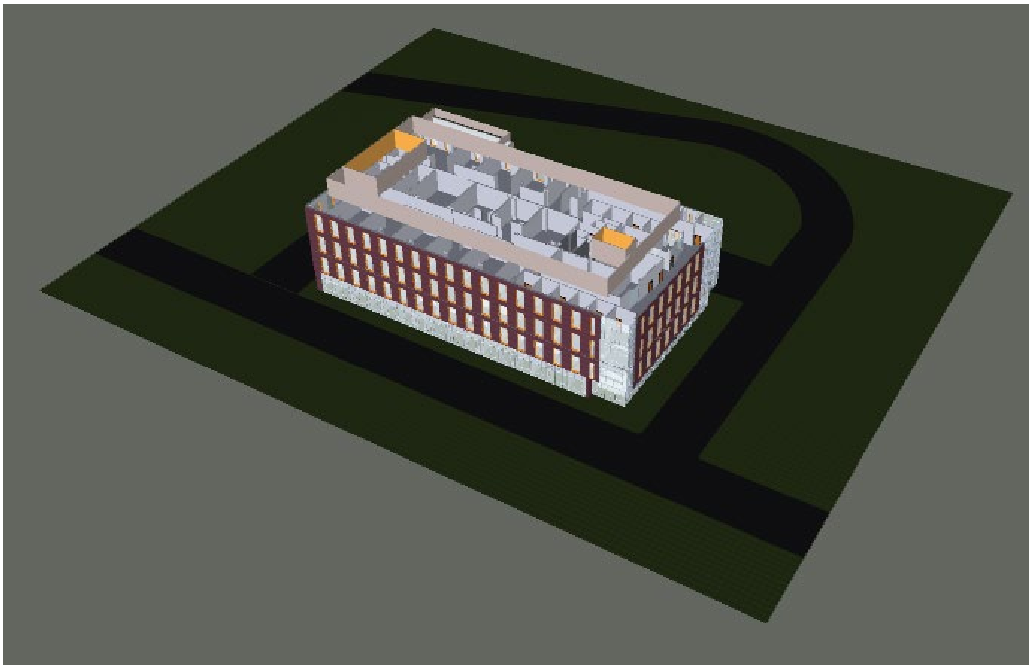

Figure 24: 3-D Navisworks View of the Gateway II Building

After the file has been uploaded from Revit to Navisworks successfully the time and cost can begin to be associated with the model. The first step in this process was accessing the TimeLiner tool in Navisworks. The TimeLiner tool allows the project to become organized by: date, duration, cost etc. Please see figure 25 for a screenshot of the TimeLiner tool.

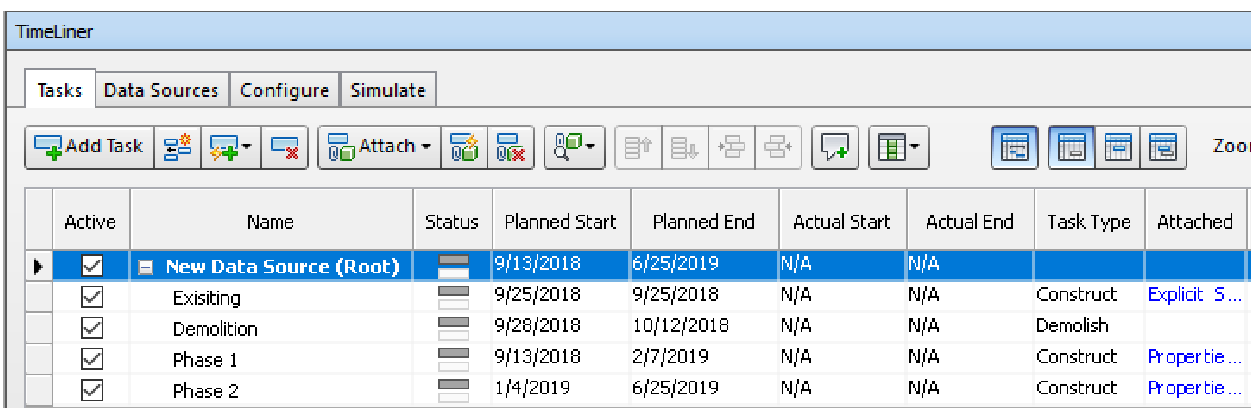

Figure 25: TimeLiner Tool in Navisworks

The TimeLiner is a great tool for the project; however, it can be difficult to set up directly within Navisworks. Therefore, to mitigate the challenges that were presented during the building of the 5-D model, Microsoft project was imported into the Timeliner tool to set the phases and dates of the project. The final step in the 5-D model build was connecting the different phases of the project from the TimeLiner tool: Existing, demolition, phase 1 and phase 2, to the model itself. This was accomplished by taking the phases from the selection tree and linking the phases in the TimeLiner to the different options in the selection tree. The first Navisworks model posed some difficulty when incorporating the cost. In the end we were not able to properly associate the BCWP, BCWS and ACWP in the Navisworks file; however, we were able to display the construction over time. Below in Figure 26: Phase 1 Navis works, the work performed during phase 1 can be seen. The third floor is visible in the figure because of the programs ability to hide selective object in each view.

Figure 26: Phase 1 Navisworks

Below in Figure 27: Phase 2 4th floor Navisworks, the work performed on the fourth floor of phase 2 of the project can be seen. For this view of the Gateway II building the fourth floor was unhidden from the view to properly display the whole fourth floor of the building.

Figure 27: Phase 2 4th Floor Navisworks

6.0 Staircase Proposal.

In the very early stages of this project, the design team (Isgenuity) included a staircase between the 3rd and 4th floors of the Gateway II building. However, after a reviewing a preliminary cost estimate, the proposed staircase was cut from the design drawings due to financial restraints. As the Owner's Project Manager, KVA decided the staircase added unneeded costs to the project and consequently could not be included in this renovation. However, if not for budget constraints, this staircase would only add to the serviceability and egress of the Gateway II Building.

This MQP gives a detailed proposal for the addition of a staircase between the 3rd and 4th floor of Gateway II that could be implemented in a future renovation. The proposal will include structural analysis, and a rough cost estimate.

6.1 Structural Analysis.

When initially starting to design and analyze the staircase, the design from the original SD drawings were used as a baseline. As seen in figure 28, the original staircase design consisted of two quarter turn landings and a long straight staircase in between the two quarter turn landings.

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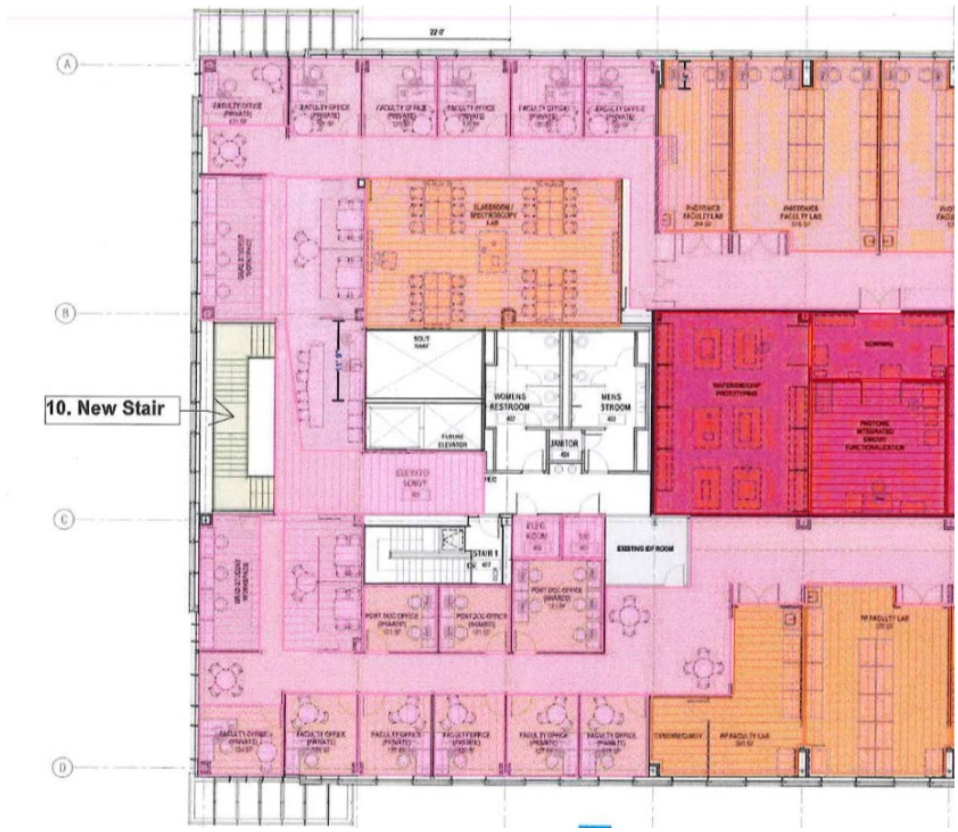

Figure 28: SD drawings showing the original staircase design.

With the acquisition of the original structural drawings of the Gateway II building, it was decided that this design was not the optimal design in terms of money and space used. To save money on the staircase project, a half-turn open well staircase was chosen. An example of this staircase can be seen in figure 29. From the structural drawings (figure 28), it can be noted that three beams are running north-south inside the bay the staircase would be constructed.

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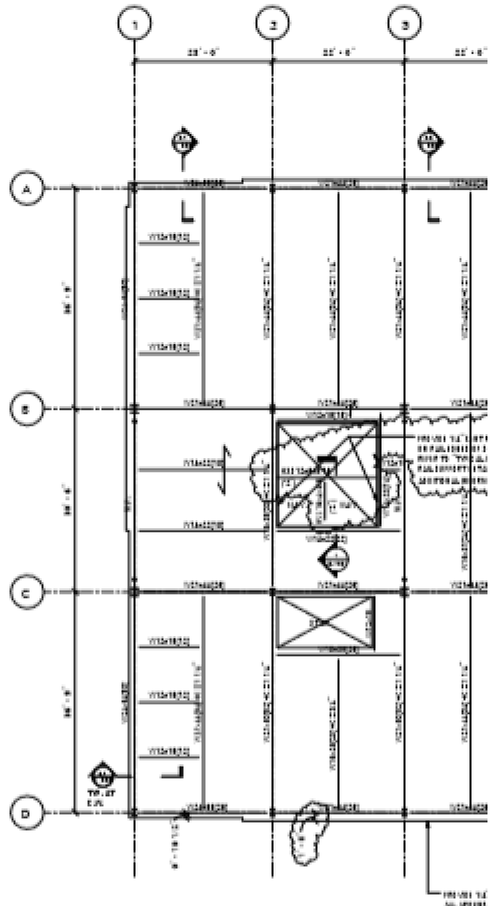

Figure 29: Structural drawings of the 4th floor in the Gateway II building

In order to go through with the original staircase design from Isgenuity, a lot of structural work would need to be performed on the three beams located in the bay between B and C and 1 and 2. Structural work and structural beams are very expensive, so if effort to cut costs and increase the likelihood a staircase is built in the future, it was decided the half-turn open well staircase design was the better option. Also, throughout the WPI campus, the most common staircase design is the half-turn open well design, meaning the new staircase would be matching what already exists on the WPI campus. An example of a simple half-turn open well design is seen in figure 30.

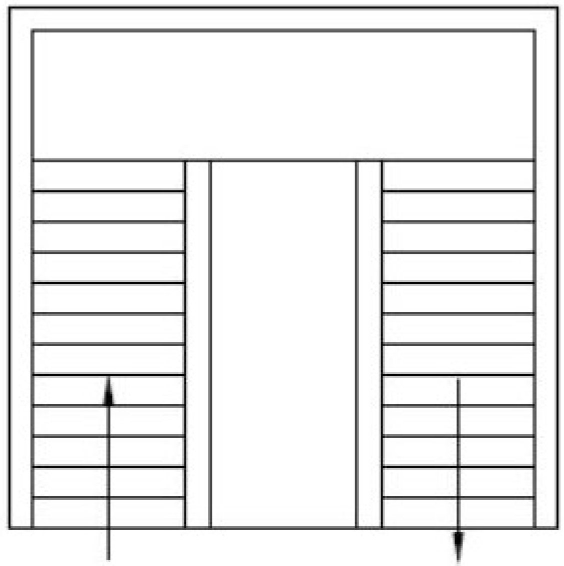

Figure 30: Open-well Half-Turn Longitudinally Supported Staircase

This type of staircase is designed as a one-way slab that is supported at the top and bottom. In this type of design, the steps are treated as nonstructural elements as the staircase is supported at the top and bottom of the flights.

After deciding what kind of staircase, the group was designing, the next step was to determine the location of the stairs. To determine the best location, both the structural plans and the finish plans for the 3rd and 4th floor were analyzed. The group planned on having another conference call with the architect to see their opinions on the best possible way to deal with the floor layout changes that are going to be needed with the addition of the staircase. After conversing with our advisor and within our group, it was decided that a second meeting with the architects was not needed and we had our own plan on the new layout would look like.

Keeping in mind the structural beam layout in the desired bay, the layout would best work with a staircase running in the south-north direction that would be located between two beams also running south-north. Figures 31 and Figure 32 show a before and after picture of the 3rd and 4th floor once the staircase was incorporated.

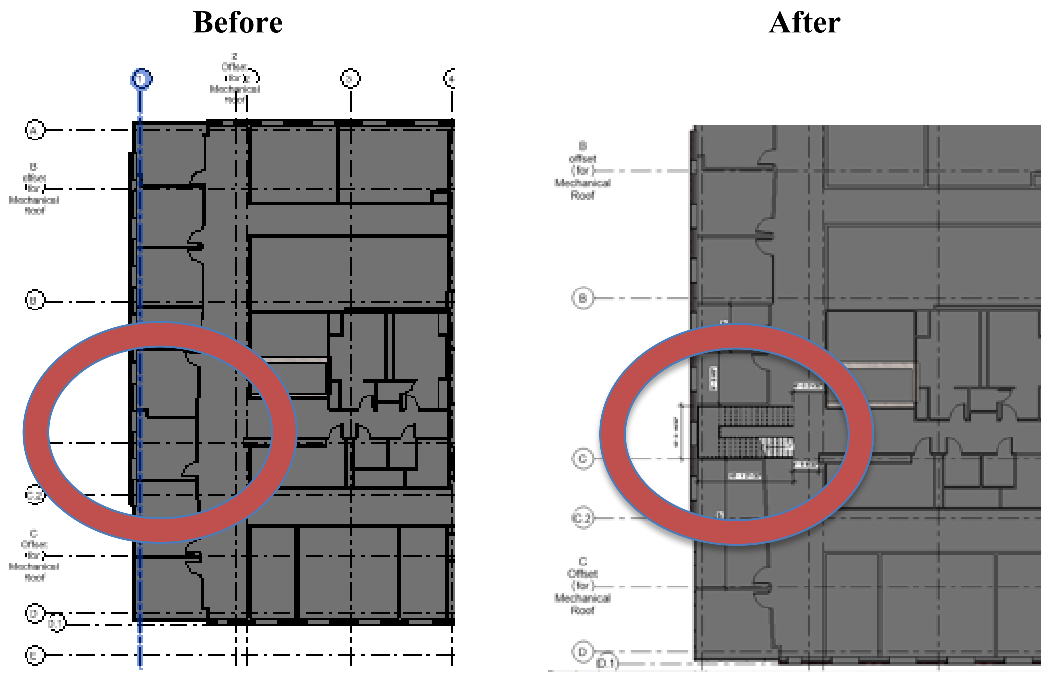

Figure 31: 3rd floor layout before and after the installation of the staircase

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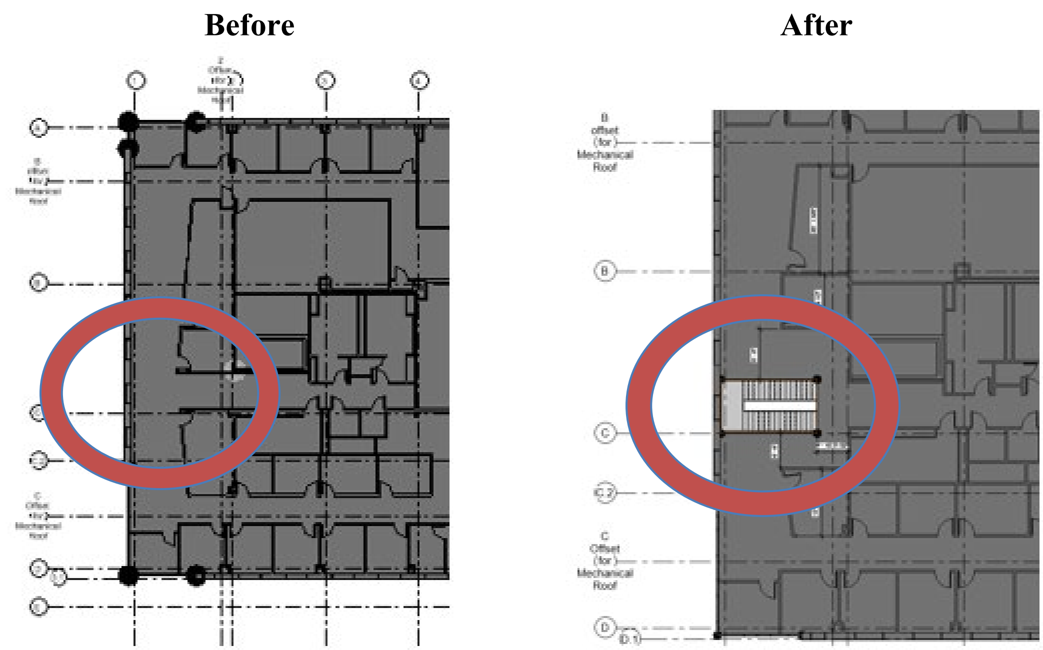

Figure 32: 4th floor layout before and after the installation of the staircase

When designing the staircase, structural analysis was performed. The structural analysis considered deflection requirements, effective span length, loading capacities (both dead and live), as well as shear and flexure requirements. Throughout the structural analysis, all design considerations were made in conjunction with *Minimum Design Loads for Buildings and Other Structures*, Standard ASCE 7. Along with the ASCE standard, codes from the IBC and the National Association of Architectural Metal Manufacturers (NAAMM) were referenced to design the staircase. REVIT and AutoCad were both used to help assist in the structural analysis and placement of the stairs. Figure 33 below is a screenshot of the staircase in the structural Revit model the group received from an old MQP who worked with Professor Guillermo Salazar in 2012.

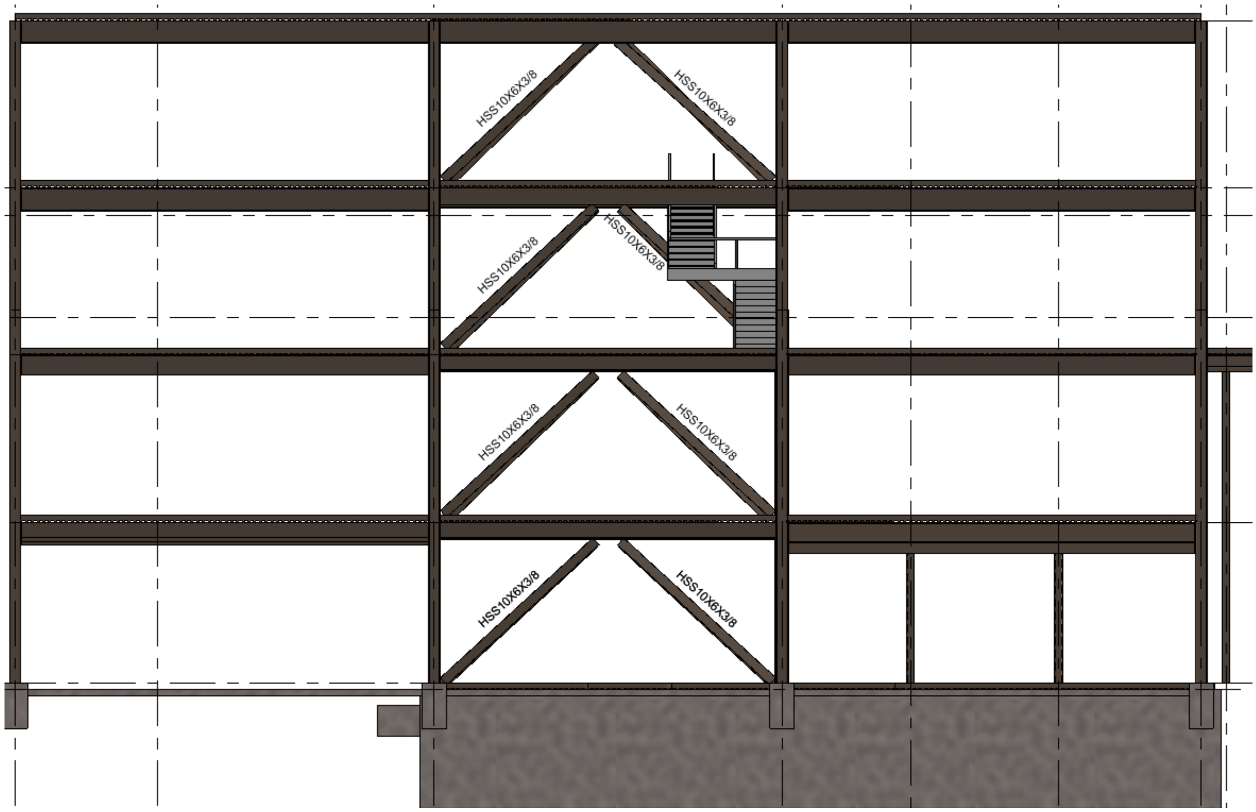

Figure 33: Staircase in the structural Revit model (view from the south side of the building)

After completing the structural analysis, the materials and steel members needed for the stairs were now known. All the steel was determined to be A36 and the railings and posts were determined to be aluminum. The following table shows the members of the staircase and their sizes:

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Steel Members and Sizes for the Staircase	
Stringer	MC 10x2
Flight Header	C 9x15
Platform Header	C 5x6.7
Hanging Supports	A) ½" hanger rod with 4x4x3/8" angle brackets B) Use ⅞" hanger rod with 4x4x1/2" angle brackets
Hand Railings	1"x2"x.125" (aluminum)
Posts	2" schedule 80 pipe (aluminum)

Table 4: Steel Members and Sizes for Staircase

The members were picked and decided using tables 5.26-5.33 from the National Association of Architectural Metal Manufacturers (NAAMM). The stringers and headers are channels and not the typical I beam. A copy of the work and calculations performed to determine these members can be found in Appendix 5. To help illustrate where some of these members are on the staircase, Figure 34 below is a screenshot from the structural Revit model with the Stringer and Platform Header labeled.

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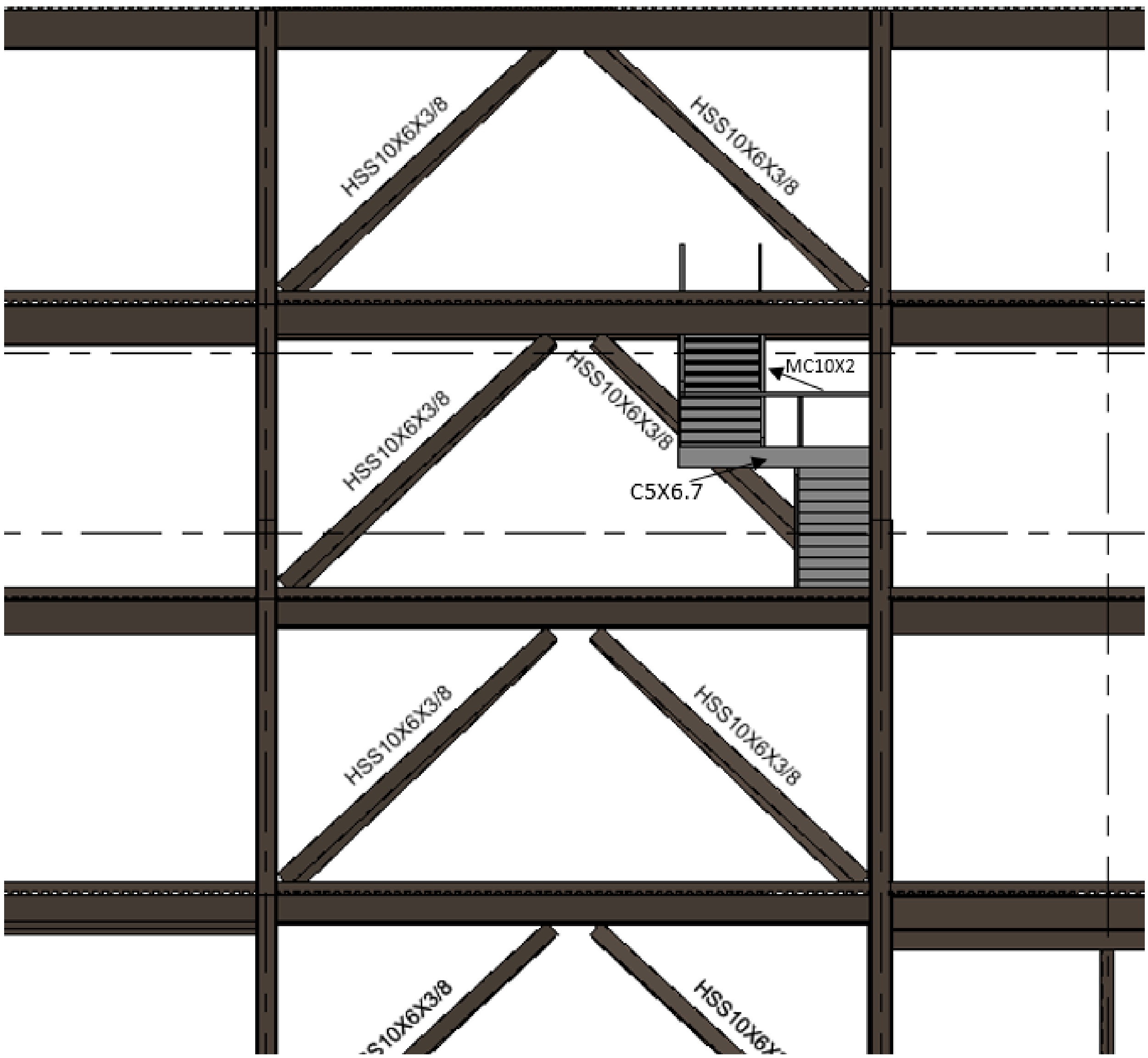

Figure 34: Structural Revit Model Displaying Staircase

The next step in the structural design is to design the connections for the hanging supports to attach to the four corners of the landing platform. Three different types of connections are being considered and can be seen in Table 5 below.

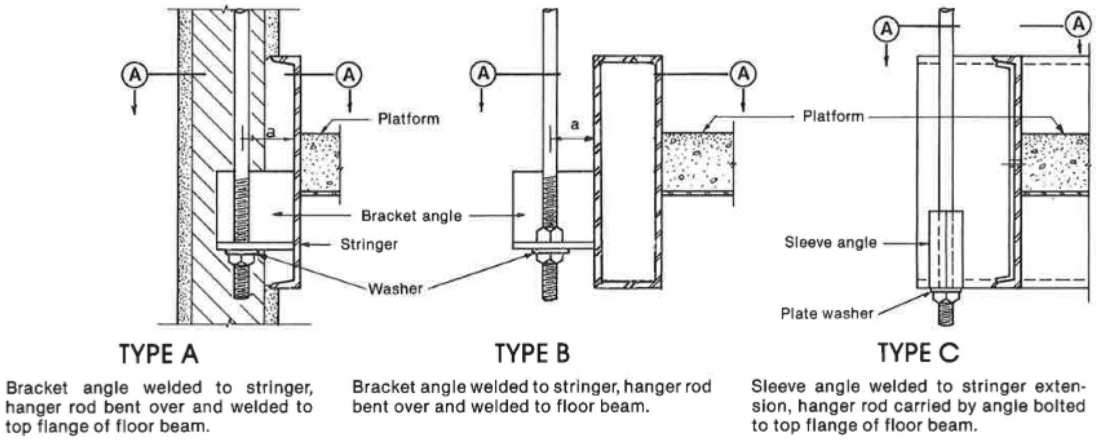

Table 5: Three possible connections for the staircase hanging supports

The next step performed was to calculate and see whether the existing structural beams will need to be supported to hold the new loads staircase addition bring. After calculating and researching connections it was determined two beams would needed to be added for the two runs to connect at the bottom and top of the staircase. After determining the beam to be the same as the flight header, C9X15, the next calculations were the connections between the stringers and headers or beams.

When the connection calculations were completed, the next steps in the staircase design was the landing and stair pans and treads. It was important to determine the proper metal the stairs needed to have to prevent the concrete on top from cracking from deflecting too much. Also, the platform needed to be designed with reinforcements for the concrete and once again the proper metal had to be selected.

All the calculations for these stairs were conducted by hand. Two main references used to perform these calculations were the IBC and the National Association of Architectural Metal Manufacturers (NAAMM). Along with the hand calculations, a structural Revit model was provided from an old MQP was used as an extension. Unfortunately, when trying to structurally analyze the building including the staircase, the structural analysis program in Revit did not work and no valuable data could be collected. A copy of all the staircase calculations can be found in Appendix 5 along with the codes used to design the staircase.

6.2 Cost Estimate and Schedule.

As part of our proposal for a staircase to be placed in the Gateway II building, a cost estimate as well as a schedule for the project are included. The staircase was cut out of the plan early enough in the design stages that there was no formal estimate created by KVA or Consigli. To accomplish the cost estimate portion of the proposal, pricing for the material and labor needed to be calculated.

The location and orientation of the stairs was a topic of discussion in the group throughout the completion of the staircase proposal. Mentioned above, the initial design of the staircase given to us by Isgenuity would've called for more structural work, time and money added to the project. After making the decision to change the design, the next question faced was how the staircase should be oriented. Some questions considered were: how much structural work would be needed (such as reinforcing beams, adding beams, etc), how much would the new staircase effect the existing area, and does the staircase follow all the proper codes (fire protection and building codes). Knowing that this staircase would be implemented in the future, how the buildings 3rd and 4th floor is laid out was very important to help us determine the cheapest option to orient the stairs. From the architectural plans given to the group by Consigli, we were able to determine that there are offices, huddle rooms, and a student lounge in the area the stairs would be built. The group then went through a few different orientation options for the stairs and determined the most logical place to put the staircase was running North and South. The figure below shows where the stairs would be built. After determining the location, the group then moved onto the cost estimate.

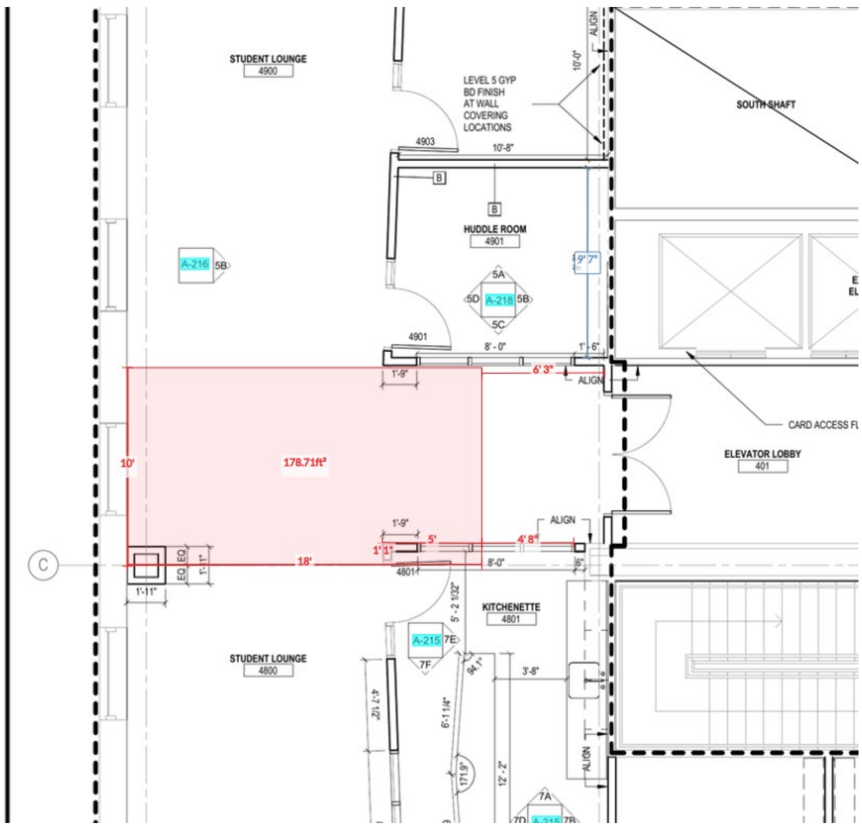

Figure 35: Floor plan of level 4 (south end) showing the staircase footprint

The pricing for the members were found online from discountsteel.com. Also, the pricing for the handrails, posts, spindles, landing sheet metal, and landing supports were found using the same website. For the concrete, the total amount of concrete needed to have a 2-inch slab on each step and a 3-inch slab for the landing platform to be roughly 1.33 cubic yards. Getting an average cost of concrete from various sources to be $90/cubic yard, the total cost of the concrete was calculated. Table 6 below is a breakdown of the cost estimate for strictly the materials.

Staircase Material Cost Estimate			
Item	**Unit Cost**	**Quantity**	**Total Cost**
MC10X8.4 (Stringer)	236.88/20' length	4	$ 947.52
C9X15 (Flight Header)	$382/ 10' length	3	$ 1,146.00
C5X6.7 (Platform Header	$73.31/10' length	1	$ 73.30
Handrail	$63.1/10' length	13	$ 823.03
Posts	$305/10' length	14	$ 4,270.00
Spindles	$8/ spindle	390	$ 3,120.00
Concrete	$90/ cubic yard	1.33	$ 119.70
Landing Sheet Metal	$39.35/ sf	30	$ 1,180.50
Landing Supports	$70.00/20' length	1	$ 70.00
Stair Pans	$221.08/each	30	$ 6,632.40
Total:			**$ 18,382.45**

Table 6: Staircase Cost Estimate

The only other material that was needed to be found was the stair pans. After researching around for the average pricing on the stair pans, a distributor with a very detailed price breakdown was found. Using the price information found from all cost information detail, the total pricing for the stair pans were calculated. A copy of the price breakdown from the distributor can be found below in Table 7.

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Item	Rate
Material	190.80 / EA
Structural Steel Workers Apprentice ($38.65/hour for 0.15 hours)	5.99 / EA
Structural Steel Workers ($45.84/hour for 0.31 hours)	14.21 / EA
Structural Steel Workers Foreman ($46.99/hour for 0.15 hours)	7.28 / EA
WELDER, 200 AMP, W/1 AXLE TRLR ($8.73/hour for 0.32 hours)	2.80 / EA
Other	0.00 / EA
Total	**221.08 / EA**

Table 7: Price Breakdown for Stair Pans

After the total cost of the materials were calculated, the next step was to calculate the labor to involve with the construction of the staircase. The trades needed to perform the task were determined to be concrete demo, steel erectors (welders included), and concrete pourers. The time allocated for each trade was based off past experience and research. Wages for each trade were gathered from past experience or from ProCore. Table 8 below is a rough cost estimate for the labor needed to construct the staircase.

Staircase Labor Cost

Trade	Position	Hourly Rate	# of men	# of Hrs	Total Cost
Steel	Foreman	$95.12/hr	1	40	$ 3,804.80
Steel	Journeyman	$88.28/hr	3	120	$ 31,780.80
Concrete (Demo)	Journeyman	$60/hr	1	8	$ 480.00
Laborer	Laborer	$30/hr	1	8	$ 240.00
Concrete (Pouring)	Foreman	$65/hr	1	8	$ 520.00
	Journeyman	$60/hr	3	8	$ 1,440.00
Total:					**$ 38,265.60**

Table 8: Staircase Labor Cost

With this information we know that the total cost of the staircase and the labor is about $57,000. This however, is not the complete total of the staircase. To get the complete total cost of the project the cost to build the offices that would be built if the staircase was not built need to be subtracted from the total from the material and labor. From the work performed in the earned value analysis, a cost per square foot for each of the trades was obtained. With this information and the square footages of the two offices, the cost of the two offices was obtained. Table 9 below is a cost breakdown for the two offices.

Cost of the two Offices				
Trade	cost per square foot	Office 1 square foot	Office 2 square foot	Total Cost
HVAC	45.35	218	241.11	$20,820.64
Electrical	34.37	218	241.11	$15,779.61
Drywall	25.33	218	241.11	$11,629.26
Paint	2.91	218	241.11	$ 1,336.01
Install Flooring	11.8	218	241.11	$ 5,417.50
Acoustical Ceiling	7.38	218	241.11	$ 3,388.23
Finish Carpentry	4.14	218	241.11	$ 1,900.72
Comunication	2.57	218	241.11	$ 1,179.91
Total				**$61,451.87**

Table 9: Cost of Offices

Now with all the calculations for the cost estimate done, the next and final step to perform is to get the total final cost of the staircase by subtracting the cost of the two offices from the cost of the staircase. This step is performed in Table 10 below.

Total Cost of Staircase	
Material	$ 18,382.45
Labor	$ 38,256.60
Cost of 2 Offices	$ 61,451.87
Total	$ (4,812.82)

Table 10: Staircase Total Cost

From the table you can see that to build the staircase is cheaper than building the two office areas by $4,812.82.

After the completion of the cost estimate the last and final step of the proposal is the schedule. Based off our labor estimated in Table 8 found on the page above, the staircase will take roughly a week and a half to build. Keeping in mind the time for the concrete to cure, it was determined to give the staircase two weeks to be built. Looking at the schedule provided to us from Consigli, spaces where the staircase would not affect the critical path were examined. From these available spaces, the time slot that would best fit in the staircase project was selected. After examining the schedule, it was determined that the best time to perform the staircase work would be during phase 1 sometime between November and December. During this time phase 1 the motion lab tech suites and offices are being built around the area the staircase is located so this would be an ideal time to construct the staircase.

7.0 Conclusion.

In modern construction Building Information Modeling Technology is a cutting edge, intelligent, technology that allows projects to be more effectively planned, designed, constructed and managed. This MQP uses BIM and Earned Value Analysis to not only track the Gateway II project, but also to analyze the projects efficiency and productivity. At the beginning of the MQP we believed we would get exposed to more of the construction occurring in phase II. As the project progressed we realized we would not be able to analyze phase II all the way through. Therefore, most of this MQP focuses on the construction and costs concerning the phase I area of the third floor which was complete at completion of this study. The BIM portion of this project created a visual display of the construction schedule of the different phases. The Earned Value Analysis evaluates the project's schedule and construction costs, while also noting any causes or sources of project delays or inefficiencies. To effectively perform Earned Value Analysis, the renovations schedule and cost variance were calculated to evaluate the projects budget and schedule. The schedule and cost variance both showed that the Gateway II renovation is currently on budget and ahead of schedule at the completion of this MQP. Additionally, this MQP includes a detailed proposal for a staircase between the 3rd and 4th floors of the Gateway II building that could be implemented into the current project as an alternate design. The staircase proposal included a structural analysis of the staircase and its members, cost estimate, and a schedule for the staircase. The structural analysis was performed by hand and a 3-D structural model was created using Revit Software. The cost estimate included cost of materials, cost of labor, and cost of the two offices that would be going into the building if the staircase is not built. With the help of the cost estimate, a schedule was completed for how long the staircase would take to build and where it would fit into the current schedule for the Gateway II building.

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Appendix.

Appendices 1: Interview with Eric Beattie and Ron O’Brien

Location: 37 Lee Street
Time and date: 12 PM on 9/17
People Present: Eric Beattie, Ron O’Brien, Shea Mooney, Constantine Galanis, James Curtin

Question 1: As Vice President for Campus Planning and Facilities Management at WPI, what was your role in the original construction of the Gateway II building or what has your role been on WPI projects in the past?

ANSWER: *Involved in the longer term aspects of projects, including the Gateway II project. Concerned with where WPI will be as a university in the future. Created a 5 year capital spending plan in January 2018. Involved in identifying where project are needed throughout campus. Fairly involved with the logistics of the project, but Ron O’Brien is more heavily involved with logistics as the Director of Design and Construction at WPI. Ron and his staff handle the majority of the project management during construction. Essentially, Eric is responsible for relaying project objectives and Ron is responsible for taking the necessary steps to complete the project.*

Question 2: When the Gateway II building’s construction was first proposed, what was the main purpose for construction?

ANSWER: *The first two floors of the building were intended to be used by WPI, but WPI did not see a need to occupy the third and fourth floors at the time of construction. There is a private-developer ownership model between the Owner (O’Connell) and the Tenant (WPI).*

Question 3: Specifically, what was the main initial purpose for the third and fourth floors of the Gateway II building?

ANSWER: *Mainly for the O’Connell group to lease out. Originally, the third and fourth floors of the Gateway II building were not intended to be used by WPI. Other tenants used the third and fourth floors during the first five years of the buildings’ life.*

Question 4: We understand that WPI is a tenant to the O’Connell Development Group, Inc., how was this relationship formed and how might this relationship differ from the ownership of other buildings on campus? Is this relationship going to remain the same after the completion of the renovation or change?

ANSWER: *WPI knew they did not need the entire building so they opted for this option. WPI owns the land, O'Connell funded the project because they could recoup funds by leasing to WPI and other tenants. O'Connell leased the land from WPI for long term use. There is a private-developer ownership model between WPI and O'Connell.*

Question 5: What has your role been in the planning/bidding of the renovation of the Gateway II building?

ANSWER: *Normally, Ron's position (Director of Design and Construction) would handle most of the project, including the planning and bidding phases of the project. KVA also had a collaborative relationship with WPI when planning and bidding this project.*

Question 6: What do you anticipate your role will consist of as the project progresses forward?

ANSWER: *Ron and his staff will handle the majority of the remainder of the project, but important details will be communicated.*

Question 7: What is the purpose of the renovation and how was the need for the photonics lab identified?

ANSWER: *Two large funding grants are driving the project. There was a need for research space, and WPI identified the third and fourth floors of Gateway II as open space adequate for the project needs. There will be an MRI machine and equipment installed as well as PracticePoint, which is intended to develop new robot technology to assist in medical practices such as surgery.*

Question 8: How were the different parties involved, such as Consigli and Isgenuity, selected for the project?

ANSWER: *Affordability is a problem with this particular project, but the basic requirements need to be met. About five RFPs from different CM firms were analyzed. Evaluated the strength of the management team, related experience, etc. to choose Consigli. There was an emphasis on looking for teams involved with healthcare projects in the past.*

Question 9: Who does the estimation in projects such as this one?

ANSWER: *A little bit comes from everyone as WPI made the original estimate with help from KVA. Recently, KVA and Isgenuity performed a more in depth cost estimate. However, once Consigli became a part of the team they took over lead responsibility for estimating*

Appendix 2: Interview with Jeff Lussier and Dan Sullivan

Location: Foisie Innovation Studio Tech Suite 122
Time and date: 9 am on 9/25
People Present: Jeff Lussier, Dan Sullivan, Shea Mooney, Constantine Galanis, James Curtin

Question 1: What kind of prior work experience do you have?

ANSWER: *Worked 18 years at the Boston Medical Center as the Director of Design and Construction. Collaborated with KVA on a project and decided to join KVA's team when the project was completed. Essentially went from being the owner to the owner's representative.*

Question 2: Where did you go to school?

ANSWER: *Dan attended Worcester Polytechnic Institute and Jeff attended Wentworth Institute of Technology. Many of the people working on the project are WPI alumni, including the Project Management and Super.*

Question 3: We were all members of the class you spoke in last year, so we understand you've worked with WPI in the past. What was your role/ how did you influence those previous projects?

ANSWER: *Will have essentially the same role as the Foisie Project. This project started with two funding grants, and WPI realized 50 Prescott was the only place that could accommodate these research grants. KVA interviewed 3 GC firms. For each party involved in this project there was an emphasis made on healthcare work. KVA's role is fairly consistent every project. KVA helps everyone efficiently get what they need, and essentially advocates for each different party during construction. KVA works closely with the WPI team.*

Question 4: How is the Gateway II renovation different than the previous projects you've worked on?

ANSWER: *No two projects are the same, but this project certainly isn't specifically out of the ordinary. There are two phases during this project which may pose some challenges. Additionally, WPI doesn't own the building and there are tenants who are currently occupying space in the building that won't be undergoing construction.*

Question 5: What is your role in the bidding process? For the design team? For the General Contractor?

ANSWER: *Jeff has an extensive amount of experience, over 20 years. He makes an initial rough estimate, but the GC makes the actual cost estimate by trade. It is important to always consider past experience during the bidding process. For this project, it was important that both the design team and the general contractor had past experience in the healthcare field.*

Question 6: How many other companies bid the project? Who were they?

ANSWER: *Bond, Shawmut, and Consigli bid for this project. KVA put the list together as they knew these firms have previous experience. KVA has worked with two of the firms on projects involving MRI technology, and knew the third has had previous experience. O'Connell also bid for the project, but was not seriously considered because they had little or no experience in the healthcare field in the past.*

Question 7: What sort of things influenced your choice when aiding WPI in a decision on who to choose for the GC and Design team?

ANSWER: *Start by looking at the scope and scale of the job size and essentially scale the size of the job to the size of the CM firm. Has the company done this kind of work before and at what scale? Who are they proposing as the project team? Is the team competent, likeable, honest, reliable, etc.? Always need to interview the team to find these things out. Jeff has working with the super of this particular project in the past, and has had good experiences.*

Question 8: Are you involved in the estimating process? If so, how are you involved?

ANSWER: *This project is specifically hard to estimate because the space is so varied. The 35000 sq ft space is broken up into many different components and priced by square foot, and it is very hard to put definitive number on such things. The Architect and GC also did a cost estimate, which ended up being fairly close.*

Question 9: We know there were talks of a staircase from the third to the fourth floor but it was cut due to budgeting reasons. Do you know if there are any plans, cost estimates for the staircase?

ANSWER: *There may be some cost estimates from the early plans which can be shared. Dan will look into these documents and share them if any relevant information can be found. There may also be a floor plan that can be shared.*

Question 10: Have there been any challenges that come to mind so far that will be faced in the Gateway II renovation?

ANSWER: *The biggest challenges that come to mind are the two different project phases and the tenants who are currently occupying the building. Throughout the project it is crucially important to keep the tenants happy and make sure there are as little complaints as possible. It is always important to communicate effectively with the tenants before any issues arise.*

Question 11: Will there be a webcam or any sort of device recording the progress of the construction?

ANSWER: *No, there are currently no plans to use a webcam for this project.*

Question 12: What is KVA's role in troubleshooting throughout the project?

ANSWER: *Provides leadership. Review things, surveys, ask questions. Finds creative solutions to budget and schedule constraints to preserve quality. Not their job to design or build, but there is often a conflict between the two parties. OPM is kind of like a middle man between the two (encourages collaboration) Involved with budget, schedule, and quality of project. KVA is essentially the project Facilitators.*

Appendix 3: Interview with Isgenuity

Location: Conference Call
Time and date: 10:30 AM on 11/7
People Present: Shea Mooney, Constantine Galanis, James Curtin, Guillermo Salazar, Sarah Edwards, Dena Zyrofff and Jennifer Vachon

Question 1: What sort of projects have you worked on in the past?

ANSWER:
Jennifer Vachon: *Involved in some of Isgenuity's most technical healthcare projects, such as radiology upgrades, emergency department additions and family-focused housing for patients at Boston Children's Hospital.*

Dena Zyroff: *Worked with Isgenuity since 2007. Isgenuity has been around for 15 years, and has focused predominantly on healthcare, lab design, research, and academic projects. Projects are primarily in Boston and the East Massachusetts area. This is Isgenuity's first time working at WPI, but the firm has experience at other universities. Working on an entire floor renovation at Dana Farber. WPI is currently the largest project.*

Sarah Edwards: *Dedicated entirely to the WPI project.*

Question 2: Is this the only project you are working on right now? If not how many other projects are you working on and where are they located?

ANSWER:
Jennifer Vachon: *Working on 5 different projects, WPI the largest one.*

Dena Zyroff: *Working on WPI and an entire floor renovation in boston for Dan Farber. Currently designing a wet lab. Also beginning another large project involving MRI rooms and other healthcare rooms.*

Sarah Edwards: *Gateway II is currently the only project she is working on.*

Question 3: What things do you prepare for the bid process/ how are you involved with the procurement of the job?

ANSWER: *Received RFP from KVA. Interview process included presentations. Not necessarily a "bid", but the firm was up against two other architects. Proposal included a fee, followed by an interview process, which presented Isgenuity's proposal to WPI. Hired originally for conceptual design phase, which lasted 8 weeks, then proceeded into detailed design. Proceeded to request fee from consultant, and considered 4 different MEP engineers. Lowest* *fee won for both MEP and structural engineers, however for acoustic and vibration consultation Isgenuity didn't go with lowest fee due to politics. For the proposal, the firm only submitted relevant experience, resumes, and schedule. Conceptual Design Phase was a series of meetings about discussing what the needs, wants, etc. of the project are. At beginning of the project, Isgenuity didn't know the 3rd floor had a tenant. The early diagrams and creative process is very conceptual. Additionally, a design for a Grand Staircase was cut for Budget reasons.*

Question 4: What sort of relationship do you have with KVA and WPI as the design process and project progresses?

ANSWER: *In this project, KVA is the owner's rep, so KVA is essentially directing Isgenuity, as they are representing WPI. Early project meetings had more contact with KVA, however, during the production phase there has been less contact. There is not necessarily a day to day interaction between Isgenuity, WPI and KVA.*

Question 5: How does your team interact with the Consigli Team?

ANSWER: *Isgenuity has been working with Consigli for a month or two, not yet a developed relationship per say, but both teams are working for the client (WPI). Isgenuity is responsible for producing construction documents for Consigli. Consigli issues submittals to ensure everything is in order. All communication is documented formally for project records, as there are often unforeseen existing conditions that require further revision.*

Question 6: We know there is a lot of fairly complicated MEP coordination in this project, how does your team efficiently coordinate these MEPs in design?

ANSWER: *Consulted 4 different MEP companies. WSP is the name of the MEP coordinator that was chosen. One issue during design is that Isgenuity didn't have drawings of the 3rd and 4th floor MEPs. Recently the owner found the MEP drawings which was helpful, but things are constantly changing in construction. Still in the process of deciding what the building needs to hold, what it can hold, what can we add to it. There is an consistent effort to try to future proof things for the project, which is hard because the professors may not know exactly where there research will be going.*

Question 7: How do you/Isgenuity go about choosing the team for the project? How is the team structured internally?

ANSWER: *The president of the firm (Martin Batt), is very heavily involved in the programming process. Typically, the principles are heavily involved in the initial design phases, but less as the project progresses. Kate Spinelli (Director of interior design) was heavily involved in conceptual design and rendering for the Gateway II project. There is a bookkeeper who deals with bills, etc, not project base but essential to the project*

Appendix 4: Project Meeting Notes

11/8 Owner's Meeting
Attendance:
MQP Group:

Shea, Constantine

Isgenuity:

Jennifer Vachon

Deena Zyroff

KVA:

Dan Sullivan

Jeff Lussier

WPI:

Tim Reilly

Guillermo Salazar

Ron O'Brien

Consigli:

Thomas Duszlak

Ryan Stock

Safety: (TOM)

- Calling for fire alarm testing, going to be sporadic, not everyday
- Non WPI tenants need to be let know
- Level 2- classes start, limit chipping on 3rd floor- getting work done today so its quit tomorrow
- Brick is done, noise complaints coming from call center (8-4 workday), some chipping needs to be done.
- Weekly heads up on what days there will be noise, work from there before doing work on off hours

Hot Work:

- Access road for the winter being completed tomorrow

Admin Items

- Ryan is talking with accountant. Need to get a more finalized budget to submit documents to the accountant, Using DD estimate
- Contract wise- sent docs to Jeff and he forwarded it to

Phase I building permit is out

Phase I Construction Update:

- Procurement for fire alarm is sent it
- Only things that need to be bought out is flooring and paint
- Security/IT: Del Signoli is a sub of WPI but will be contracted by Consigli

Drawings-75%

- Drawings aren't done, some aspects are further along than others.
- KVA thinks the design team should get together as a group and go over the RFI's instead of submitting 25 RFI's. Open dialogue and probably going to be a half day meeting.
- Consigli (Ryan Stock) Sending questions to Isgenuity ahead of meeting- mostly architectural and MEP's. More comfortable about architectural but more questions for MEP.
- Meeting roughly tuesday or wednesday next week (Boston).
- Some questions on GE drawings

Schedule

- Permitting for phase two, waiting for signature and then going to submit, everything else is ready to go (specs, drawings)

Phase 1

- Framing done
- Duct work done
- Plumbing mobilizing
- Gantry needs to be squared away
- In good shape to be done in January
- Lab wastes testing was good and everything is tied in good to go.
- The waste for the manufacturing area is not known exactly what is in it. Metals?
- One printer is here and want to set it up in the fire protection area to test what waste is produced. Also different waste for different printing material. Create a profile for each material- need to order solvent so can't do immediately but will do soon.
- Double door (glass) in residential sweet when every other door in the residential area is single. Ryan wants to get rid of the door. Take the design for the location back to greg.
    - Do we need a door at all?
    - If yes, we are going to change it from a glass door to a wood door and do we need to place a lock?

- Door hardware specs in general, submitted door schedule and hardware specs (matched existing)
- Only 6 doors for phase 1
- Who is installing force plates? - greg thought Consigli. Consigli thought they were picking from WPI's pricing. Preference is that the vendor will install the force plates.
- Pit location might need to be leveled out to create a better floor for the force plate railings to be installed. 5x6 area.
- Next bulletin coming soon

Occupied Work:

- Floor boxes need to be removed on the second floor that needs to be performed on a Saturday
- The work above the call-center going to work with them
- Moving lab waste work to phase 2
- MRI steel submitted and shop drawings sent in, fireproofing submittals will be sent soon.

  Animal lab waste is sanitary but should it be considered a lab waste?

FFE Coordination:

- Not too much additional info on specs but we have some clarity on a few questions

GE MRI:

- Is it ordered? Delivery of magnet is early May. The magnet has not start building yet and is behind schedule now.
- Critical that the magnet is on time- the whole project schedule revolves around it

Animal MRI

- Real possibility that this doesn't make it into the project- going to become a shell with structural for future use. No shielding due to need of opening the side of the building again.

RFIs and Submittals:

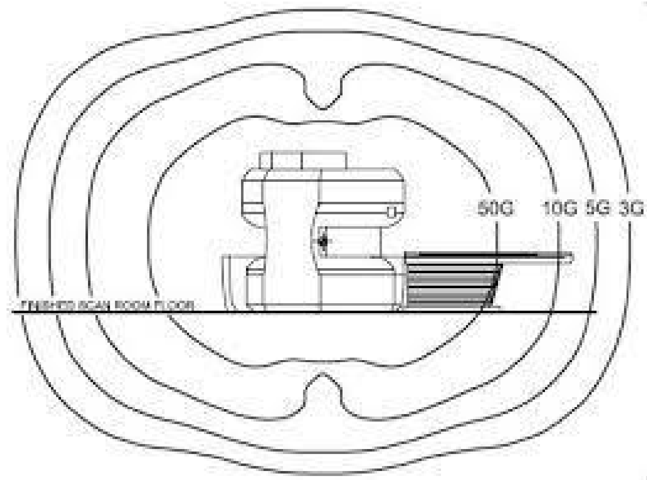
- Door Hardware
- Raised floor submittal? Just need material submittal so Tom can order material. Ramp submittal isn't the biggest issue.
- Need to approve floor color for pit. lighter grey is what is looking for approval- Approved by Jeff
- Yellow and Orange paint are a no-go for WPI

- Jeff wants a new solid surface for the kitchen surface areas. Not Corien because of the premium associated. Wants the difference of Corien and another manufacturer.
- Carpet colors for offices and corporate pods are both shades of grey and waiting for KVA and WPI approval-
- Phase 1 floor finishes need approval
- KVA holding onto board of sample floorings and colors and going to get greg and Doug's approval
- 3 open RFI's: 1) floor drain- reopened- Isgenuity waiting back from manufacturer

Scope Items:

- Phase 1 Security
- Door Hardware: ISgenuity going to put a manual hardware list together
- Motions lab raise floor layout: revising the ramp
- New Bulletin coming out
- Fire stopping: sent drawings off to UTS to get a quote for firestopping inspection, steel fireproofing etc.
- Salvageable material quantities submitted
    - Should go through the materials and see which ones we want to use and which ones we should throw out
        - Fire alarms and other materials are reusable: Will get a confirmation from the electrician that the materials are reusable in writing
        - Potential savings of reusing fire alarms
- Generator Power- getting power data from test on Monday
- MRI Shielding- documents and drawings received by Consigli going to reach out to get estimated on installation **Critical Path item**- Dave Adams needs to be involved for review
- Dave Adams to review Gauss lines as well- each institution has their own specs

- Gauss Lines: Gauss lines serve as a reminder that you are inside a magnetic field which increases sharply as you move closer to the magnet

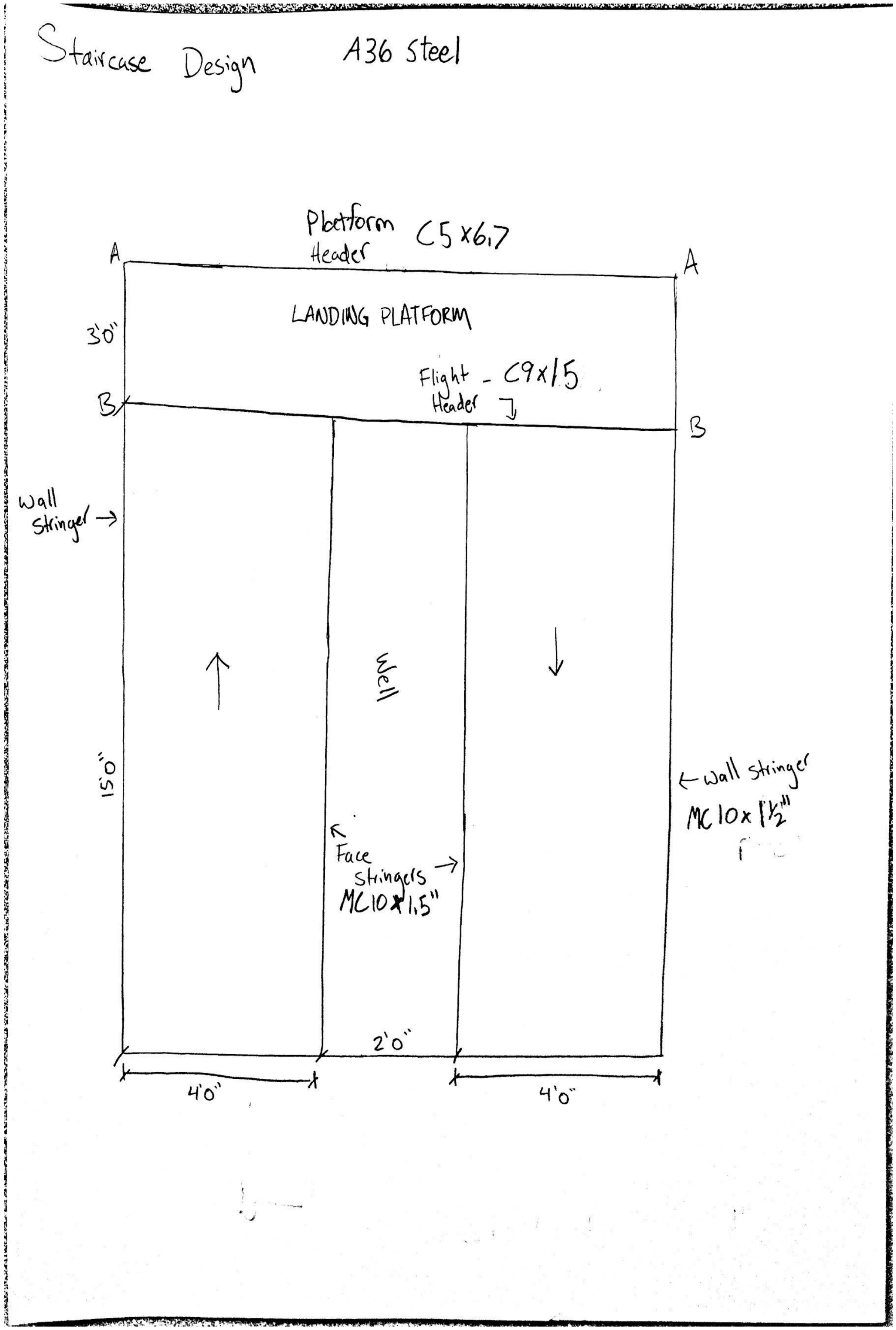


- Hazardous storage closet location? Where is it going?- Jeff
    - Going to serve more than floors 3 and 4 so it should be in a common area (like the basement). Need to find a spot over 50 ft from the property line. WPI would rather place the closet in the basement and not comply with the EPA regulations rather than put the closet on the 4th floor. Storage closet typically needs 2 50 gallon drums and wire rack space (16'x5').
- Vibration analysis of the Photonics lab: Meeting set up for next Wednesday
    - Focus on frequencies identified and options active for vibration cancellation
- Finish board presentation
-

New Business:

- TIm: Looking at 75% drawings for Mechanical ventilation
    - Why are we splitting the requirements for the exhaust fans into more fans, can we consolidate this?
    - How did we get to the point where each fan in the clean room has its own fan for the exhaust
        - Deena: The chemicalist isn't known yet therefore we can't make the decision to consolidate yet
        - Jeff: we currently have too many systems and need to do something to alleviate this.
- Ron:
    - Believes he left Tom hanging on the fire alarm system today
- Deena:
    - Need to setup a meeting time with WSP and Consigli (meeting on wednesday)
- Ryan:
    - HVAC equipment submittal got returned
    - All equipment to be installed during phase 2
    - Raising the duct in the motions lab cost an additional $16,000
    - Have run over $20,000 budget for HVAC by $17,000

Appendix 5: Staircase Steel member Calculations and Codes



Variables for Staircase Calculations

W = Total Uniform load (lb or k)
P = Concentrated load (lb or k)
w = load per lineal foot (lb/ft or k/ft)
M = Bending Moment
S_{req} = Section Modulus required (in^3)
I = Moment of Inertia (in^4)
F = Max allowable tensile stress in bending
R = resultant
h = height
Δ = deflection
Δ_p = deflection of post
Δ_r = deflection of handrail

Staircase Design

Loads

LL = 100 psf

DL = concrete - 50 psf

stringer, risers, other plates, Flight Header, Platform Header — 50 psf

T.L. = 200 psf

Face Stringer

$$W = ksf \times \frac{\text{tread length}}{2} \times L$$

$$.2 \times \frac{4}{2} \times 15 = 6k$$

MC10 x 1½" → from table 5.26

W = 6.2

$$R = \frac{W}{2} = \frac{6.2}{2} = 3.1k$$

Wall Stringer

Same as face stringer

R = 3.1k

Flight Header

$W = ksf \times \frac{\text{platform width}}{2}$

$.2 \times \frac{3}{2} = .3 \text{ k/ft}$

$P = 2 \times 3.1 = 6.2 \text{ k}$

$M = \frac{wL^2}{8} + \frac{PL}{4} = \frac{.3(10^2)}{8} + \frac{6.2(10)}{4}$

$M = 3.75 + 15.5 = 19.25 \text{ kip-ft}$

$S_{req} = \frac{12M}{F} = \frac{12 \times 19.25}{22} = 10.5 \text{ in}^3$

A36 steel

C9x15; $I = 51.0 \text{ in}^4$ $S = 11.3 \text{ in}^2$ → table 5.32

Δ

$I = .02288(1.6P + W)L^2$

$I = .02288((1.6 \times 6.2) + (.3 \times 10))10^2$

$I = 29.56 \text{ in}^4 < 51.0 \text{ in}^4$ ✓

$R = \frac{W + P}{2}$

$= \frac{.3 \times 10 + 6.2}{2} = 4.6 \text{ K}$

Platform Header

$W = KSF \times \frac{\text{Platform width}}{2} \times L$

$W = .2 \times 3/2 \times 10$

$\boxed{W = 3\,k}$

$M = \frac{WL}{8}$

$M = \frac{3(10)}{8} = \boxed{3.75 \text{ Kip-ft}}$

$S = \frac{12M}{F}$

$S = \frac{12(3.75)}{22} = \boxed{2.05 \text{ in}^3}$

$C5 \times 6.7;\ S = 3.00 \text{ in}^3;\ I = 7.49 \text{ in}^4 \rightarrow$ table 5.32

Δ

$.000763\, WL^3 / I$ $\qquad \Delta x \quad \frac{10 \times 12}{360} = .33$

$\frac{.000763(3)(10^3)}{7.49} = .305 \text{ in.} < .33$ ✓

$R = \frac{W}{2} = \frac{3}{2} = 1.5\,k$

3

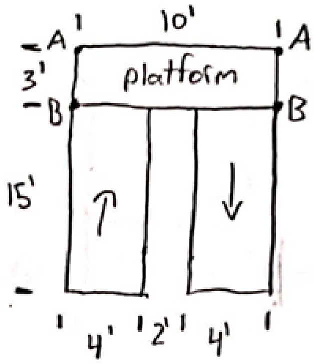
Supports

@ A

Load = R of Platform header = 1.5 k

Use 1/2" rod with 4x4x3/8 Angle brackets

Tables 5.27 & 5.28



@ B

Load = R of flight header + R of wall stringer

= 4.6 + 3.1

= 7.7 k

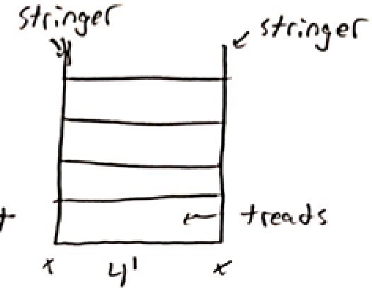
Use 7/8" hanger rod with 4"x4"x1/2" angle brackets (a must be less than 5 1/2")

Tables 5.27 & 5.28

a is length b/w hanger rod and stringer.

4

Stair treads:



$W = \frac{200 \times 10}{12} = 166.67 \text{ plf}$

$M = \frac{wL^2}{8} = \frac{166.67(4^2)}{8} = 333.34 \text{ lb-ft}$

$P = 300 \text{ lb}$ (min concentrated load a stair must hold - AISC)

$M = \frac{PL}{4} = \frac{300(4)}{4} = \underline{300 \text{ lb-ft}}$ (governs)

$S = \frac{300 \times 12}{10{,}000} = .36$

F of Alloy 6061-T6 → 10,000

From table 5.13

| 1/4" tread plate, S = .365, I = .586 |

$\frac{.0036PL^3}{I} = \frac{.0036(.3) \times 4^3}{.586} = .118"$ ✓

$\frac{L}{360} = \frac{4 \times 12}{360} = .13"$ ✓

Platform Design

4 support channels
plate span = 2'

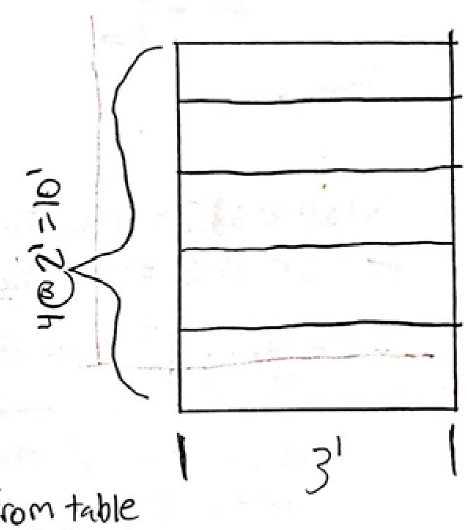
$M = \frac{200 \times 2^2}{8} = 100 \text{ lb-ft.}$

$M = \frac{300 \times 2}{4} = 150 \text{ lb-ft}$

$S = \frac{150 \times 12}{16{,}000} = .1125 \text{ in}^3$

F for steel sheet → 16,000

$I > .01875(.2 \times 2)(2^3) = .03 \text{ in}^4$



From table 5.6

| 5/16" plate, S = .1953, I = .03052 in⁴ |

Platform Supports

Span = 3'

$W = .200 \times 2 \times 3 = 1.2k$

$R = \frac{1.2k}{2} = .6k$

$M = \frac{1.2 \times 3}{8} = .45$ kip-ft

$S = \frac{.45 \times 12}{16} = .3375 \text{ in}^3$

$I > .0675 \times 1.2 \times 3^2 = .729 \text{ in}^4$

From table 5.34

C3×1.42, $I = 1.66 \text{ in}^4$
$S = 1.10 \text{ in}^3$

Design of Connection of Header to Stringer

Connection angle welded to header,
bolted to stringer.
Eccentric load moment taken by welds.

$2\frac{1}{2}" \times 2\frac{1}{2}" \times \frac{3}{16}"$ angle
E60 welding electrodes

$V = R\sqrt{(.5)^2 + \left(\frac{1.25}{e}\right)^2}$

$= 4.6\left(\sqrt{(.5)^2 + \left[\frac{1.25}{3.5}\right]^2}\right)$

$V = 2.83k$

$R = \frac{2.83}{\sqrt{.25 + \frac{1.5625}{3.5^2}}} = 4.61k$

Max R of welds = 5.86 > 4.61 ✓

Max V of bolts = 3.92 > 2.83 k ✓

weld length req = $\frac{5.86}{3.92}$ = **1.50"**

Use two $\frac{3}{16}" \times 1.5"$ welds along the top & bottom of the $3\frac{1}{2}"$ angle

6

Design of connections of pan tread-riser to stringer

A_v = t of steel x Length of weld

$.25\ in^2 \times 1.5'' = .375\ in^3$

(see stair tread calcs)

$V_{prov} = .4F_y \times 2A_v$

$.4(33) \times 2(.375) = 9.9\ k$

W on tread = ksf x tread width x tread length

$= .15 \times \frac{11''}{12} \times 4 = .733\ k$

$R = \frac{w}{2} = \frac{.733}{2} = .3665\ k$ $\quad .3665k < 9.9k$ ✓

Two welds $\frac{1}{8}'' \times 1.5''$ are adequate

7

Railings

NAAMM – min force of 200lbs applied in any direction at any point @ the top of the rail.

uniform – 20-50 $^{lbs}/_{LF}$

NFPA – no less, than 25 $^{lbs}/_{LF}$

uniform load

$$F = \frac{W/12 \times I^2}{S \times K}$$

K = 8 for one or two spans

K = 9.5 for 3 or more spans

concentrated

Deflection Considerations

lateral deflection

$$\Delta = \frac{W/12 \times I \times h^3}{3 \times E \times I}$$

vertical deflection

$$\Delta = \frac{5 \times W/12 \times I^4}{384 \times E \times I}$$

Max post Spacing

$W = 25\ ^{lb}/_{ft}$

$h = 36$ inch

h – must be 34-38"

1-¼" schedule 40 aluminum pipe posts of Alloy 6063-T52.

$S = .235\text{in}^3$, $F = 11{,}500$ psi

I = .195

$$F \times S = W/12 \times I \times h$$

$$I = \frac{F \times S}{W/12 \times h} = \frac{11{,}500(.235)}{(25/12) \times 36}$$

I = 36 in max

8

Determine Section Modulus req. of post

$P = 200$ lb $F = 11{,}500$

$h = 36$ in.   6063-T52 aluminum post

$$F \times S = P \times h$$

$$S = \frac{P \times h}{F} = \frac{200 \times 36}{11{,}500} = .626$$

→ Have to use either 2½" schedule 40 pipe or 2" schedule 80 pipe

table 5.35

Max Span for handrail

$P = 200$ lb $K = 5$

$$F \times S = \frac{P \times l}{K}$$

use aluminum tubing 1.00 x 2.00 x .125

$S_x = .210$

$F = 11{,}500$

$$l = \frac{K \times F \times S}{P} = \frac{5 \times 11{,}500 \times .210}{200} = 60.375 \text{ in}$$

Horizontal & Vertical Handrail Deflection

post

2" pipe schedule 80 Aluminum $I = .868$

handrail

1" x 2" x .125" $I_x = .105$

$I_y = .332$

loading

$w = 40$ lb/ft horizontal

$w = 100$ lb/ft vertical

Δ post

$$\Delta p = \frac{\frac{w}{12} \times l \times h^3}{3 \times E \times I} = \frac{\frac{40}{12} \times 36 \times 36^3}{3 \times (10 \times 10^6) \times .868} = .215 \text{ in}$$

9

Δ handrail (horiz)

$$\Delta r = \frac{5 \times \frac{w}{12} \times L^4}{384 \times E \times I_y}$$

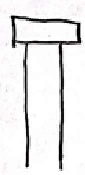
$$= \frac{5 \times \frac{40}{12} \times 36^4}{384 \times (10 \times 10^6) \times .332} = .022 \text{ in}$$

$\Delta = \Delta p + \Delta r = .215\text{in} + .022\text{in} = \boxed{.237\text{in.}}$ → total horizontal Δ

Δ handrail (vert)

$$\Delta r = \frac{5 \times \frac{w}{12} \times L^4}{384 \times E \times I_x} = \frac{5 \times \frac{100}{12} \times 36^4}{384 \times (10 \times 10^6) \times .105} = \boxed{.174 \text{ in}}$$ → total vertical Δ

post – 2" schedule 80 pipe
handrail – 1" x 2" x .125"



10

Appendix 6: Codes used for Staircase Design

<u>Loads:</u>

Load combinations were selected in accordance with ASCE 7-10: Minimum Design Loads for Buildings and Other Structures.

The load combination selected was 1.2D + 1.6L.

<u>Staircase Design</u>

The staircase was designed in accordance with the 2015 International Building Code. Some specific codes used are listed below.

Section 1011 Stairways

1011.1 General Stairways serving occupied portions of a building shall comply with the requirements of Sections 1011.2 through 1011.13.

1011.2 Width and Capacity The required capacity of stairways shall be determined as specified in Section 1005.1, but the minimum width shall be not less than 44 inches.

1011.3 Headroom Stairways shall have a minimum headroom clearance of 80 inches (2032 mm) measured vertically from a line connecting the edge of the nosing's. Such headroom shall be continuous above the stairway to the point where the line intersects the landing below, one tread depth beyond the bottom riser. The minimum clearance shall be maintained the full width of the stairway and landing.

10115.2 Riser height and tread depth Stair riser heights shall be 7 inches (178mm) maximum and 4 inches (102mm) minimum. The riser height shall be measured vertically between the nosing's of adjacent treads. Rectangular tread depths shall be 11 inches (279 mm) minimum measured horizontally between the vertical planes of the foremost projection of adjacent treads and at a right angle to the tread's nosing.

1011.5.4 Dimensional uniformity Stair tread and risers shall be of uniform size and shape. The tolerance between the largest and smallest riser height or between the largest and smallest tread depth shall not exceed 3/8 inch (9.5 mm) in any flight of stairs.

1011.5.5 Nosing and Riser Profile Nosings shall have a curvature or bevel of not less than 1/16 inch but not more than 9/16 inch from the foremost projection of the tread. Risers shall be solid and vertical or slopped under the tread above from the underside of the nosing above at an angle not more than 30 degrees from the vertical.

1011.6 Stairway landings There shall be a floor or landing at the top and bottom of each stairway. The width of landings shall not be less than the width of the stairway. Where the stairway has a straight run the depth need not exceed 48 inches (1219 mm).

1011.7 Stairway construction Stairways shall be built of materials consistent with the types permitted for the type of construction of the building, except that wood handrails shall be permitted for all types of construction.

1011.8 Vertical rise A flight of stairs shall not have a vertical rise greater than 12 feet between floor levels or landings

Section 1014 Handrails

1014.1 Where required. Handrails for stairways and ramps shall be adequate in strength and attachment in accordance with section 1607.8. Handrails required for stairways by section 1011.11 shall comply with sections 1014.2 through 1014.9. Handrails required for ramps by section 1010.9 shall comply with sections 1014.2 through 1014.8.

1014.2 Height. Handrail height, measured above stair tread nosing's, or finish surface of ramp slope, shall be uniform, not less than 34 inches (864 mm) and not more than 38 inches (965 mm).

1014.3.1 Type I. Handrails with circular cross section shall have an outside diameter of at least 1-1/4 inches (32mm) and not greater than 2 inches (51 mm).

1014.6 Handrail extensions. Handrails shall return to a wall, guard or the walking surface or shall be continuous to the handrail of an adjacent stair flight or ramp run. Where handrails are not continuous between flights, the handrails shall extend horizontally at least 12 inches (305 mm) beyond the top riser and continue to slope for the depth of one tread beyond the bottom riser.

1014.7 Clearance. Clear space between a handrail and a wall or other surface shall be a minimum of 1-1/2 inches (38 mm)

Section 1015 Guards

1015.1 General. Guards shall comply with the provisions of section 1013.2 through 1013.7.

1015.2 Where required. Guards shall be located along open-sided walking surfaces, including mezzanines, equipment platforms, stairs, ramps and landings that are located more than 30 inches (762 mm) measured vertically to the floor of grade below and point within 36 inches (914 mm) horizontally to the edge of the open side. Guards shall be adequate in strength and attachment in accordance with section 1607.8.

1015.3 Height. Required guards shall not be less than 42 inches (1067 mm) high, measured vertically as follows:

1. From the adjacent walking surfaces;
2. On, stairs, from the line connecting the leading edges of the tread nosing's; and
3. On ramps, from the ramp surface at the guard

Along with the IBC stairway codes, the new floor layout with the stairs is in accordance with the ADA (hallways minimum 3 feet wide)

asstech.org/press-releases/baker-polito-administration-announces-4-milliona-millionWPI. (2018, July 1). PracticePoint. Retrieved from https://www.wpi.edu/research/centers/medical-cyber-physical-systems

https://www.photonics.com/a62995/WPI_Quinsigamond_CC_to_Share_4M_Grant_for_Joint

https://www.practicepointinc.com/Who-We-Are/Accrediting-Alliances

Appendix 7: Site Walk Photos

November 29, 2018

November 29, 2018

November 29, 2018

November 29, 2018

November 29, 2018

Appendix 8: E-files.

Revit: Finishfile.RTE, Architectural Model Staircase.RTE, Structural Model Staircase.RTE
The work done in Revit consisted of taking a previous file from an old MQP, adding in necessary 3rd and 4th floors, creating 4 phases: existing, demolition, phase 1 and phase 2. The phases visually depict the different stages of the construction of the Gateway II renovation. Another aspect of the work done in Revit consisted of a structural and architectural model of the alternative staircase design

Navisworks: Finish1.NWF, Phase1.NWC
In Navisworks the group used the timeliner tool to create a time lapse view of the construction project. The schedule, based off duration, was incorporated to show when the different phases of the project occur and where certain work occurs.

Excel: BCWP.xlsx, Cost Management by Phase.xlsx, Cost Management by Room.xlsx, Lazy S-Curve.xlsx

In excel all the cost estimates and graphs for the lazy-S curve were developed based off the requisitions and Design Development estimates received from Consigli.

Link to all Files:
https://drive.google.com/drive/folders/1jeIPPH31ZIJyBYyWePpQb-kVe2kch1id