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WPI New Athletics Facility

An Integrated Approach to Pre-Construction Practices

A Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

In Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science

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Abstract

This project encompassed various limited pre-construction tasks, including conceptual design through BIM Modeling, structural design, construction feasibility, cost estimation, and investment analysis concerning Worcester Polytechnic Institute's new athletics facility within the context of integrated practice. Currently Integrated Practice is still young in development and has had limited exposure to the construction industry. The project determined that integrated practices can reduce errors, address issues earlier in the design phases, and reduce construction times only if specific project objectives, scheduling, and modes of communication are clearly defined. With proper implementation and organization, Integrated Practice can possibly become the standard method of construction in the future.

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In the context project integration this report was authored by the following individuals, each with specific authorship responsibilities as well as collaboration between each discipline.

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Capstone Design Statement

The capstone design requirement of the Master Qualifying project was met through the design of a three different components of this project. The first was the design of the trusses to support the floor of the proposed gymnasium. Another component was the design of an acceptable site plan design for the construction of the gymnasium. The final component was the three dimensional model of the building design made using the software Revit.

The truss design was of particular importance to the structural design of this facility as it provided support for the gymnasium floor on the second level of the proposed building, while providing enough open space to allow room for the competition sized pool below. This span of 110 feet necessitated the use of a truss system because a truss is more efficient at supporting large loads over a large span than a single beam. The truss design was based on the dead loads and the occupation live loads and was reviewed for future analysis for lateral loading.

The site plan was developed as a solution for the access, unloading, and storage of materials. It was also designed for access to the site for supply deliveries and employee parking during construction. This is an important aspect when beginning project design. It affects not only the speed and ease of construction but the WPI community as well.

The schematic design of the building allocated space required by the architectural program. The 3D model allowed for different parties in the preconstruction phases to come together and ensure the building would be completed accurately during construction. The model allowed for changes to be made to the building early, potentially reducing the number of errors later in the project. It was particularly important for this project because it promotes collaboration among parties during the pre-construction phases. It also allowed the group to see how the work of each discipline was affecting the overall outcome.

Six of the seven realistic constraints were met during the capstone design of this project. Further explanations of each are as follows:

Economic:

The economic effects of this project were considered during the capstone design. The truss was designed to have lower costs than other truss options. This was done by using three different member sizes to avoid costly overdesign. A common truss type was also selected than many fabricators would be able to make without any specialty manufacturing charges. The site plan as designed to provide entrances to the site without needing to spend extra money on police men or temporary traffic lights for traffic control on nearby streets.

Sustainability:

During the Revit design of the building a portion of extra flat roof was found. Through this design the group was able to find a place where the option of a green roof could be considered. As the new athletic facility is planned to be LEED certified, this will certainly add to its qualification.

Manufacturability/Constructability:

Manufacturability was addressed during the truss design during truss type and member size selections. For both situations it was important to select an option that would keep the fabrication of the trusses simple and less complicated.

The group was only provided with initial rough designs, thus it was up to the group determine a reasonable building draft that could be used during the project. The Revit design had to be a realistic design with consideration to constructability.

Health and Safety:

Safety was also a major concern with regards to the layout of the site during construction operations. Many students, faculty, and staff travel by foot near buildings located close to the construction site in the center of c the campus. Due to the extreme hazards of construction, the site plan was designed in such a manner as to minimally interfere with day-to-day routines of the campus, and to locate the primary construction area distant from high-volume campus traffic in an effort to maximize safety of the WPI community.

Social:

A main factor of the site plan design was to consider the social impacts of the construction on campus life. The site had to accommodate enough room for work, but also had to be situated correctly to avoid overtaking too much of the campus. One site plan considered, then rejected because of social impact had required the site to overtake half the quad. As the quad is a popular place for student to gather and interact, this social impact was unacceptable.

Another social issue considered during the site plan design was the effects of using both union and non-union laborers for the project. In order to prevent the labor unions from picketing the entrance to the site, a second entrance would have to be appointed for the non-union laborers.

A social strategy utilized in this project was integrated practice. The different members of the group met and worked directly with one another to ensure any changes were addressed quickly and correctly. Integrated practice was a cornerstone of this project and is discussed in more detail later in the report.

Political:

One of the few local political issues considered during the site plan design involved the possibility of using part of a nearby churches parking lot as an entrance onto the work site. WPI has worked with this church before but would need to come to an agreement with them to use their space.

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1 Introduction

Integrated Practice (IP) is a relatively new way to approach the design and construction of a building. Standard practices divide up work between disciplines and communicate on a need to know basis. While these standard practices have been proven to work, there is room for improvement. Integrated Practice seeks to promote collaboration among all involved parties through increased communication techniques. Through the use of integrated practices in the pre-construction phases of a project, errors, issues and changes can be made early and therefore reduces costs and speeds up construction. While integrated practice seems all well and good on paper, it has yet to be implemented in the construction industry. In fact, the first construction project utilizing IP in Massachusetts is currently occurring on the Autodesk Headquarters in Waltham, Massachusetts.[1]

Many companies are tracking this project in order to understand and try to overcome the challenges of implementing Integrated Practice into their own program. Most of the resistance to incorporating integrated practices into the industry simply comes from unfamiliarity with IP and little willingness to take risk. Integrated Practice is not an addition or a tweak to standard practices. It is a shift from having disciplines separated to working as a group. Many companies prefer the ability to defer responsibility to other parties and protect themselves, while IP puts every party in the same position. Thus if one part of the project fails, every party takes the blame. This closed-mindedness within the industry is the major hurdle

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[1] Sullivan, P. (2008, November 18). Autodesk to Open New AEC Headquarters in Waltham, MA Seeks Leed Gold Certification for Core and *Shell, Platinum Leed for Interior.* Retrieved February 25, 2009, from AEC Cafe: http:..www10.aeccafe.com/nbc/articles/view_article.php?articleid=619494

that IP must overcome. While IP has many advantages, this aspect is unappealing to construction companies and many are hesitant to implement it.

Worcester Polytechnic Institute promotes collaboration in the development of its construction projects, but it did not explicitly did not pursue IP in the development of its new athletics facility. It is commendable that WPI promotes IP and even exhibits features of IP in other projects, but due to time constraints, budget, and various other concerns with such a large project , WPI decided to not to take the risk of trying a new approach to construction WPI is in a great position to explore IP in future projects as identified in its Revised Strategic Plan.[2] Unfortunately, the decision to not take the risk and attempt an unfamiliar and untested method of construction is a typical response towards IP from most institutions and businesses. Without proper exploration and studies on how to properly implement IP into the construction process it will remain as a side note to the industry.

This Major Qualifying Project (MQP) is a limited exploration of how Integrated Practice can be implemented into the pre-construction phases of WPI's new Athletics Facility. The disciplines of construction management, cost management, structural engineering performed standard pre-construction tasks within the context of IP. By exploring and implementing various aspects of IP, and with the aid of Building Information Modeling (BIM), the project team sought to provide insight into the potential benefits and limitations of IP to the construction industry

[2] Revised Strategic Plan. (2009, April 8). Retrieved February 2, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/Admin/president/strategicplan.html

and from the results, provide recommendations on how IP can be properly implemented into other construction projects.

2 WPI New Athletic Facility

As Worcester Polytechnic Institute (WPI) continues its long term goals of expanding both its student body and facilities, the need for a new state-of-the-art athletics facility is now a top priority for the institution. The current facility is barely adequate for the continuously increasing student population, an issue that has been voiced by both the students and the faculty.[3] With high aspirations of continually revitalizing the experience of undergraduate education at WPI, planning, programming, and design for a brand new athletics facility began in the 2007-2008 academic year.

Worcester Polytechnic Institute is a NCAA division III collegiate athletics department consisting of nine men's sports varsity teams and nine women's sport varsity teams.[4] The WPI community also includes approximately two dozen club sports for students to participate and even create more with administrative approval. Detailed in the WPI Athletics Department Mission Statement [below], the university firmly believes in the overall development of their student body by encouraging all students to become involved in athletics and recreational activities.

"The Department of Physical Education, Recreation & Athletics is committed to promoting an appreciation for lifelong wellness, to fostering growth in leadership, encouraging the pursuit of excellence, and enhancing the overall experience for our students.

[3] Richardson, J. (2008, May 2). WPI Town Meeting for Faculty. (B. Blanck, & B. Sealund, Interviewers)
[4] *WPI Athletics.* (n.d.). Retrieved November 24, 2008, from Worcester Polytechnic Institute: http://wpi.prestosports.com/landing/index

We will provide an environment which develops health, work ethic, teamwork, leadership and integrity, all of which are essential for our students, both personally and professionally.

Through participation, our students will emerge well-rounded with the skill, knowledge and abilities to maintain active lifelong learning in order to help them be successful in life." [5]

WPI has established a large master plan of expansions and renovations to take place over the next ten years in order to improve the administrative, academic, housing, and recreational condition of the campus.[6] These improvements are designed to increase student enrollment, advance academic and research efforts, and maintain WPI's mission to integrate technology with the humanities.[7] Recently completed projects include the Campus Center, opened in the spring of 2001, the Bartlett Center, and the residence Hall currently named East Hall.

Construction of the two-level, 15,000 square foot Admissions/Financial Aid building, the Bartlett Center, was completed in 2005 at the cost of four million dollars. The Bartlett Center, shown in Figure 1 and named for the generous donations by the James and Shirley Bartlett, provides a beautiful and warm welcome to the WPI campus and was WPI's first Leadership in Energy and Environmental Design(LEED) green building.[8] With enrollment gradually increasing each year, the need for more on-campus living space for upper class undergraduate students was the next construction item on WPI's grocery list of expansions. Not long after the opening of the Bartlett Center, President Berkey and the WPI board of trustees announced the

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[5] *WPI Athletics Mission Statement.* (2004, May). Retrieved November 24, 2008, from Worcester Polytechnic Institute: http://wpi.prestosports.com/navbar_red/mission_statement/index

[6] *Revised Strategic Plan.* (2009, April 8). Retrieved February 2, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/Admin/president/strategicplan.html

[7] *Mission and Gaols.* (1987, October 16). Retrieved January 12, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/About/statements.html

[8] "*James and Shirley Barlett.* (2008, March 27). Retrieved January 12, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/About/Bartlett/bartletts.html

construction of a brand new five-story residence hall. Construction for the new, and also LEED certified, five-story, thirty-five million dollar residence hall. Following a fast track schedule, design started in the summer of 2006, demolition of existing buildings quickly followed in the winter of 2006-2007 with construction and ground-breaking in the spring of 2007. Currently named East Hall, Figure 1, it was successfully completed without time delays or budget overruns in August of 2008, ready for the arrival for the upper classmen for the 2008-2009 academic year.[9]

While the construction of new buildings provides modern-day designs and top-of-the-line materials and technology, major renovations to older facilities on the WPI campus is also being done to incorporate these upgrades. Current renovations include the biology and chemistry building, Goddard Hall as well as the close out on the renovation in the Science and Arts building, Salisbury Labs.[10] The major upcoming changes include the conversion of Alumni Gymnasium into an academic center, major renovations to Harrington Gymnasium, and the addition of an underground parking garage under the class of '93 Field.

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[9] *A New Experience in Student Housing.* (n.d.). Retrieved January 12, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/About/NewResHall/

[10] *Recent & Ongoing Construction & Renovations at WPI.* (2008, October 17). Retrieved January 14, 2009, from Worcester Polytechnic Institute: http://admissions.wpi.edu/Images/CMS/AO/Campus_Construction.pdf

Figure 1: Left - The Bartlett Center; Right – East Hall[11]

WPI's plan of expanding the campus facilities is extensive to say the least, but it was clear to the institution's executives that the Harrington and Alumni Gymnasiums were restricting not only the development of the university's athletic programs, but more importantly the fitness and athletic growth of the WPI community. Alluding back to the universities global initiative to attract more students, the construction of a new athletics facility would exponentially adhere to and help fulfill this goal. With the current main operating gymnasium and athletics center of the campus being one of WPI's original buildings in 1865, the construction of a new athletics facility quickly rose to the top priority of facility expansion.[12]

During the planning stages WPI's new Athletics Facility, the institution is faced with a financial hurdle with which it has not had to overcome during the construction of its previous facilities. Preliminary estimations have put the cost of constructing the new facility slightly above $40 million with added expenditures such as mitigation efforts. Currently the budget is not a fixed number but WPI is pushing to keep the design between to $40-45 million. As with

[11] The Bartlett Center. Photo taken April 2, 2008. East Hall Photo taken August 25, 2008.
[12] Richardson, J. (2008, December 3). (B. Sealund, & B. Blanck, Interviewers)

any new construction project, funding and financial planning is an important factor in regards to the project's success and development. The amount of funds available directly affects how a facility will look, and more importantly, if it will even be built. During the pre-construction phases of this project, an economic recession has jeopardized the planned construction of the new athletics facility. Even though the recession in the global market harms WPI's chances of funding this project, it also lightens the costs of labor, materials, and equipment. As a result of the poor economy, competition for fewer jobs among contractors increases, therefore they are bidding significantly lower prices as a method to gain work. On the other hand, financing is becoming more stringent which reduces the incentive of owners to take risks and start construction projects. With the help of construction managers, WPI can capitalize on this opportunity and thus reduce the direct costs attached to the construction of the athletics facility. [13]

Furthermore, the decision from the board of trustees to begin construction has yet to be made. WPI's design committee and stakeholders have decided to continue with the design phase of the athletics facility and will continue to monitor the financial situation as time progresses.[14] With the enormous financial obligations that the new athletics facility will bring, the institution must weigh the costs and benefits along with economic conditions before the decision to start construction can be made. The architectural design of the building directly influences the cost of construction and so it will be closely monitored by both WPI's design committee and Gilbane Construction Company in order to keep the cost within budget. While

[13] Benner, N. (2008, November 26). (T. Grant, A. Petrocchi, & R. Bernard, Interviewers)
[14] (2008, December 11). WPI Design Committee Meeting. (T. Grant, & B. Blanck, Interviewers)

the preconstruction process continues, all eyes are on the board of trustees to give the final thumbs up on the new athletics facility that so many people have been waiting for.

3 Literature Review

The development of a new building requires the personal efforts and skills of many professionals within the construction industry, as well as their willingness to work together as a team to complete the project. Architects, structural engineers, cost estimators, schedulers, financial accountants, contractors, and project managers all play major roles throughout the process. It is important for the reader understand how these divisions fit into the construction of a building, the roles they play, and how these parties must interact in order to produce a timely and efficient construction project.

3.1 Integrated Practice

There is nothing new about architects, clients, and consultants collaborating to produce a project that fits the owner's needs as well as fulfill proper functionality and costs. William Caudill, FAIA, of the firm Caudill Rowlett Scott, coined the term squatters in the 1950s to describe meetings between the architect, engineering consultants, owner, and users—on the owner's home turf before design began—to program, clarify values, and brainstorm design ideas. William Lam, the renowned lighting designer, who often worked with Caudill, says, "Rapport and sensitivity among individuals is essential so that meaningful dialogue can continue. An individual has to care more about results than his or her ego."[15] It is interesting to note that Caudill did not mention the use of a construction manager which reveals that construction managers have not always been part of traditional design practices.

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[15] Pressman, A. (2007, May). *Integrated Practice in Perspective: A New Model for the Architectural Profession.* Retrieved January 11, 2009, from Architectural Record: http://archrecord.construction.com/practice/projDelivery/0705proj-1.asp

The construction industry is becoming more and more complex every day because of more demand for faster construction, tighter budgets, and more MEP systems. The cultural change needed within many firms is not an integration of technology but an attitude change, an adjustment to collaborate effectively from the start of a project to the very end. Technology is just a tool that requires a conscious choice and competency to use. With the increasing complexities of construction projects, a better effort to collaborate, with the help of new technologies, is the next step forward for the construction industry. In the past the architects lead the way on most projects but today the process of construction has become much more complex which requires a new approach.

Integrated Practice (IP) is a relatively new term that seeks to enhance collaboration between parties and facilitate communications.[16] IP is a response to the construction industry's drive for buildings that are faster to design and construct, at lower cost, as well as more sustainable and of higher quality than those built in the past. IP also requires the construction manager (CM) to get involved in the pre-construction and design processes, instead of waiting until the final designs are completed. Building Information Modeling (BIM), a relatively new type of software that creates virtual smart models of buildings rather than drawing lines that represent an object, is enabling— some say forcing—this information-sharing, integrated-practice culture to emerge.

The advantages to incorporating integrated practice into the design and construction processes are numerous, but since the term is still in the infant stages many construction companies do not understand how to properly implement it and therefore disregard it.

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[16] Ibid.

Integrated practice allows for changes, issues, and problems to be addressed earlier in the construction process than normal practices. By addressing these issues earlier the overall project can be constructed faster and with less RFIs and change-orders. These RFIs and change-orders are the bane of many construction projects because they add time and cost money which often brings the cost over the original budget. Since IP is still young in development there are no specified ways to implement its practices and where it fits into the construction process.

Figure 2 below depicts how BIM Modeling, which forces integrated practices, fits into the scheme of the construction process. Any project begins with the "discovery" of a need for a building. During the pre-construction process of design, BIM Modeling helps articulate aspects of the design to various parties as well as address issues related to construction planning. BIM Modeling is also used during the construction phases of the project as a reference point for superintendants and managers alike.

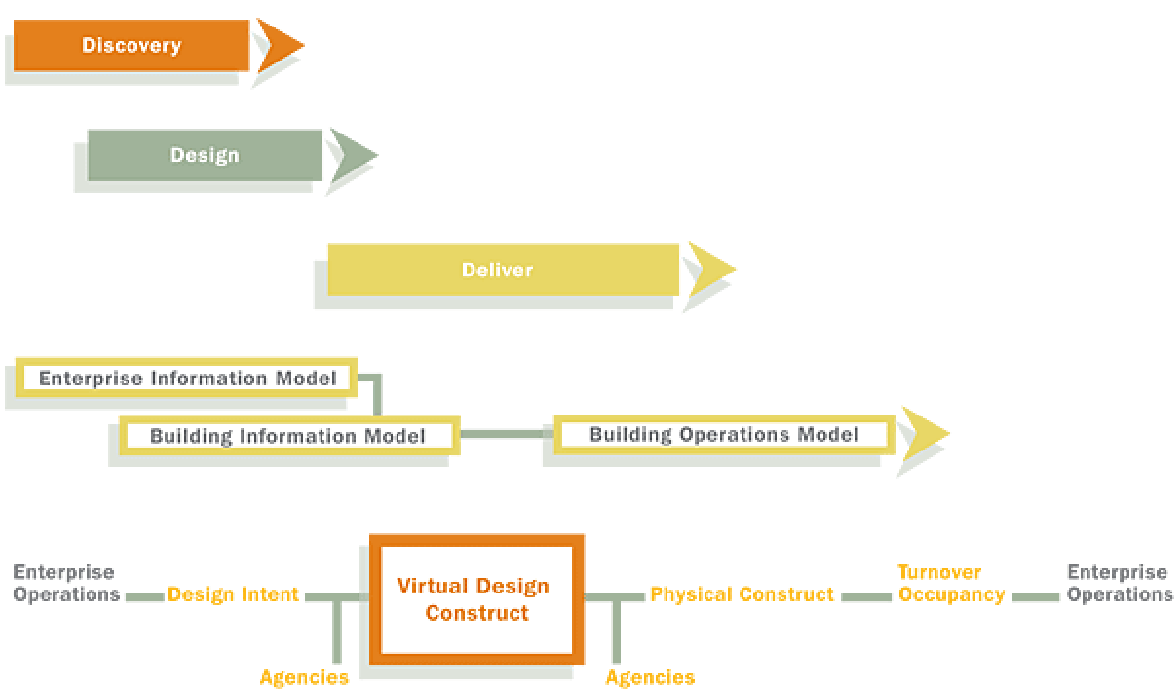

Figure 2: BIM Outline[17]

3.2 Building Information Modeling

The development of any construction project requires extensive communication among owners, architects, engineers, project managers and contractors. Each of these parties' duties vary greatly and their knowledge is rather confined to specific tasks. This increases difficulties in communications, and when communications break down mistakes are made. However, there is a push towards the integration of these parties in order to facilitate communications.

Building Information Modeling (BIM) is a relatively new process for the construction industry that is slowly gaining popularity. BIM was developed in the late 1980s to incorporate three dimensional modeling, real-time development, spatial relations and more recently geographical information. Although the origin of BIM is debatable, it is agreed that it was popularized by Jerry Laiserin in Graphisoft's ArchiCAD software.[18] BIM can be used to examine the life cycle of a building, incorporate materials of construction, define scopes of work, and display the systems of a building. The most important aspect of BIM is that it promotes integrated practice between parties involved with a construction project. Although BIM is a powerful tool for the industry it is not used by many companies. Like any new addition to an already functioning industry, BIM requires time to become a mainstay of the construction industry.

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[17] Mueller, V. *BIM Modeling in the Construction Process.* AIA of NBBJ.

[18] Laiserin, J. (2003, January 19). *Comparing Pommes and Narajas.* Retrieved January 25, 2009, from The Laiserin Letter: http://www.laiserin.com/features/issue15/feature01.php

BIM has been defined by the AGC as "an object-oriented building development tool that utilizes 5-D modeling concepts."[19] However BIM is much more than a modeling method. BIM has evolved into a method to bridge communication within the architectural, structural and construction industries. In order to make this bridge BIM encompasses many different software packages. Although each software package is unique, they all strive to offer similar components:

- Improved 3D visualization
- Support 4-D (Time), or 5-D (Cost) Models through interoperability between cost estimating/scheduling software
- Coordination of construction documents
- Simple retrieval of vital information such as materials, dimensions, etc
- Increased speed of delivery

BIM is a tool to enhance the integration of the different aspects of a development and increase communications between the parties involved. In this project we utilize Revit, an Autodesk BIM software package, to increase communications, collaboration and exemplify project integration.

Currently AutoCAD™ is the mainstay drafting tool of the construction industry and has proven to be quite resilient. Many companies in the industry express concern that using BIM

[19]Khemlani, L. (2006). *Contractor's Guide to BIM.*

modeling means retraining workers and revamping practices. In a response to BIM/Revit's 2003 proposal for the construction industry Bentley Systems Incorporated, a software engineering company, expressed that starting over with a new software platform is not an option. This report expresses that the construction industry is too heavily dependent on AutoCAD and that an overhaul of the system will not work.[20] There are several other BIM software packages available, such as ADT or Triforma, but Autodesk's Revit has become the front runner. While it is true that the construction industry is very dependent on AutoCAD, BIM and Revit are still evolving.

Revit is simple enough for owners to understand yet sophisticated enough for architects and engineers to design with. The program is capable of creating detailed documents that meet the standards of the construction industry and at the same time it creates 3-D models that a person outside the construction industry can easily visualize. Currently AutoDesk has produced three distinct versions of Revit: Revit Architecture, Revit Structure and Revit MEP. Each of these packages is based on the same software, but they each have unique capabilities. Revit Architecture has increased customization capabilities allowing architects to create any type of object. Revit Structure has analysis capabilities for structural engineers. Finally Revit MEP provides information to design MEP systems for a building before it is built. These three software packages are interlinked which allows users to overlay architectural, structural and MEP designs on the same model. Many times there are discrepancies between designs, owners' needs and information provided to contractors. By utilizing the same platform of

[20] Bentley, K. (2003). *Does the Building Industry Need to Start Over?* Bentley Systems Incorporated.

communication these differences can be found and dealt quickly with before they become a problem.[21]

Among the many facets of construction, Revit is gaining the most ground with architects. Dr. Lachmi Khemlani, a consultant and author of *Autodesk Revit: Implementations in Practice*, said,

> "The parametric building modeling technology of Revit...has revitalized the architectural profession and brought the fun back into design. Those who have persevered in their learning and use of Revit have come to love the application and find it anathema to go back to traditional CAD. For them, the practice of architecture will never be the same again."[22]

In the book, *Autodesk Revit: Implementations in Practice,* Khemlani documented several case studies of architecture firms who just introduced Revit Architecture into their company, such as Cannon Design, the architectural firm for WPI's new Athletics Facility. User reports from these firms confirmed an increased level of service, quality and performance for their clients. Among these companies over half reported productivity increase of 50% and 17% of the firms reported productivity gains over 100%. In addition to the increased efficiency firms reported reduced errors because of Revit's automatic coordination capabilities. It also reduced the frustrations between project designers and IT support.[23]

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[21] Balding, J. J., & Fox, C. (2007). *Introducing and Implementing Autodesk Revit Building.* Cengage Delmar Learning.

[22] Khemlani, L. (2004). *Autodesk Revit: Implementations in Practice.* Case Study.

[23] Ibid.

This software also supports construction management capabilities. Most construction management firms require an entire department to scour over drawings and develop estimations for a project. Much of this work, such as counting every instance of windows and doors, then referring to encyclopedia sized specifications for instructions, is painstakingly done by hand. Since Revit is object based, it can easily create schedules that count objects, total costs, and link to specs, which drastically cuts down on the time needed to make these estimations. It is interesting to note that the CM for the athletics facility, Gilbane, is using Revit to some extent for construction management functions.

Through the utilization of BIM modeling, the construction industry can become much more efficient. The use of BIM modeling promotes increased communications among parties, reduce discrepancies and provide owners with tangible evidence of the progress of their development. This project strives to explore aspects of BIM.

3.3 Construction Project Management

The Construction industry is one of the largest and most important industries affecting the world today. The products of the construction industry can be seen everywhere. From the residential homes, to commercial office buildings, to industrial factories, the construction industry is responsible for almost every building known to man. Not only does the construction industry build buildings, it also is responsible for the infrastructure of any country, i.e, roads and bridges. The construction industry is not just a single job. It incorporates workers and scholars of all backgrounds to keep the industry functioning.

Construction in itself is a process to create a finished product; a building or road, on schedule. Construction is a detailed and extensive collaboration among people, materials, equipment, time, and money. The efficiency of the process of construction directly relates to the efficiency and state of the resources used to drive this process, as well coordination of resources. Similar to any other processes, construction needs to be managed. It is very difficult for an untrained party to coordinate the involvement of many different people of varying skills to meet working standards, government laws, company guidelines, time deadlines, and financial quotas. Thus, construction management has become a very important role in the construction industry. It is the duty of construction managers to ensure that the project is completed in the most efficient and convenient manner while keeping the clients' best interests in mind – and it is during the pre-construction phase that this process, and its results, can be most influenced.

Every construction project, whether large or small, entails at the very least, the involvement of a project owner, a designer, and a builder[24]. While the titles and magnitude of responsibility may fluctuate, their duties are rather self-explanatory, and the relationships between each of them are essential to the construction of a facility.

All projects are driven by the owner's incentive and initiative to build a new facility. Once the owner decides that a new facility is to be constructed, it is then time to begin appointing a team that will assist in the development of this facility from project conception to opening. The

[24] Nunnally, S. (1980). *Construction Methods and Management.* Prentice Hall.

owner must have clear and accurate project objectives to relay to the other team members – most importantly the designer.

These project objectives may be derived and composed in several manners. In projects where the owner decides to assume a more active role, the owner may take on full responsibility and self-compose the master plan with all objectives for the project. Another approach builds upon the previous method in which the project owner will appoint a team, usually being people whom he/she has a business relationship with, that will assist in developing the project objectives. In these scenarios, the owner is very involved in the project development at the early stages and plays a major role in making decisions. A step away from the intense involvement of the owner occurs when he/she hires an agent to oversee the entire project. This agent will work for the owner and be granted a large amount of responsibility. In this scenario, the agent must carefully make decisions and understand that ultimately, the owner has the final word. Once the owner has established the proper relationships, then the master plan and project objectives can be further developed in the next phase of the project: the design.

The primary responsibilities of the designer are to deliver an architectural, structural, and mechanical/electrical/plumbing (MEP) solution to the owner based on the project objectives that have been developed. Several meetings with the owner, as well as extensive preliminary research of the site are conducted by the architect. This is done to ensure the design will serve the owner in the most productive manner possible. The architect must a have a thorough understanding of the owner's objectives of the project, as well as their cost and schedule limitations. These two factors will greatly affect the design product.

Once the designer feels confident in their background knowledge and has a good understanding of what is requested by the owner, it is then their responsibility to produce a design. The design is often presented in phases: a conceptual design, a schematic design, and a detailed development design. One phase builds upon the one preceding it and takes into account the modifications and opinions that are continuously presented until the project is constructed. Most construction begins once the detailed design is completed, but in some cases construction may occur earlier.

Throughout the construction phase of the project, it is the often the architect's responsibility to act as an agent to the owner to ensure the building is being is constructed according to the drawings and specifications that have been set forth. While this type of relationship fluctuates based on the contractual regulations of the project, it is most often in the best interest of the owner to have an architect serve as an agent, to ensure construction accuracy and quality. The architect shall remain as an agent throughout the lifetime of the construction of the project, maintaining a relationship with both not only the owner, but the contractor and construction manager to complete the project and meet all specifications, design criteria, time and cost limitations, and overall objectives.

For projects being completed using Construction Management services, a professional construction manager is most often hired during the pre-construction phase of the project. A construction management firm has a broader understanding of the construction of facilities and can be a positive influence to the design of the project. It is often very important that the construction management firm has a thorough understanding of the development of the design, as well as its key components. The integration of owner, architect, and general contractor/construction manager will prove to be a very crucial matter throughout the development of the project.

Project Management is defined as the art and science of coordinating people, equipment, materials, money and schedules to complete a specified project on time and within approved cost."[25] Pertaining to construction, professional construction management unites a three-party team consisting of the owner, designer, and construction manager in a non-adversarial relationship.[26] This three-part team works together under the limitations of people, equipment, materials, money and schedule, to produce an Architectural/Construction/Engineering product. The degree of collaboration among these three parties is essential to the development of any project. It is important that each member understands that they are a crucial part of the project and that without the other, success is impossible. While each party may have a thorough understanding of their duties and required contributions to the project, miscommunication and lack of properly presenting information can cause more severe issues within the project, including cost overruns, schedule overruns, adversarial relationships, and design flaws.

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[25] Oberlender, G. D. (1993). *Project Management for Engineering and Construction.* McGraw-Hill.

[26] Barrie, D., & Paulson Jr, B. C. (1978). *Professional Construction Management.* McGraw-Hill.

Due to the fact that no two Architectural/Construction/Engineering projects are alike, the duties of a construction project manager are never pre-determined. Their role and responsibilities are dependent on the project scope, as well as the contractual relationships between the parties of the project. However, in a broad sense, the duties of a construction manager can be broken down into seven categories[27].

- *Project Planning Management* – this entails planning of the overall project. The construction manager creates an overall plan and a method of how to successfully meet the requests of the owner. Analyzing the owner's project objectives to develop a more specific project scope is a key task. This scope will then be implemented through the process of construction project management.

- *Time Management* – the construction manager must continuously be aware of the schedule requirements and trends - making sure that all deadlines are met. This entails creating preliminary schedules, tracking the work as it progresses, presenting periodic schedule reports to the owner, and assessing if the project is ahead of schedule, on schedule, or behind schedule.

- *Cost Estimation and Management*– Cost control is a primary concern of the owner. The construction manager must create their own cost estimates; keep an up-to-date track of the costs and expenditures of the project; make sure that all charges are accurate; present the owner with periodic cost analysis reports that assess whether the project is

[27] *Outline of CM Functions.* (n.d.). Retrieved March 4, 2009, from Construction Management Association of America: http://cmaanet.org/outline-cm-functions

under budget, on budget, or over budget; present cost trends to the owner and provide recommendations on how to remedy any problems.

- *Quality Management* – It is the duty of the construction manager to ensure that the sub-contractors are performing according to the specified details, building codes, and construction standards.
- *Contract Administration* – The construction manager is often contractually related to the sub-contractors involved in the project. This makes the construction manager responsible for the sub-contractors' quality of their product, the time in which they deliver their project, the cost of their product, and more.
- *Safety Administration* – Safety is of extreme concern in the construction industry due to its dangerous conditions. Safety ratings of the construction management firm are significant factors in developing a positive reputation. Projects can be stopped and ceased due to the potential costs of severe accidents that take place on site. It is the responsibility of the construction manager to perform periodic accident reports and on-site inspections to ensure all safety standards are met.
- *Professional Practice* – In essence, this duty is "people management" to ensure that the project runs smoothly and efficiently. Here the construction manager organizes and leads the project by implementing project controls, defining roles and responsibilities, and developing proper communication protocols. The CM also takes on the responsibility of identifying elements of project design, project construction, and contract administration likely to give rise to disputes and claims.

An extensive process takes place in hiring a construction management firm. The firm can be introduced to the project in one of two ways – by negotiation, or via a proposal and bidding session. Negotiation is limited to private projects only, and results in the owner choosing the firm to construct and manage the project. This negotiation process is often the result of a lasting relationship between the owner and the general contractor or construction management firm. If the owner decides to bid out the project, a requirement of all public projects, an invitation to bid is sent out to various general contracting firms or construction management firms who will then choose to accept the invitation and create a bid proposal.

If the invitation is accepted, a bid package is sent out to the firm which specifically details the project objectives, deadlines, conceptual designs, and project limitations. At this point, the general contractor or construction management firm composes a bid package to be presented to the owner in an attempt to win the project. In compiling this package, the firm must convince the owner that they are the best suited firm to manage the project and provide extensive information to the owner in an attempt to prove this point. To do this, the firm will gather background knowledge of the area in which the project is being constructed, research secondary logistics that the project is concerned with, explain their experience with similar projects, prove to be financially stable, and produce a cost estimate with a schedule that will meet the requirements of the owner. All firms who have submitted all materials as requested will be reviewed and some will be allowed to present their information in-person. Based on all this information, the owner will then choose the firm to manage and construct the project, at which point, the contract is discussed, awarded, and finalized.

When a construction management firm is hired, they are contracted on an “at-risk” or “no-risk” basis. A CM not-at-risk contract is typically formatted in the following manner:

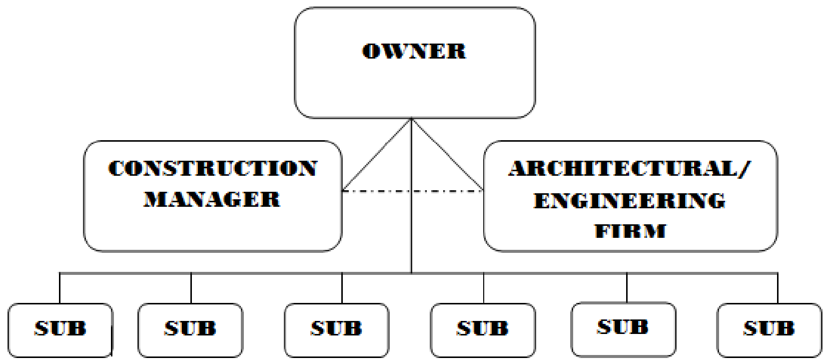


Figure 3: CM at No-Risk[28]

In this format, the owner has separate, direct contractual relationships with the Architectural/Engineering firm, the Construction Management firm, and each of the subcontractors involved in the project. Although they work with one another very closely, the construction management firm and architectural/engineering firm do not have a contractual agreement between them. Under a “no-risk” contract, the CM firm acts as an agent to the owner and is released from the financial and scheduling obligations, with the subcontractors. It is the owner’s responsibility to ultimately negotiate all contracts with the subcontractors, usually with advice from the construction manager. However, the construction management firm does hold the responsibility of executing the contracts that have been negotiated with the owner. While the construction manager may not be at a direct financial loss for mishaps with the sub-contractors, their reputation for successfully managing projects is at stake.

[28] Barrie, D., & Paulson Jr, B. C. (1978). *Professional Construction Management.* McGraw-Hill.

Construction management firms involved in non-risk contracts typically charge a fee to the owner for their services. This fee may be a lump-sum price or a percentage of the project cost.

Construction management "at-risk" contracts result with the CM firm holding complete responsibility for the coordination of the project, as well as the project cost and schedule. A CM at Risk relationship is set-up as follows:

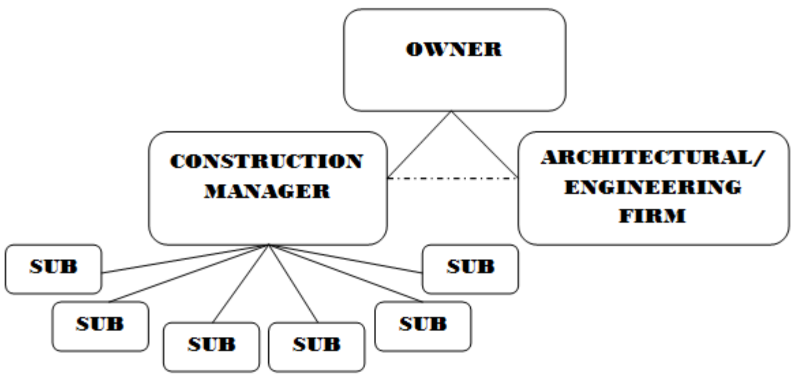


Figure 4: CM at Risk[29]

Here, the owner has a direct contractual relationship with the construction management firm, and the architectural/engineering firm. It is important to note once again that, while the construction management firm and architectural engineering firm work closely together throughout the entire project, the two organizations do not have a contractual relationship. As the above figure represents, the CM firm has direct contractual relationships with all subcontractors involved in the project. The subcontractors are hired and managed by the construction management firm, and it is the responsibility of the construction managers to

[29] Ibid.

ensure that these contracts are performed as specified. As a result of these relationships, the construction manager is entirely responsible for cost and schedule commitments. Therefore, if the sub-contractors do not perform under their contractual obligations, the construction management firm will suffer from all cost and schedule overruns. These obligations make many construction management firms performing under "at-risk" contracts create agreements with the owner to complete the project at a Guaranteed Maximum Price (GMP). Under a GMP, the construction management firm ensures the owner that the project will be completed for no more than the specified maximum price. It is the construction manager's responsibility to ensure this contractual arrangement is met, and if not, they will suffer the losses. The Construction Management firm is compensated for their services based on a negotiated fee with the owner.

There are many benefits to taking a construction management approach within the construction industry. The simple fact that an experienced professional is managing the project is the greatest benefit – most especially during the pre-construction/design phases of the project development. The professional construction management firm has the resources and knowledge to properly handle all situations within the project and execute the job in the most efficient manner. An added benefit of having a construction manager on-hand, is that there will most likely be an overall time reduction of the project which can greatly affect the projected cost.

Benefits of a construction manager are both prominent and very influential to the project during the design phase. The construction manager is available to provide construction expertise and knowledge in areas where the architect does not have a clear professional authoritative knowledge of the situation. With a construction point-of-view as a resource, the designer can avoid taking the time to develop an idea and design component that is not feasible for construction. In preparation of construction, professional construction manager develops site plans and constructability reviews that will faucet construction approach best suited for the building and construction scenario. This service, acting not only as a means of increasing the efficiency with which the building is constructed, but also researches any major issues which may potentially force the owner into re-evaluating his decision to build. This opportunity for the owner saves extremes amount of money when compared to situations where major issues are discovered once the construction phase of the project has already begun.

Besides their expertise in constructability, construction managers also provide the owner with cost and schedule estimates. These estimates provide a characteristic gauge for the life-cycle of the project development. This service allows the owner to have an early understanding of the approximate length of time the project will take to complete, the associated costs, the relationship between the two, and, any possible infringements that may force either prediction [cost or time] to stray from its estimated track. From the owner's side, the construction manager is a professional consultant with binding responsibility, and shoulders some of the risks involved with construction. The construction manager also has professional experience with the interaction of sub-contractors which results in better cost control and a much less risk of overruns from sub-contractor issue

At the end of a project, the Construction Manager is responsible to ensure that all aspects of the project were carried out and completely properly and as per the requests of the owner. As a benefit to the owner, the contract of the Construction Manager is continually binding until all requirements are met and the owner is fully satisfied.

3.4 Structural Engineering

Many consider the Colosseum in Rome to be the first athletic facility. Constructed between 80 and 96 A.D. it housed many sporting events including chariot races, naval battles, and gladiatorial combat. Built with blocks of solid travertine, the Colosseum was built with little explicit consideration to structural analysis. The building was constructed using overly large stone blocks which guaranteed that the building would stand. These examples imply a primitive sense of structural design and analysis. A huge supply of material and a bloated budget made this feat possible. As the available materials and financial constraints changed, structural analysis became more important. Modern athletic facilities are constructed of many different materials that rely upon proper structural analysis to obtain the greatest strength from the economical components.

The structural branch of civil engineering was one of the earliest to distinguish itself. Structural analysis can be found as early as 1638 when Galileo's "Dialogues concerning two new sciences" was published in Holland. In this manuscript he reviewed experiments concerning the strength of materials in different construction situations such as cantilever beams and simply supported beams. Truss analysis can be found as early as 1826 in the French engineer Navier's published work "Leçons". One of the topics discussed in this work was the analysis of a truss with three bars and a single redundancy. Through his study he established some of the earliest truss analysis equations.

The profession of a structural engineer is to use mathematical calculations to satisfy the design criteria of a specified brief. Although most well-known for the design and analysis of buildings, this profession is much broader. Structural engineers may also work on projects involving bridges, tunnels, dams, or even submarines. They are also not restricted to just projects before or during initial construction, but also work on the renovation of historical buildings in need of restoration.

When designing a project, a structural engineer is not only responsible for computing the most cost efficient solution for the owner, but more importantly is responsible for the safety of the users of the design as well. This makes it imperative for structural engineers to not only adhere to the local building code during the initial design, but to ensure the structure still remains true to it after any revisions. One example of substandard work is the Hyatt Hotel disaster of 1981 in Kansas City. One of the most attractive features of this new hotel was the aerial walkways that spanned the lobby. There were three suspended walkways in all, one on each of the second, third, and fourth floors. The walkway on the second floor was placed directly beneath that on the fourth. The design conducted by Jack D Gillum& Associates called for two W 16 X 26 beams to cross the lobby connected by box beams created from pairs of MC 8 X 8.5 beams welded toe-to-toe. The initial design had these walkways secured individually by a series of rods hung from the ceiling, Figure 5. During construction a series of calls were conducted between the engineering firm and the fabricator, the Havens Steel Company, to revise the design from a single hanger rod system to a double hanger rod system.

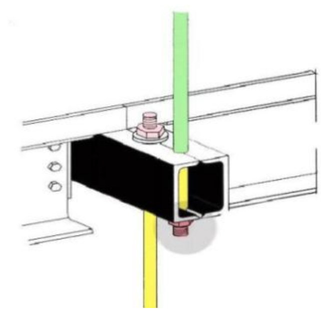


Figure 5: Double Hanger Rod System

As shown in Figure 5Figure 5the double hanger rod system involved hanging the second floor walkway from the welded cross beams of the fourth floor walkway instead of hanging it from the ceiling. Although this was thought to reduce the complexity of the construction process it also effectively doubled the load on the fourth floor box beams.[30]

On July 17, during a large dance event, the connections failed on the fourth floor walkway resulting in a catastrophic collapse killing 114 and injuring more than 200 more. In the following investigation it was discovered that the hanger rod connections were not designed to hold the loads specified in the Kansas City Building Code. The initial connection design of hanging the walkway from the ceiling could only hold approximately 60% of the load required by the code and the revision only compounded the problem. As a result of this incident Daniel Duncan and Jack Gillum, the structural engineers for the project, were found guilty of gross negligence, misconduct, and unprofessional conduct in the practice of engineering. They were

[30] *Hyatt Regency Walkway Collapse.* (n.d.). Retrieved November 9, 2008, from Engineering.com: http://www.engineering.com/Library/ArticlesPage/tabid/85/articleType/ArticleView/articleId/175/Walkway-Collapse.aspx

subsequently stripped of their engineering licenses to practice in Missouri or Texas. G. E. C. International, the father company to Jack D. Gillum& Associates, was also found guilty of these charges and its certificate of authority as an engineering firm was revoked.[31]

Figure 6: Hyatt Regency Walkway Collapse

As depicted in the Hyatt Regency Hotel incident, each project is unique and has specific problems that must be solved. In this MQP the ceiling trusses of the natatorium were chosen for design. Following the trend of multitudes of previous projects, this design came with its own unique problems. Since these truss systems spanned over the pool they were subjected to conditions different from other recreational areas. The air was more humid than most areas and corrosive vapors, such as chlorine, were present in much larger quantities. This situation also required the trusses be able to provide support over an open span of at least seventy-five feet. Another uncommon aspect was that a gymnasium was located directly above it. This

[31] Ibid.

caused the live loads to be much greater than in other cases. A few solutions for dealing with these issues included using appropriately sized beams within the trusses to provide enough support to satisfy local, state, and national building codes and coating them with an anti-corrosive paint.

3.5 Budgeting, Investment Analysis, and Community

The goal of every academic institution is to provide students with the best higher level learning opportunities available, but every institution needs funding to function. There are many avenues to attain funding for a university but in the case of a private college much of that money comes from student tuition. If a university cannot provide adequate facilities for students how will it support academic and social functions? No matter how a person looks at the situation, except for some well-invested schools such as Harvard, a university needs student tuition to finance the rest of school's operations.

School facilities serve an important role in influencing students' choice of which university to attend. Though academic factors will always serve as the primary decision maker, facilities do provide some additional pull for schools to bring in new students. According to a study done by Matzdorf, Smith, and Agahi, depending on the institution, facilities can play a major role in a student's choice of university.[32] The study shows that reputation and facility quality serve as two different factors in college choice, where the weight of each factor depends upon the school itself and the public's overall view of said school. The general physical appearance of the facilities caused their importance in students' minds to increase. This means

[32] Matzdorf, F., Smith, L., & Agahi, H. (2003). The Impact of Facilities on Student Choice of University. *Facilities*, 21.10.

that the more modern and clean facilities of a university are, the more of an impact they will have upon student enrollment.[33]

The new athletic facility can serve an important role in the development of not only the WPI community but the surrounding areas of Worcester as well. Though there have been studies proving that there is no statistically significant correlation between newly constructed sports facilities and local economic development, promotional studies usually state just opposite.[34] Promotional studies refer to literature written to strengthen the public's view of their own respective facilities using selective evidence. These studies refer to professional level sports arenas, such as Fenway Park or Yankee Stadium, not smaller facilities of institutions and their local communities. For relatively small facilities such as the one WPI is planning, the negative impacts discussed by these studies are negligible. This new facility will add to the recently renovated look of the campus already provided by the Bartlett Center and East Hall dormitory. The more attractive a campus, the more the community will enjoy campus and the area around WPI. The new athletic facility can only bring help to the community. Local camps and groups will be able to rent the gym space for use during the summer, using it however they see fit. Summer athletic programs may use the facility for practice or game space. While the new athletics facility serve many functions on campus and possibly generate some revenue, gaining funding such a large project can stop it before it gets off the ground.

There are many ways in which organizations generate funding for capital projects. One such way is through alumni donations which account for a significant part of funding. Alumni

[33] Ibid.
[34] Siegfried, J., & Zimbalist, A. (2000). The Economics of Sports Facilities and Their Communities. *Journal of Economic Perspectives* , 14.3.

donations help to pay for other items such as scholarships and professorships. Donations can range from 100 dollars to legacy gifts. A legacy gift is one in which a person donates a portion (usually 10 percent) of their net worth to the organization after their passing away. Another way in which organizations fund new projects is through tax exempt bonds. Not for Profit (NFP) organizations such as WPI can issue these bonds to be traded on the market. The way these bonds work is since WPI is NPF the interest paid to the bond holders is exempt from both Massachusetts state tax as well as federal tax. WPI also pays a lower interest on these bonds since it is a NPF organization. While WPI is an institution that wants its facilities to be up to date and technologically advanced within the realm of financial feasibility, it also needs to be aware of its impact on the health of the people using those facilities.

In today's world the health of the natural environment is important to everyone, including institutions. We as the human race have a responsibility to try not to pollute the planet in order to sustain our current environment. LEED or the Leadership in Energy and Environment Design Green Building Rating System will be used to rate the new athletic facility. The goal of LEED certification is to reduce the negative environmental impacts a building may have on its environment; as well as improving the building's occupants' health. This rating system has four levels of certification: Certified, Silver, Gold, and Platinum. These are achieved through five different green categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources and indoor environmental quality.[35] It is important that the new building obtain the highest rating possible in order to show that the Institution is interested in environmental sustainability. Environmental sustainability is an important subject

[35] U.S. Green Building Council. (2005). *LEED for New Construction & Major Renovations (Version 2.2).* U.S. Green Building Council.

that everyone considers in order to continue living on this planet. If we do not try and sustain our current environment then the Earth will deteriorate. The higher the LEED rating, the more the institution will show that it is interested in “green” projects. This higher rating denotes an increased performance in the building’s environmental sustainability through the use of recycling technologies and better construction practices. Certified buildings are receiving marketing exposure through the United States Green Building Council (USGBC) Web site, Greenbuild conferences, and media announcements. There are also an increasing number of state and local government incentives such as tax breaks available, depending on the level of certification.

4 Methodology

This MQP incorporates various tasks and ties them together within the context Project Integration. Every individual both led specific pre-construction tasks and constantly collaborated on group work throughout the project. The five major topics of work that this MQP includes are Integrated Practice, Construction Management, Structural Engineering, BIM Modeling, and Cost Analysis. It is important to note that even though each member has different training and individual tasks to complete, everyone was working on the same project with the same goals in mind.

4.1 Integrated Practice

In order to complete the project within the context of integrated practice, the project team first defined various integrated practice activities and programs before splitting up into individual tasks. It is important to note that these programs were designed and implemented before actual work on the new athletics facility began. These programs, along with BIM practices, were designed to force collaboration among the team members.

The various methods the project team implemented included the use of technology, scheduled group meetings, and individual meetings. The project team used the myWPI website where project members posted information for all to examine and collaborated on materials hosted. Weekly meetings were scheduled in order to force communication among members and keep the project on schedule. These meetings became increasingly frequent as the project progressed, in parallel the increasing amount of work the project entailed. Lastly the individual meetings were performed outside group meetings and were more focused on specific tasks that required input from different disciplines, such as the design of the truss system which required the attention of the structural engineer and BIM modeler.

4.2 Construction Management

In any preconstruction process, there are several professional tasks that must be executed by the construction manager during the early phases of design. This student project concentrates on the following: site plan, project schedule, constructability review, and the use of union vs. non-union labor.

The site plan is an important issue with regards to any construction project. For the construction of the WPI new Athletics Facility the design of the site plan requires additional attention due to the added considerations of volume of traffic throughout the college campus – thus making safety an important matter of business. With reference to literature used within the academia and professional realms, several site plan alternatives have been designed as options during the construction phase of the actual project. As a topic for project integration, the site plans were analyzed with a final site plan providing the best compromise of the issues chosen.

A project schedule has been composed to provide deadlines to move the project along as time passes. The schedule includes the planning and programming phase, design phase, construction phase, and post-construction project closeout. Combined with their working knowledge of construction-task durations, the team analyzed the schedules of similar, previously-completed facilities to compose the schedule of the WPI new Athletics Facility. The schedule accounts for all possible concerns that may affect the efficiency of the work.

A constructability review of the site was conducted to properly acknowledge and become aware of the standing issues related to the feasibility of construction the project design. Major considerations for any construction project lie within the general topics and concerns that constructability reviews encompass. The project team consulted a guidebook, written by professional consultants, in order produce a constructability review of the WPI new Athletics Facility. The results and general conclusions generated from the constructability review were considered during the design phase of the WPI new Athletics Facility.

The use of Union vs. Non Union labor was researched to determine the benefits and downfalls of hiring one versus the other to complete work on a building. The typical contractual stipulations associated with these parties were analyzed with consideration to the early stages of the project development and the design process. The financial obligations and managerial obligations associated became the prime area of research and comparison.

4.3 Structural Engineering

The project team's discussions involved the design of the supporting structure for the floor above the large new natatorium arose. A large truss system with A-36 structural steel was designed to accommodate the gym floor above. The use a long girder to support the ceiling was also considered as an alternative solution. However, this was not used because of the ridiculously large beam size it would require. Due to the truss being in a high humidity area wood was quickly eliminated as an option. Synthetic materials were also considered though their higher price was too high given the limitations of the building's budget. A-36 steel was selected for the truss members because it is a common steel type and can withstand reasonable weather conditions, including heat and humidity, with little or no extra weatherproofing.

Joists were also deemed necessary to provide stability to the floor slabs between the trusses. Joist size selection was based off of the dead load of the floor and the maximum load capacity of each type of joist. A-36 steel was used again here to simplify the connections between trusses and joists.

The most important references used during this portion of the project were the Massachusetts State Building Code and the ASCE 7 manuals. These references included vital information regarding expected loading patterns, regional building regulations, and load combination equations.

4.4 Building Information Modeling (BIM)

Though BIM is a relatively new practice for many construction companies it was incorporated it into the pre-construction processes of this student project in order to explore its uses and challenges. In order to develop preliminary cost estimates, scheduling and feasibility analyses, the project team assumed both the role of an architect and a construction management firm. The design process involved a constant dialogue between the group members in order to address any concerns that arose. Every section of work in this project either directly or indirectly influenced another. This constant influence required us to work very closely with one-another. In order to create the BIM model a simple design cycle was conceived that encompassed several checks and balances.

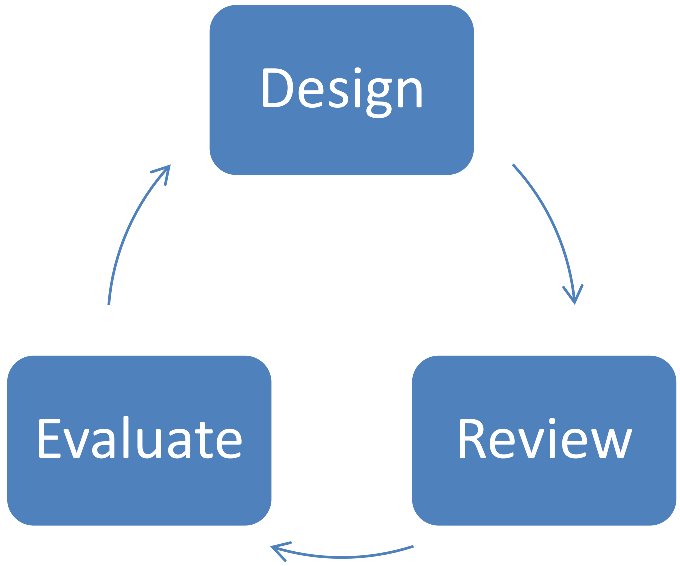


Figure 7 BIM Chart 2

This process was applied to every facet of the BIM Model; from the design of trusses to the building's layout on the site plan. Examples of this interactive process are described in the Results section below.

Considering that the design process was a constant ebb and flow of changes we used the model to construct two major and several minor quantity take offs with varying accuracy. As the project scope was gradually defined the estimates became increasingly accurate. These estimates were then compared with the budget and the building design was changed accordingly.

4.5 Cost Analysis

Two major preliminary cost estimates were performed from the Revit models produced by the project team. The first estimate was based on a square footage estimate from massing models, and the second, more accurate, estimate was based on a rough schematic design Revit model. In order to estimate the cost of the building several key items must be determined: the size of the building, geotechnical soil reports, the cost of materials based off of current market values, labor costs, and the project scope. In today's economy it is important for plans to be made to make sure the project is feasible.

A large source of information for the project group was historical data and interviews. Historical data provided a basis for preliminary cost estimate with an accuracy of +30% to -20% for a conceptual design. An example of historical data research was how the project group determined the cost of materials from similar completed projects around the country, Gilbane Construction Company, Cardinal Construction, and the RS Means data. Interviews helped take historical data and refine it to be more accurate within the context of the current project. Multiple face-to-face interviews were conducted with key personnel related to the actually construction project. The interviews were accomplished using open-ended questions leaving much time for the interviewee to delve further into any subject they felt was important.

Lastly the project team examined the probable maintenance costs of the proposed facility and researched the impact LEED certification can have over the life cycle of the building. These analyses were completed through interviews and research into the constantly growing movement of green building and design.

5 Integrated Practice

In order to explore the concept of integrated practice, the student project team identified different roles and developed an internal organization and coordinated their activities in an integrated fashion. Organized collaboration and efficient integration became the foundation upon which the project team formulated its solutions and results of the new WPI Athletics Facility MQP. The student project team incorporated integrated practices into the pre-construction tasks of planning, design, organization, project management, and analysis. In order to combine and relate each aspect of the project, the team established several systematic methods of collaboration which allowed for efficient communication, organized file exchange, efficient problem solving, and supportive use of resources.

The decision-making process for the WPI new Athletics Facility MQP team, although rather simple, was effective. Being efficient can be described as the strongest combination of effectiveness and use of time. Thus, utilizing the simplest method of achieving a task is equivalent to using the most efficient method. The project team's decision making process derived from the discussions of project details, goals, and objectives in face-to-face weekly meetings. At these meetings, the project members came prepared with completed work, necessary materials, reliable resources and background knowledge, all available to support input into the decision making process. Presenting these materials in a physical manner allowed for other project members to clearly understand the project status, provide input, and work together on deciding what needed to be done in order to move forward with the MQP.

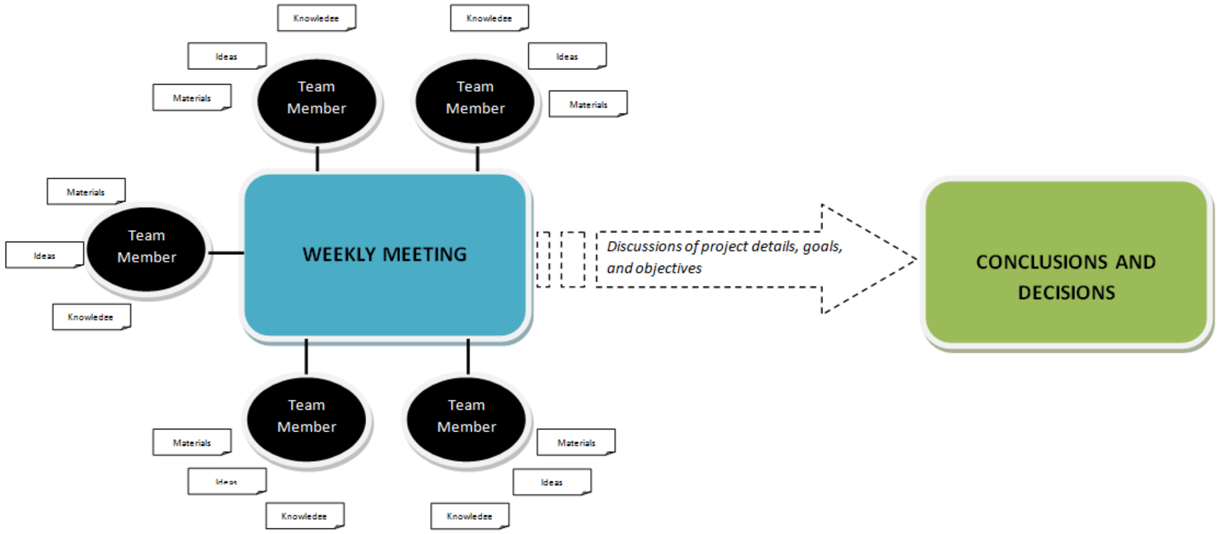
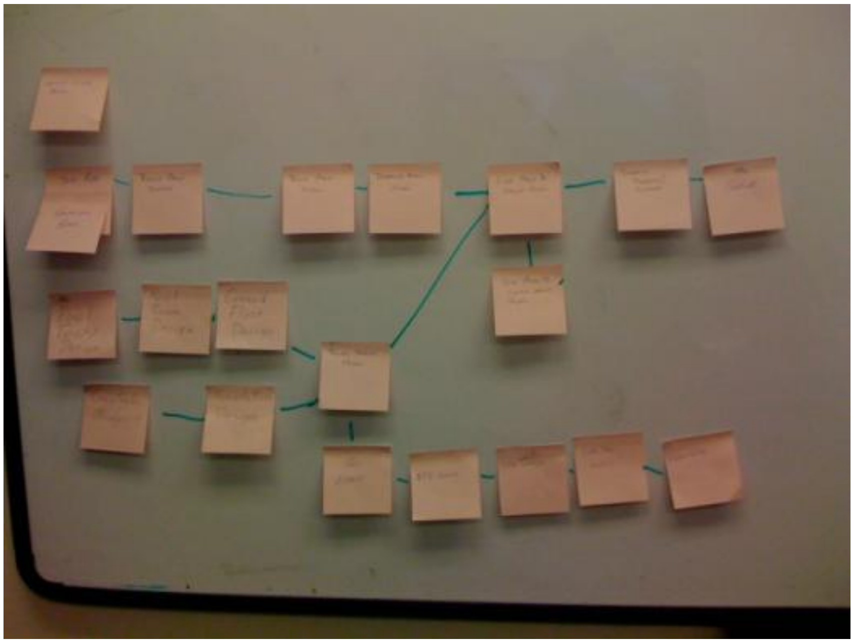


Figure 8: Decision Making Process of MQP Team

Communication served as the basis for all work, and quickly became the most crucial aspect of project integration for the success of the MQP team. Knowing that technology would serve as an integral tool to the communication process but recognized that it could hamper communication, the project team scheduled face-to-face meetings and open forum discussions of work. These meetings were established in an effort to reduce confusion made from technology and improve efficiency. During the beginning weeks of the project, the MQP team scheduled two weekly meetings; one that only included the project members to discuss the progress of work internally, and a second meeting to display and communicate this progress of work to the project advisors and collect their feedback. This system of holding internal meetings allowed for the project members to decide and combine thoughts on tasks that needed to be done, set deadlines, divide work fairly and accordingly, and to review previous work completed with the feedback given from meetings with project advisors.

To better organize their work over the life of the MQP, one of the earlier meetings between the members of the project team resulted in the performance of a "card-trick." In construction jargon, a "card trick" is a process in which all sub-contractors involved in the construction of a building meet together with their major tasks written on post-it notes. With the project scheduler often acting as the organizer of the meeting, the sub-contractors would "stick" their duties on a large calendar in relation to the other sub-contractors also performing work on the project as seen in Figure 9. Related activities are connected and the result is a time-lined network of project activities. [36] Understanding that much of the work performed for the project is interrelated, the project team simulated this process and proceeded to write down the respective activities they each plan to accomplish over the course of the MQP on post-it notes. With some trial and error, the project team was able to successfully create an organized network of activities. The network put into perspective how the integration process throughout the life of the MQP will evolve and clearly identify which activities are directly depend on the one another.

[36] Frank, J. (2004, December). *Construction Scheduling 101.* Retrieved November 24, 2008, from Pinnacle One: http://www.pinnacleone.com/assets/files/PinnacleOne_Characteristics_Good_Construction_Schedule.pdf



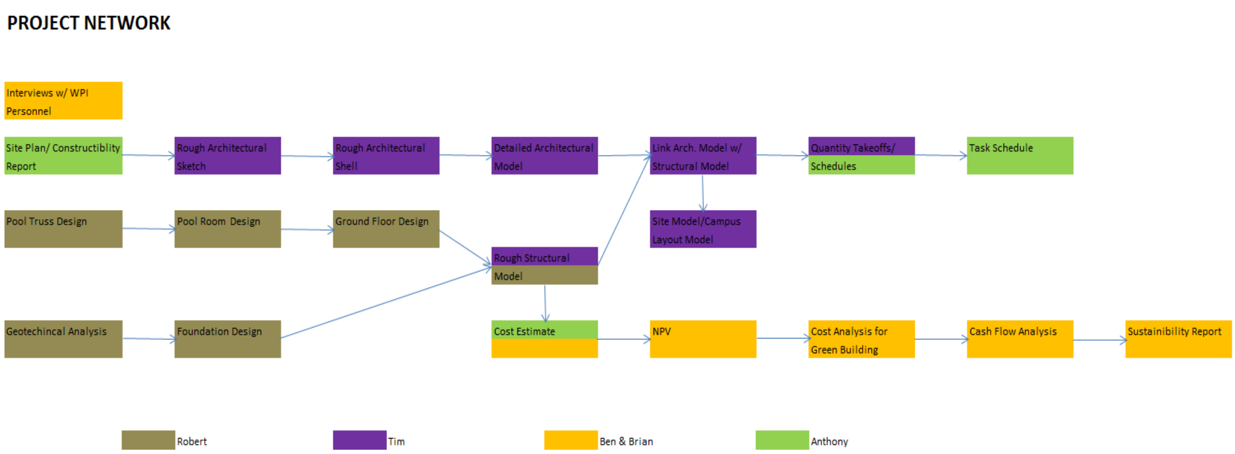


Figure 9: Card Trick of all activities of WPI new Athletics Facility MQP (top), with graphic representation (bottom)

The project team made efforts to make the communication process more efficient by using methods of direct communication. Direct communication eliminates the "passing of information" through a middle man, therefore preventing miscommunication, as well as wrong information being transferred. By directly communicating with fellow team members, conversations discussing work could be effective and productive.

The WPI new Athletics Facility MQP team did not have to use a middleman within the communication process. Quite often in the industry, this situation is un-avoidable – or is implemented for convenience; however, direct communication provides many benefits when collaborating with several team members. As shown below, the use of a middle-man increases the chance of miscommunication between party members and can reduce the overall efficiency of the process.

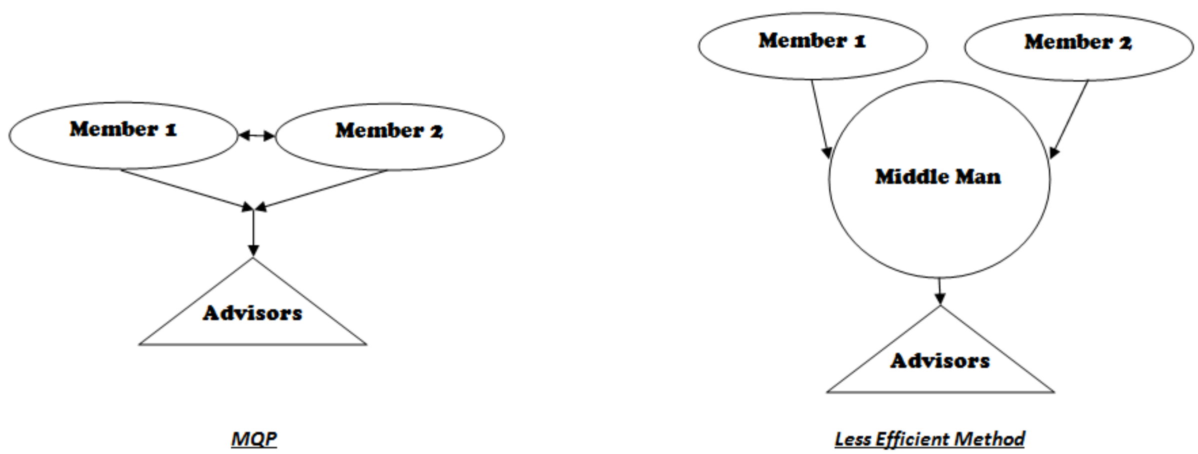


Figure 10: Lines of Communication - MQP team vs. Actual Design Team

Overall, direct, face-to-face communication, with the support of intermediate e-mails, proved to be a successful method of collaboration for the project team. These meetings were designed to make members aware of their responsibilities, as well as to ensure an understanding of how each person's tasks interacted with each other and the project as a whole. Along with the use of e-mail for quick updates, the project team stayed in constant contact and continuously understood the goals and projected status of the project for upcoming work development.

With technology as the primary tool used to produce work and results for the pre-construction tasks of the WPI new Athletics Facility, utilizing a convenient and organized file exchange portal was crucial to the efficiency of the project team's collaboration and integration. Within this approach are several software packages and programs used to electronically display the project team's ideas and solutions. Realizing that the work done by any one member of the project team would be integrated with work done by another member of the team, the myWPI portal for communication and file exchange was implemented as a way of conveniently transferring files.

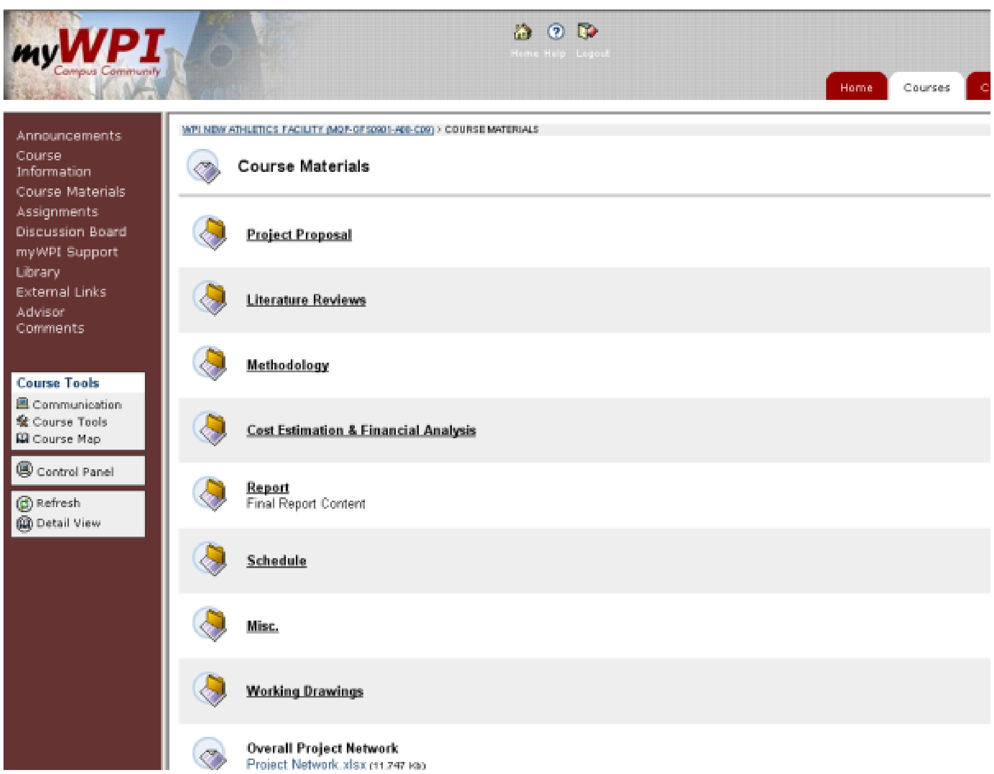


Figure 11: 'Course Materials' tab for the WPI new Athletics Facility MQP myWPI portal.

To create efficient teamwork and integration through use of the myWPI, Similar to the "card trick" procedure, each team member noted the major portions of the project for which they were responsible for, and from this, created folders on myWPI that would house all materials related to the completion of this portion of work. Through discussions between the team members and the project advisors, the implementation of a 'Final Report' folder and an 'Advisors' Comments' tab was set forth. The final report folder served as an on-going, working culmination of all materials presented by the project team members. This allowed the team to continually hold a sense of "percent complete" of the final project report. The members of the team, as well as the advisors, agreed that an efficient tracking system would increase efficiency throughout the lifespan of the project.

MyWPI served its purpose as a collaborative device well, however it was not without some faults. While we planned to gather reports and results in a constantly updated file, at times it created confusion. By not signing updates or hosting incorrect files at various times, sections of results were lost. It was reassuring that every member kept personal copies of their individual work, but these confusions produced minor delays in the generation of the final report. Another example of miscommunication using myWPI was the absence of submittals. Appendix B: Meeting Minutes shows the minutes from weekly meetings with the project team and the advisors. Unfortunately as the project progressed, reporting these minutes onto myWPI became lax and copies are missing. This failure to report can have major implications in the real work place and cost a company valuable time and money. It is important to note that this file sharing technique was very successful in the creation of the BIM model where individual designs, specifications and analyses were compiled in an easy to access folder. By utilizing myWPI, the project team was able to implement the BIM process efficiently, but overall any type of file sharing network needs explicit directions on how to conduct the collaboration in order to reduce confusion.

One of the key factors in determining the level of efficiency of integration is the speed with which problems are identified, resolved and solutions implemented. While each member contributed their own ideas, values, methods, and practices to the working MQP project team, all members developed a very similar approach and understanding of team work and collaboration. Similarly, the members of the team often sought the input and advice of other project members as a method of improving work and ensuring the end product was a fair representation of a group effort. Project team members understood that each decision made no matter how small, due to the level of integration and reliance of one another's work, would have a global effect on the project. It was from this understanding that constant communication was prevalent throughout the project.

Important to the advancement and development of the WPI new Athletics Facility MQP was the ability to attend the bimonthly design committee meetings with members of the WPI executive team, Gilbane Inc., Cannon Design, and fellow WPI community members. These meetings were led by Cannon Design and occasionally Gilbane with the purpose of defining the project scope and discussing various design options. It is important to note that Gilbane and Cannon Design meet on a weekly basis outside of WPI's influence to work on various design and cost estimating issues that are more involved than defining the scope. In comparison the MQP team met more often in the given period of three academic terms, initially having biweekly meetings and increasing to tri-weekly meetings near the end of the project, however Gilbane and Cannon Design have dozens of professionals at hand constantly working on this project internally. It is difficult to say whether or not this MQP's integration was better than that of

Gilbane and Cannon but it is clear that project integration used both in this MQP and in the actual design process greatly increased the efficiency of work.

Overall, the project team relied on their own personal efforts and interactions to procure meetings and to garner results – only reverting to technology as a form of simple discussion or convenient transfer or files. In-person discussions served as the foundation for the integration process and allowed to team to clearly transfer ideas, explain material, and make definitive decisions. This method was a prime factor in reducing the amount of effort and time required to generate results, thus instituting an efficient integration process.

As integrated practice was the grand scheme of the project, each result section reflects on how it affected the work. It has already been documented that integrated practice increases efficiency, reduces errors, and reduces construction costs, but many construction companies do not how to implement integrated practices. While there is no tried and tested way to implement project integration, this project attempted to exemplify how valuable integrated practices can be.

6 Construction Management

The processes represented by the construction management portion of the WPI new Athletics Facility MQP (site plan with analysis, constructability review, project schedule, and cash flow analysis) are the predominant tasks performed by professional construction management firms. These tasks are essential to the feasibility and execution of construction, accuracy of the project timeline, and accomplishment of the project budget. The end result of each task is the culmination of an integrated process involving the input and expertise of the important stakeholders from within the project. While organized and detailed discussions are required to assemble such diagrams, tables, and figures; the representation, understanding, and continuous tracking of the project site plan, constructability review, project schedule, and cash flow analysis throughout the life-cycle of the project proves the importance of efficient project integration. Proper tracking of such issues and tasks from project start through project end constantly have an effect on the major restrictions and definitive outlines to the project – time, cost, and scope. Properly representing the project site plan, constructability review, schedule, and cost-analysis and relying their information periodically throughout the lifespan of the project, through a method of efficient integration, will allow the major stakeholders of the project to remain aware of any possible cost overruns, schedule delays, or scope discrepancies of the project – all of which can be proven to have drastic effects on the overall success of construction.

6.1.1 Site Plan 1

The purpose of the following site plan analyses were to assess the feasibility of various site plan options in terms of accessibility, campus disruption, construction equipment, and safety. In order to determine the best site plan, each option was thoroughly analyzed to produce various pros and cons. The results of these analyses were weighed with the input from other group members and a final decision was made.

Site plan 1 places the primary construction area on the main campus of the university, taking over the western half of the quadrangle. Given the footprint of the proposed facility, the main concern and overall goal with the site plan design is to construct a way to best facilitate all necessary construction activities.

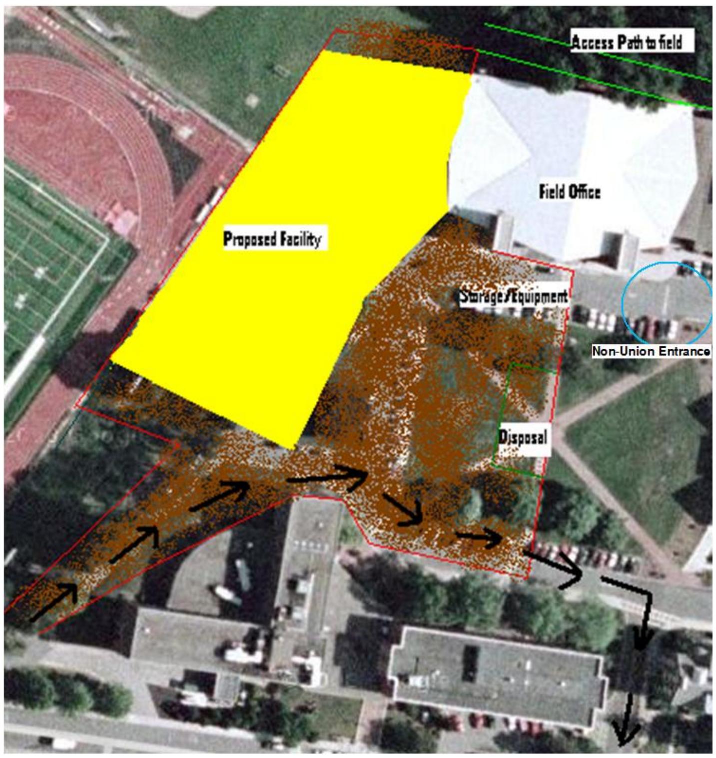


Figure 12: Site Plan 1

Figure 12, showing the design of Site Plan 1, illustrates the construction site area including the location of the necessary on-site resources, such as disposal, storage and equipment of materials, field office, and traffic patterns. Although this arrangement has a major effect on the look, as well as daily activity of the main campus, it has several benefits.

The largest benefit of placing the main construction area on the center of campus is the ability to allow continuous use of the fields, primarily the baseball field. With this arrangement, fencing can be placed in such a way that there are no major infringements on the use of the field, and therefore teams will remain to have easy access to these playing facilities.

A second benefit of site plan 1 is the opportunity for one-way pathway for trucks and vehicles. While the driving space is small, a one-way traffic path is organized and allows for easy maneuvering throughout the construction site. However, since large trucks and equipment will be interacting with the main campus, safety is a large concern. The construction schedule and timing of deliveries must be scheduled appropriately. Steel construction during the summer months will most likely be wise because WPI classes are not taking place. When classes are in session, early morning deliveries before 7:30 am should be arranged as a safety factor to avoid student traffic and interfere with the WPI community. While the traffic flow may be convenient, the pathway may not quite be possible due to the proximity in which the new athletics facility will be placed next to Morgan Hall.

Safety is a major overall concern with this plan. Placing the main construction area on the center of campus allows many opportunities to effect the WPI community. Student traffic is constantly flowing through this area of campus, and alternative routes will need to be taken.

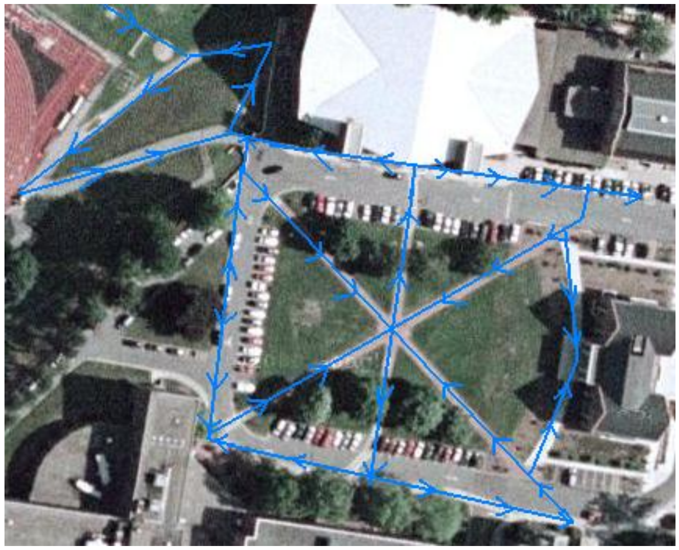


Figure 13: Traffic Flow patterns on the WPI Quadrangle

While maintaining use of the baseball field is rather nice, the amount of students effected by this option needs to be considered, as well as for the length of time. Only 25 students play on the baseball team, while hundreds of students will be facing the effects of a large-scale construction site being placed right in the center of their campus.

Parking is constantly a concern at WPI, and with site plan one, approximately 60 parking spots will no longer be available. This could pose a concern for the campus requirement of parking spaces, thus forcing WPI to provide temporary parking nearby.

Site Plan 1 also illustrates a secondary entrance for non-union workers. This entrance, (located on the top right portion of the graphic), provides easy access to the construction site from West St off of Institute Road. This entrance is essential in the case that union workers go on strike, blockading the entrance to the construction site. While work completed by union workers will be put on hold for the time period of the strike, providing secondary access to the construction site will ensure that work done by non-union laborers is also not halted.

Overall site plan 1 poses many safety concerns, inconvenience to the WPI community, tight traffic maneuvering, and several added speculations the construction activities which would be better avoided if possible.

6.1.2 Site Plan 2

Site plan 2 proposes a much safer, and WPI community-friendly, approach. Opposed to placing the main construction area on campus, the outfield of the baseball field provides a much better location. Similar to Site Plan 1, the design aims to construct a plan that best facilitates all necessary construction activities. Figure 14, an illustration of Site Plan 2, displays an alternative site plan area, as well as alternative locations for disposal, and traffic patterns.

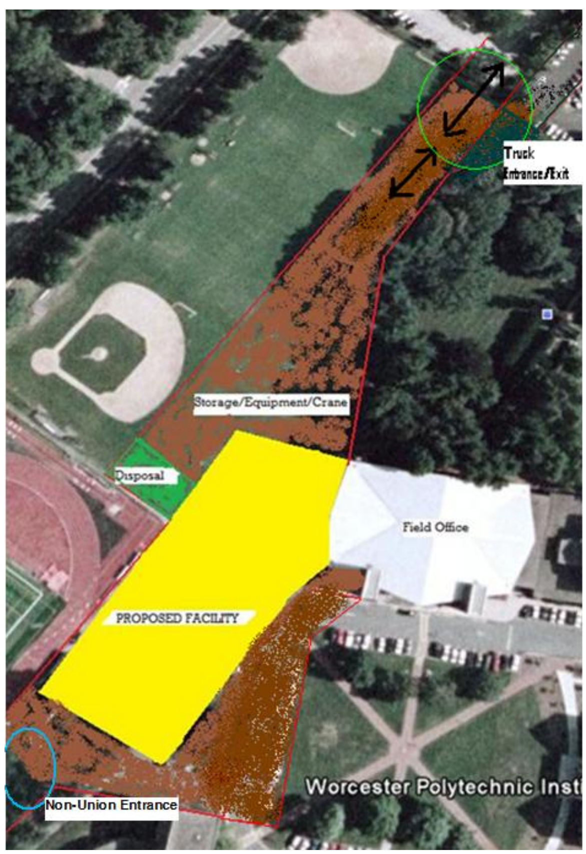


Figure 14: Site Plan 2

Clearly, with this option, the use of the baseball field will no longer be available during the period of construction. Trucks and construction vehicles will also enter in via an entrance to the fields which are located in the rear end of the softball field. There is a minor disadvantage to this approach in terms of traffic maneuvering due to the fact that there is only one option available for entering and exiting. However, due to the large amount space allotted to the construction site, trucks will have enough room to circle and/or pivot within the construction area to reverse direction and exit the site. A specified path of travel can also be laid out to reduce traffic confusions.

One of the largest drawbacks to site plan 2 is that student accessibility to the athletics fields will not be easy during construction. The fence is set-up in such a way that alternative routes the fields will need to be created to better accommodate teams and students.

Site Plan 2 also provides for access to non-union workers in the case of a union strike which blockades the main entrance to the construction site. This entrance (located at the bottom left portion of Figure 14, allows non-union laborers to continue work on-site via access to the area from Institute Road. Once again, this entrance is essential in the case of a union-laborer strike because it allows for those workers who are non-union to continue construction activities.

Site Plan 2 is a much safer approach, and affects a much smaller population of the WPI community. Baseball players will not have the luxury to play on their home field, and will need to travel to nearby fields for practices and games; however, these activities take place during less than 50% of the academic year and only affect approximately 0.5% of the WPI community.

The quadrangle would remain almost entirely open and allow for student traffic and student activities just as WPI is accustomed to on a daily basis. Parking spaces will be eliminated, however, only about 25 spaces compared to the 60 in site plan 1.

Overall, with minimal intrusion on the WPI community as a major goal of the construction site plan, site plan option 1 seems much safer, while at the same time, a very plausible approach.

6.1.3 Site Plan 2.1; Meeting with Neil Benner

A meeting with Neil Benner, project manager for Gilbane, took place on Wednesday, November 26th, 2008. Neil's knowledge and experience was a great tool for the project, most specifically for the development of the site plan.

Neil and the project team first observed and analyzed site plan 1. Neil caught on quickly to the benefits, and more so, issues with site plan 1. Neil mentioned many of the main issues with site plan 1 which the project team had already discovered. Safety was again the largest concern due to the location of the main construction site area, as well as the traffic path. Neil did bring up the largest issue with site plan 1 which the project team did not originally think of themselves. With placing the main construction area on the quad, large amounts of added construction and rebuilding would be necessary. To maintain traffic flow, a road would need to be installed to replace the service road running parallel with the football field to connect the adjoining roads on either side.

Figure 15: Demolition of the quad with normal traffic flow (blue) and changes (orange)

Beyond this, once the project is completed, the quad would be half torn-up and thus require rebuilding. To rebuild the quad is a major expense, time consuming, and a safety hazard for the WPI community. Therefore, the option to maintain the circling service road throughout the quad at full use is a must-be-made decision.

Beyond these major issues, Neil also informed the project team that having large equipment, such as excavation machinery and cranes atop the quad would not be a feasible way of operating. Excavation of the side hill needs to be done from the low-point of excavation. Secondly, due to the soil report, the soil will be laid-back onto the quad, rather than transported away. Thus, the quad space is needed for such an activity.

Neil then reviewed site plan 2. The project team was pleased to find out the plan was very similar to the actual plan that will be used during construction. However, Neil was again very helpful and brought up many good points and possible problems that would relate to the currently proposed site plan 2. While the location of the main workspace, location of crane, and truck maneuvering were all rather precise, the largest issue that would make site plan 2 unlikely relates to the entrance of trucks through the church and day-care center parking lot.

Coordination with the church and day-care poses to be a large hassle. Maneuvering large trucks in and out of the parking lot creates large safety hazards to those who inhabit the day-care center. Similarly, 50-80 parking spaces would need to be eliminated in order to allow proper space for large trucks to enter via the entrance off of Salisbury St. and onto the construction site. With this in mind, it is an unlikely situation that the use of this parking lot would be a feasible option. In the case that it would be need to be used, chances are very likely that timed deliveries would need to be coordinated – a common headache for construction managers.

To surpass this issue, Neil proposed a plan that would utilize WPI's own parking lot as an entrance portal for trucks. The initial benefit of this plan is that no coordination with outside parties is needed, as WPI is the owner of all property being used for the site plan, as well as immediate transport paths to and from. The revised option to site plan 2, which shall be called Site Plan 2.1, replaces the use of the church parking lot with that of Higgins Parking lot. Trucks and other service vehicles will enter via Salisbury St. into the Higgins House Parking lot. They will then utilize this and a gateway to the site located on the baseball fields. This will provide direct and easy access.

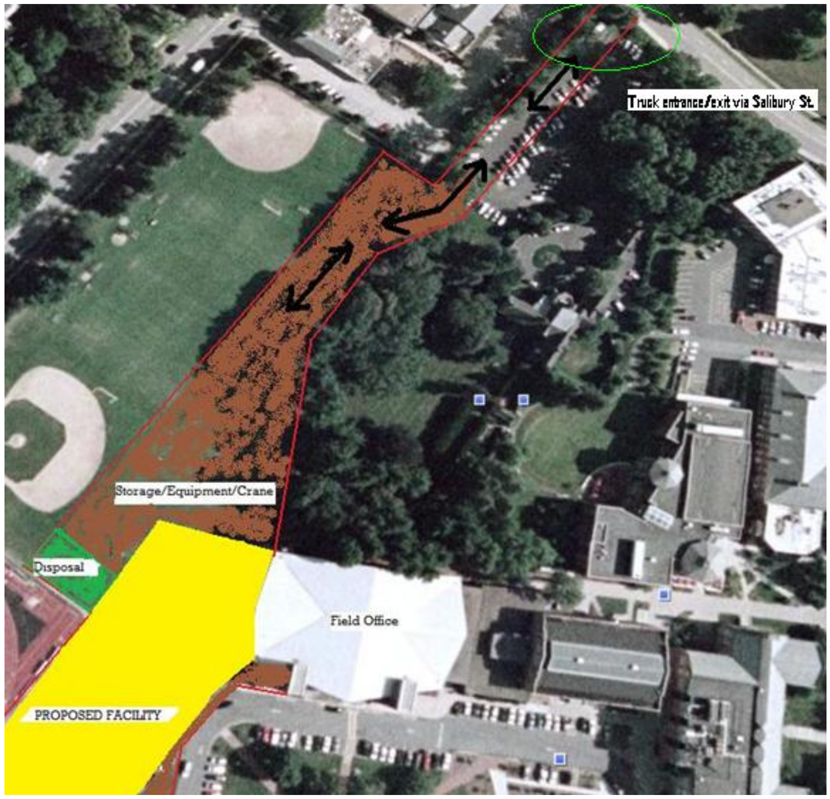


Figure 16: Site plan 2 utilizing the WIP Higgins House parking lot

There are, however, two major sacrifices that must be made to put this path of transport, and overall site plan, into play. To gain access from Higgins House parking lot to the fields, 56 parking spaces will be permanently unavailable during the period of construction and six to eight trees will need to be cut down. Both of these are tough decisions for the WPI community as parking is an ongoing issue, and cutting down trees does not follow along with the institutions recent strong initiatives to a greener environment and sustainability.

In the long run, site plan 2.1 proves to be a very efficient plan. Fortunately, making use of the baseball field and destroying its top soil, along with the cutting of trees follows along very well with WPI's master plan to renovate the entire athletics facilities and fields' area. Plans have been made to reconstruct the fields that currently exist in the given area. A complete renovation of the surface is planned, as well as to construction a single-level underground parking garage below this playing surface. As for the parking garage, the current design calls for the main entrance to be located coming off of the Higgins House parking lot – exactly the same spot where trucks will be entering the site. Thus, it was the fate of those very trees to be cut down. With these plans in mind, the demolition of the baseball field and cutting of the trees will not be any direct loss when compared to the future plans of WPI.

Site Plan 2.1, although currently not approved, seems to be the most efficient, logical, and feasible solution for the construction of the new WPI Athletics Facility, and at the same time, is a very sensible approach due to plans of future projects.

6.2 Constructability Review

All major projects typically conduct a constructability review for several phases of the project to ensure project efficiency and accuracy. A constructability review is a "multi-disciplinary examination of the plans and specifications for the purpose of catching potential change orders, uncoordinated disciplines, errors, omissions and impossible-to-build elements. If left unaddressed, these oversights and mistakes lead to confusion, change orders and Requests for Information (RFI), which in turn result in scheduling delays and costs overruns." [37] As per this definition, a constructability review is a crucial aspect of the project as it relates to the overall success of the project. Potential change orders, uncoordinated disciplines, errors, omissions, and issues with building elements can sum to large amounts of money lost if discovered during later points of the project development. Building upon this fact, time delays

[37] *Constructability FAQ.* (2009). Retrieved March 4, 2009, from Construction Specialty Services: http://www.constructibility.com/08FAQ.html

often result which adds to the overall cost of the project. Thus, conducting a constructability review is wise decision on behalf of the project owner, and a reliable construction manager engages in this process throughout the lifespan of the project. Major areas that construction managers must be strongly conscious of when evaluating the constructability of a building are the site's topographic characteristics; pedological characteristics; climate concerns; utility and resource availability; as well as any other specialized logistical issues that may relate to the project.[38]

The results of a site analysis have an extreme impact on the constructability of a building.[2] The soil type, topography, and geographic location of the site all have an effect on the structural design and structural elements that are used to support the building. Due to the size of the building, its purpose to serve a large community, and its requirement to withstand heavy loads; analyzing the overall site logistics of a university athletics facility is very important.

With the availability and experience of Neil Benner, construction manager for Gilbane Inc., as a close resource, the project team was able to gain access to the soils report created by Haley Aldrirch, which analyzed the site of the WPI new Athletics Facility. Results of the report, see Appendix M, show the existence of bedrock at an average elevation of 504 ft above sea level. This fact poses a large concern to the constructability of the facility, and even more so, the financial limitations upon which the structure is being designed and built. Excavating bedrock requires large machinery and blasting, [39] and because of this, there are many areas of

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[38] Wright, E. D. (1994). *Constructability Guide.* OBrien-Krietzberg Assoc Inc.

[39] Civil Engineering Committee. (1999). Blasting and Explosives Awareness. *Construction Safety Magazine* , 10.1.

concern that require consideration. Related to this procedure of excavation are high costs and significant amounts of heavy work. Beyond this issue, the time at which blasting is conducted must be strategically scheduled to maintain the safety and comfort of the WPI community and infrastructure.

Heavy amounts of excavation will be required to provide space for the construction of the athletics facility. As shown in Figure 17, this is a result of the large hill that currently lies on the site of the facility. This figure does not display the current buildings and vegetation on campus in order remove obstructions and provide a better view of the hill.

Figure 17: Site elevation view from Park Avenue

To properly remove this terrain from the construction site, large trucks and machinery will be required to first excavate this amount dirt, and then a retaining wall would be required to properly support the earth at the cut point. While ensuring the retention wall provides enough strength to hold back the soil, concern also exists in relation to the storm-water run-off that is typically absorbed by the earth on this site. Due to the general slope of the site, shown by the contour map provided by Haley Aldrich in Figure 18, storm water run-off is directed towards the footprint of the facility. Not only is excess water on the construction site inconvenient, the added moisture can cause issues with the site grading, as well as curing of concrete footings and slabs.[40] While these issues may be of small magnitude during the site-work and foundations phase of construction, disregarding such issues can cause severe problems and discrepancies in the structural strength of the building design. The figure below shows the contours of the WPI quadrangle and surrounding land, footprint of the current WPI athletic/recreational facilities, as well as the footprint of the proposed WPI new Athletic Facility (represented by a dotted line).

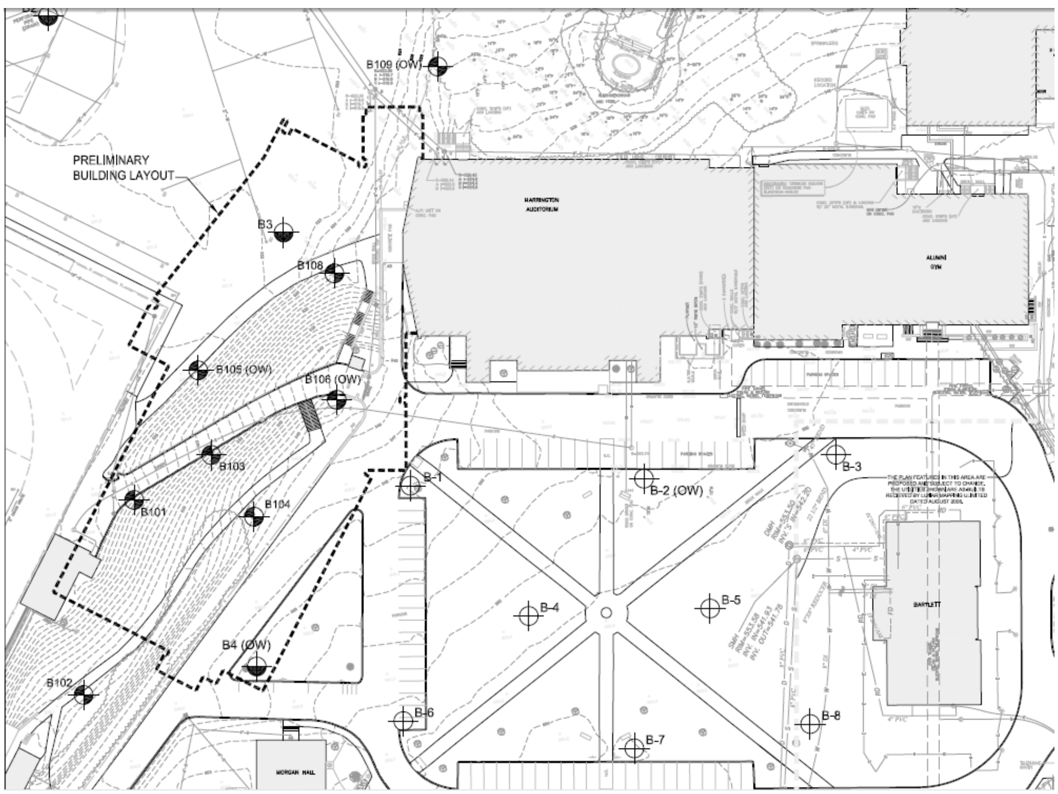

Figure 18: Contour Map of WPI Main Campus; source: Haley Aldrich

[40] Ibid.

The geographic location of the WPI new Athletics Facility also provides obstacles that must be accounted for during the construction phase.[4] With construction situated in New England, harsh weather conditions such as cold weather and snow cause unworkable circumstances during the winter months. It is extremely important that this issue be accounted for early in the project development. The project schedule must be produced accordingly and coordination with sub-contractors working on the site must also be done.

Main utilities and resources for the site are important aspects to consider when determining the constructability, maintenance, and functionality of any building.[4] Water lines, sewage lines, and electricity lines are three essential resources that must be provided to every facility meant for human occupancy. Site plans of the WPI campus illustrate that water and sewage pipelines are currently located in an easily accessible place such that the new facility can conveniently connect. However, providing sufficient power to the facility is a concern. Discussions with Gilbane representatives commented that WPI's new Athletics Facility can easily connect to the electrical grid off of which the campus functions; however, there is uncertainty about the capacity of the electrical load the facility would require. With the regards to this concern, possible upgrades to the system may be required.

6.3 Schedule

With regards to this MQP, the construction schedule for the WPI new Athletics Facility was comprised using common knowledge of a construction schedule involving procurement, design, and build, background research of previous projects, and resources available through the ongoing 'true-life' WPI new Athletics Facility. Using these three sources of information, the project team created a basic construction schedule that would be used to estimate the general points in time in which major phases of the project would take place.

All construction projects consist of four major phases: programming, design, construction, and project close-out.[41] These phases are directly dependent on one another and require a rather substantial point of completion and thoroughness before the following stage can take way. Breaking down a schedule and creating a time-frame for development of a construction project is most often represented as a simple general timeline of activities. Often created based on common knowledge of building construction the general schedule is represented in Gantt Chart form, shown in Figure 19. As the first step in approximating an overall schedule for the development of the WPI new Athletics Facility, the project team utilized their common knowledge of building construction to quickly develop a total-project time-frame, broken down into the four phases previously mentioned. While major construction on an academic campus often requires schedule techniques and decisions that aim to least interfere with the academic calendar milestones of the university, this initial representation of the project schedule was intended to estimate the length of the project development, and therefore had yet to consider such milestones.

[41] Nunnally, S. (1980). *Construction Methods and Management.* Prentice Hall.

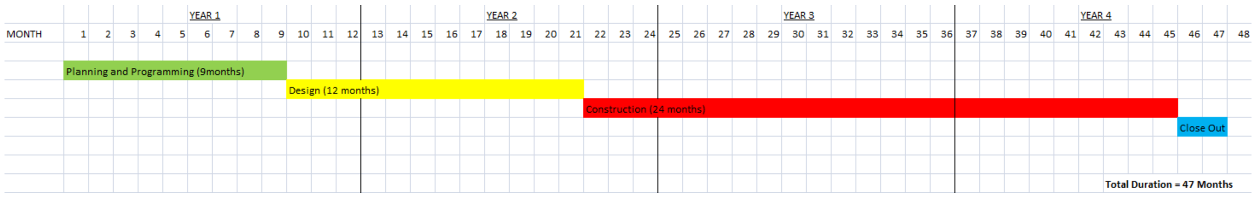

Figure 19: Conceptual Schedule: Gantt Chart

While the programming stage of a project is one large process that entails a series of documented decisions that define the scope of the project and set forth the basic circumstances under which the project is developed, the design and construction phases are much often lengthy processes which require extremely detailed plans and documents that require large amounts of attention. Therefore, these two major phases of the project development are further broken down into sub-phases. These sub-phases allow for better scope definition, finer product development with attention to detail, more accurate project management and reporting, and add to the overall ease of organization for the project. The design phase, and construction phases are broken up into sub-phases as followed:

DESIGN:

Conceptual Design → Schematic Design → Design Development → Final Design/Contract Docs.

CONSTRUCTION:

Procurement → Site Work → Structural → Exterior → Interior → Finishes → Close Out

With the understanding of the major phases and sub-phases of a construction project schedule, the project team then entered the process of determining estimates for the length of time for each phase. To do this the project team utilized valuable resources provided by Gilbane Inc. in regards to recently finished and current projects on campus. The first valuable resource that the project team was provided with was an official initial schedule outline made for the actual WPI new Athletics Facility project. Shown in Appendix F, the schedule provides dates for the programming and conceptual design phase of the project, the design phase (broken down into schematic design and design development), construction documentation, permitting, sub-contractor bid and award period, and the construction phase. This document provided a strong reference for approximating the amount of time the overall design phase of the development of an athletics facility of this size and caliber. While the preliminary schedule provided by Gilbane, Inc. acted as a valuable piece of information, to properly estimate and eventually track and analyze the development of the most important and dynamic phase of the project – the construction phase, the project team analyzed the construction schedule of a previously built building constructed by Gilbane, Inc., and on the WPI campus – the WPI Bartlett Center.

Shown in Appendix F, the construction schedule of the WPI Barlett Center provided the project team with dates of the sub-phases of the construction portion of a smaller sized facility. The project team analyzed these facts, but however, also utilized the details of the construction activities represented on the schedule as a tool to factor in differences between the construction of an academic building that is the Barlett Center, which sites on a certain plot of land, versus the construction of an athletics facility, which sits on a separate plot of land. The following dates were extrapolated from the construction schedule of the WPI Barlett Center shown in Figure 20. Shown is the construction sub-phase, its schedule begin date, it's duration in days, and the percentage of time this sub-phase is of the entire construction phase;

Construction of the WPI Bartlett Center

Milestone	Start Date		Duration to next sub-phase (days)	Percentage of Schedule
Excavation	24-Feb-05		83	18.20%
Structural	18-May-05		40	8.77%
Exterior Envelope	27-Jun-05		36	7.89%
Interior	02-Aug-05		157	34.43%
Finishes	06-Jan-06		84	18.42%
Close - Out	31-Mar-06		56	12.28%
End Project	26-May-06		x	x
		TOTAL:	456	100.00%

Figure 20: Construction Schedule: WPI Bartlett Center

This table provided a basis to interpolate the duration of the construction sub-phases of the WPI new Athletics Facility. Using the percentage of schedule data created from the WPI Bartlett Center schedule, the project team then calculated approximate dates and durations for those phases as it would relate to the construction of the WPI new Athletics Facility. Shown in Figure 21, the process yielded the following schedule:

Construction of the WPI Athletics Facility

Milestone	Start Date		Duration to next sub-phase (days)	Percentage of Schedule
Excavation	18-Sep-09		105	12.32%
Structural	01-Jan-10		120	14.08%
Exterior Envelope	01-May-10		123	14.44%
Interior	01-Sep-10		242	28.40%
Finishes	01-May-11		171	20.07%
Close - Out	19-Oct-11		91	10.68%
End Project	18-Jan-12		x	x
		TOTAL:	852	100.00%

Figure 21: Construction Schedule: WPI Athletics Facility

When comparing the two schedules, while the percentage of the construction duration for the interior, finishes, and close-out sub-phases of the project are relatively very similar, deviations are noticeable in the excavation, structural, and exterior envelope of the project. To support this occurrence, it is important to realize that in the Architectural/Construction/Engineering industry, each and every single project has its own unique identity and like no other.[42] Therefore, differences in all phases exist when comparing two projects, and for many, many different reasons. As per the construction schedule, the excavation of the WPI Bartlett center required the relocation of several on-site utilities. Because of this, the site work and excavation sub-phase might require more time than a typical construction project that does not require this type of utility work – as is projected for the WPI new Athletics Facility. Expanding upon the differences between projects, the construction of the WPI new Athletics Facility is expected to necessitate more time for the structural and exterior envelopes phases of the project due to its complexity compared to the Bartlett Center. The WPI new Athletics Facility must endure and support much heavier loads per square foot that does the WPI Bartlett Center. As a result the structural orientation and performance of the facility is more complex and larger, also requiring stronger connections. For the exterior envelope, the architectural features the facility has been designed with vary across the façade of the building. Therefore, the varying materials, trade-work, and coordination involved in constructing the envelope of the building requires more time than would a structure with simple architectural features – such as the WPI Bartlett Center.

With a construction schedule for the WPI new Athletics Facility developed, the project team then used Primavera scheduling software to represent the timeline in Gantt Chart format. Shown below as Figure 22, is a screen shot of the Primavera scheduling software.

[42] Nunnally, S. (1980). *Construction Methods and Management.* Prentice Hall.

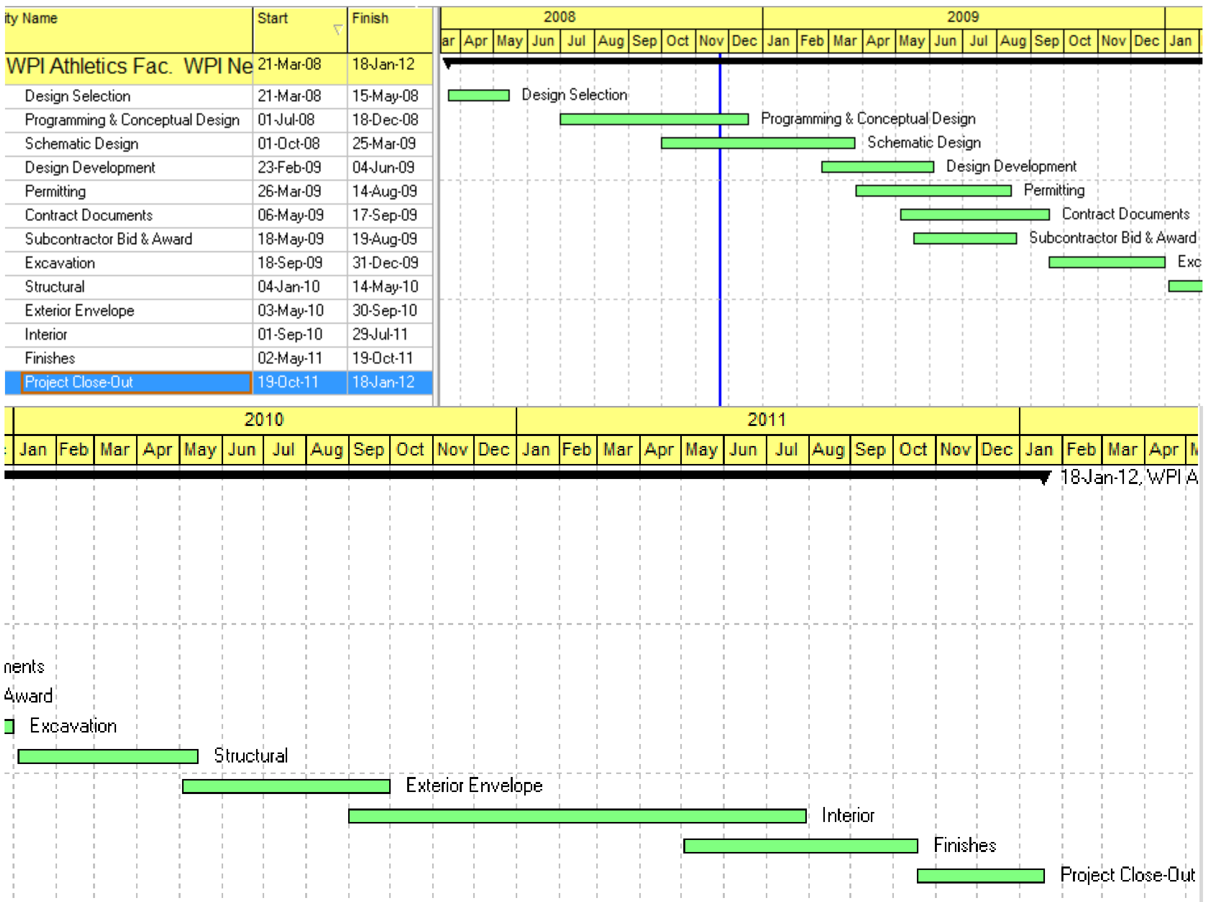

Figure 22: Primavera Gantt Chart of the WPI new Athletics Facility Construction Schedule

The project team chose to use Primavera scheduling software for its simplicity and its direct application to construction scheduling. However, the project team understood that with this decision, they would also be promoting the integration process they aimed to so efficiently exemplify. Primavera allowed for simple viewing of the construction schedule, and allowed for conversations and discussions regarding changes to the schedule to flow easily and be initiated directly on the spot in an electronic format.

6.4 Cash Flow Analysis and the "Lazy S" Curve

With a schedule and the cost estimates provided later in the project, (see section 8.3), the project team was then able to create an analysis of the cost of the project is it relates to time. Creating such a representation is important for the cost analysis and financial accounting aspects of a construction project.[43] With this representation, the owner and construction manager of a project is able to budget their expenditures against time, and eventually, track them against actual expenditures over the duration of the project. As noted before, a schedule broken-down into sub-phases allows for more organized tracking and analysis of the project.

Based on the information previously mentioned the student project team constructed a cash-flow diagram shown in Figure 24, also known as a "Lazy S" Curve[44] to represent the relationship between cost and time for the development of the WPI Athletics Facility:

WPI new Athletics Facility Schedule of Costs

Milestone	Start Date	Milestone Cost	Running Cost
Procurement	01-Jul-08	$4,288,506.84	$0.00
Design	01-Oct-08	$6,605,107.15	$4,288,506.84
Excavation	18-Sep-09	$1,152,933.03	$10,893,613.99
Structural	01-Jan-10	$9,155,933.24	$12,046,547.02
Exterior Envelope	01-May-10	$7,957,979.55	$21,202,480.27
Interior	01-Sep-10	$12,829,446.27	$29,160,459.82
Finishes	01-May-11	$4,797,875.25	$41,989,906.09
Close - Out	19-Oct-11	$1,791,100.94	$46,787,781.34
End Project	18-Jan-12	$0.00	$48,578,882.28

Figure 23: WPI new Athletics Facility Schedule of Costs

[43] Barrie, D., & Paulson Jr, B. C. (1978). *Professional Construction Management.* McGraw-Hill.
[44] Ibid.

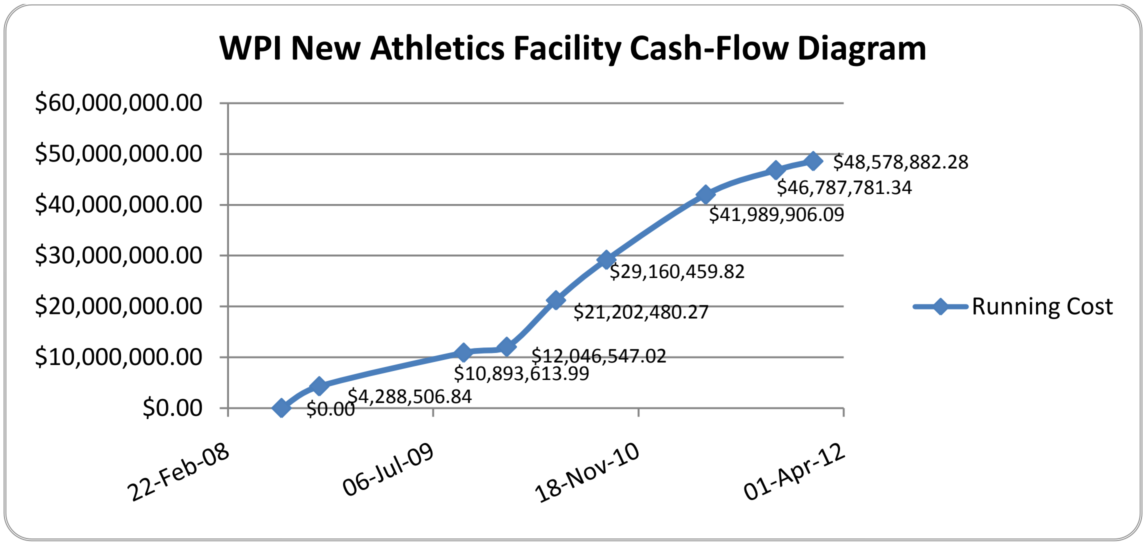

Figure 24: WPI new Athletics Facility Cash Flow Diagram

The lazy "S" curve provides a general predictive analysis of the rate at which money is spent over the time period of construction for the WPI new Athletics Facility. As shown in Figure 23, the largest percentage of dollars spent is following the design and excavation phases of the project, during the erection of the facility. The structural, exterior, and interior phases of the project account for major expenses in the areas of materials and labor. $29 million, accounting for 62% of the project cost, is spent on these three phases related to the construction of the WPI new Athletics Facility. The increased rate of money spent is represented by a greater upward slope on the cash-flow diagram. Towards the end of the construction of the WPI new Athletic Facility, expenses are less frequent and project close-out approaches. This corresponds to a decrease in the slope of the curve, creating the top of the lazy "s" shape.

Currently, as of March, 2009, the actual WPI new Athletics Facility project is in the schematic design phase. As per the estimates shown in Figure 23, the project has somewhere between $5-$10 million dollars. The project is also currently running behind schedule, therefore as a result, although the project is still in the schematic phase - it is likely that the estimated cost of design is nearly met with possibilities of exceeding the estimate by the time construction begins.

7 Project Design Tasks

This MQP was very unique because it took place in the conceptual and partly in the schematic design stages of the facility which forced the development of a conceptual design separate from Cannon Design. In these phases of the project, Cannon Design and Gilbane Construction Co. discussed design issues with the WPI Design Committee in order to develop a facility that would fulfill all of WPI's needs. With the limitations of time, experience and shear man power, the student project team decided to address four major design topics consisting of the conceptual designs, schematic designs, structural trusses, and green building analysis.

7.1 Building the BIM Model

This MQP's conceptual design solution, completed in Revit, was developed order in to perform various pre-construction tasks and evaluate our understanding of the problems and solutions in designing such a large facility. There are several stages of design based upon accuracy that must be worked through until the final detailed design is produced for the actual construction. Most owners start by stating a narrative that defines objectives and requirements for the project. The architect develops a program and solutions to meet those objectives. The rest of the design is completed by the architect, structural engineers, mechanical and electrical engineers, specialty consultants, etc. The next level of scope definition is called the conceptual design. This design has a narrative, describing the uses, layout, and functionality of the building which was provided in the master plan from Sasaki Associates who were the first architects WPI hired to design the facility but were eventually let go.[45] The details of construction are developed in the schematic designs which follow the conceptual design. It is a rare possibility that construction may start at the schematic level of design, but most construction begins at the last design stage called detailed design. This last level of accuracy fleshes out all the systems involved with the facility's construction, maintenance, and operations.

Fast track projects like WPI's Bartlett Center and East Hall are completed on a truncated time table where construction begins before the design is completely finished. The design progression of a project usually starts from the ground up, with the foundation design completed first. While the design is still incomplete, fast track projects begin construction with said completed foundation plans. This accelerated construction schedule is useful because construction takes less time but is risky because errors and changes affect the entire project. However, WPI has not chosen to fast track the new athletics facility and the design should be completed before construction begins.

The design of any construction project is rarely a linear process, and there is an enormous amount of checking, redesigning, and scope changes that go into the final detailed design. The development of the BIM Model, as well as the actual design by Cannon, was not exempt from revisions either. Throughout the course of this project, weekly updates and discussions about the Revit model addressed any design concerns before they became a problem later on in the process. While the usage of the Revit model is an ever expanding topic, this MQP's model was directed towards the overall shape, scope, basic materials, and structural trusses. It is also important to note that the BIM Model in this MQP was developed by

[45] Sasaki Associates Inc. (2008). *Recreational Facilities Master Plan.* Sasaki Associates Inc.

engineering students while Cannon Design is a professional firm with entire departments dedicated to design each section of the building.

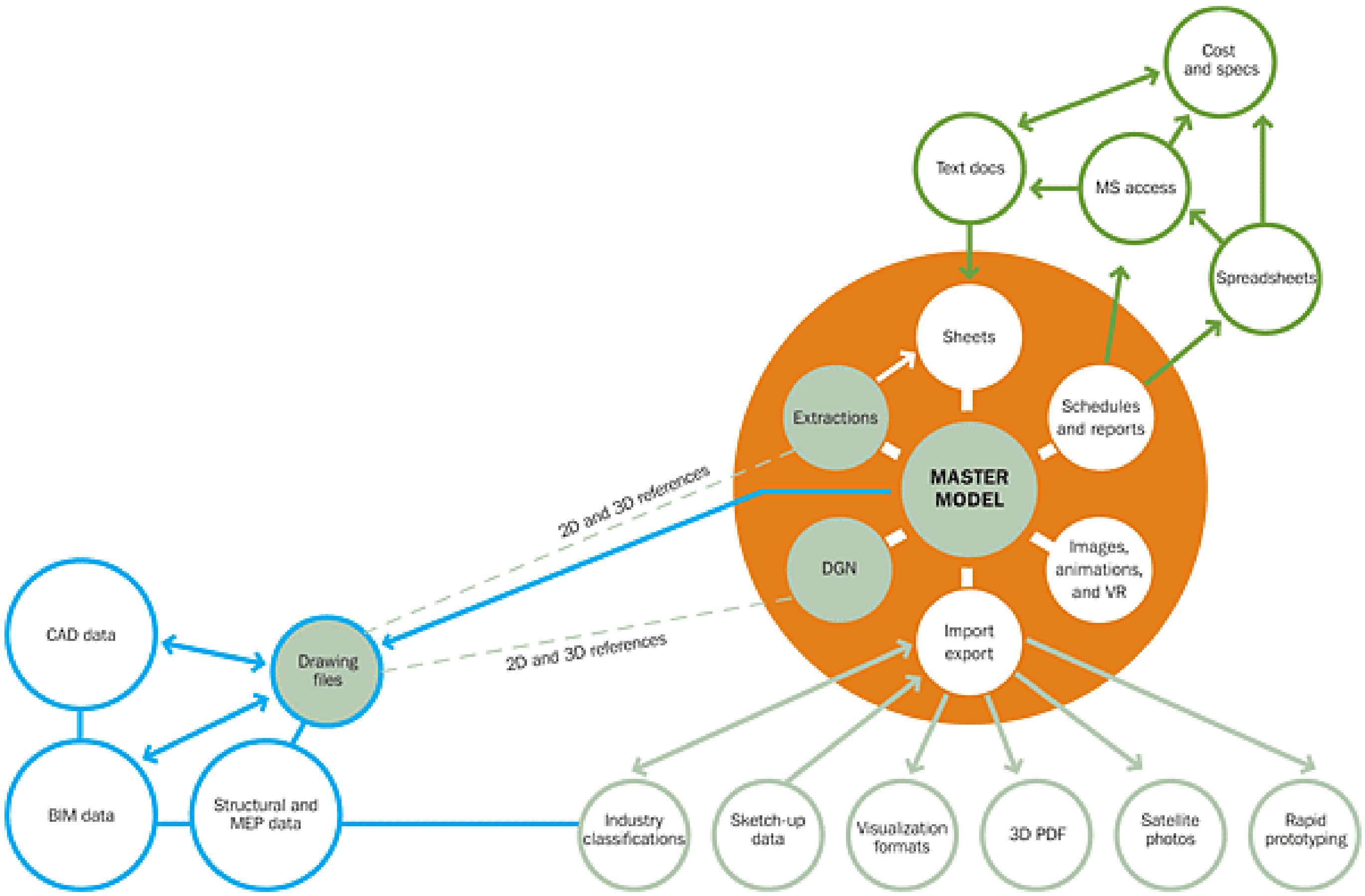

Figure 25: Using BIM Modeling to Encourage Collaboration[46]

Based on the Master Plan provided by Sasaki Associates, a conceptual BIM Model was developed from the location of the facility, floor spaces required, functionality, and site plan analyses. Through the incorporation of IP techniques, information was extracted from the Revit model for other disciplines to work with. Figure 25, authored by Volker Mueller, shows the grand scale of how utilizing BIM in conjunction with IP and how the model is shared by all

[46] Pressman, A. (2007, May). *Integrated Practice in Perspective: A New Model for the Architectural Profession.* Retrieved January 11, 2009, from Architectural Record: http://archrecord.construction.com/practice/projDelivery/0705proj-1.asp.

participants. In the actual design there are many components to take into account to develop a conceptual design.

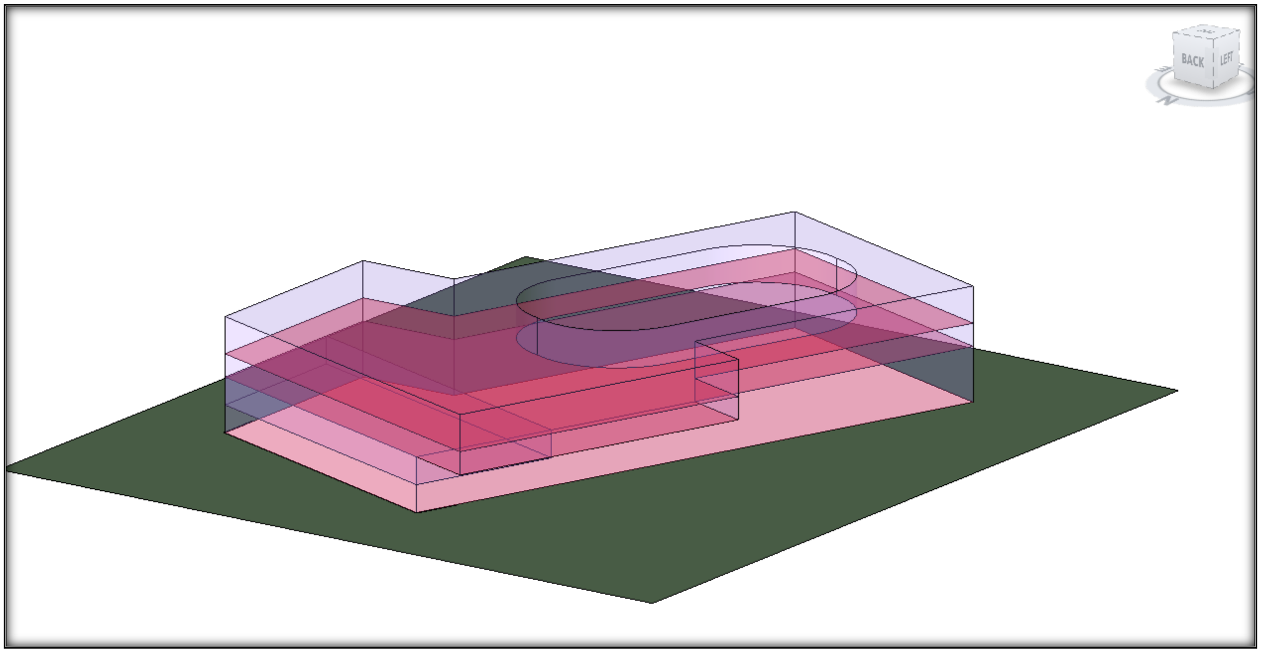

Figure 26: Conceptual Revit Model, 11/9/08

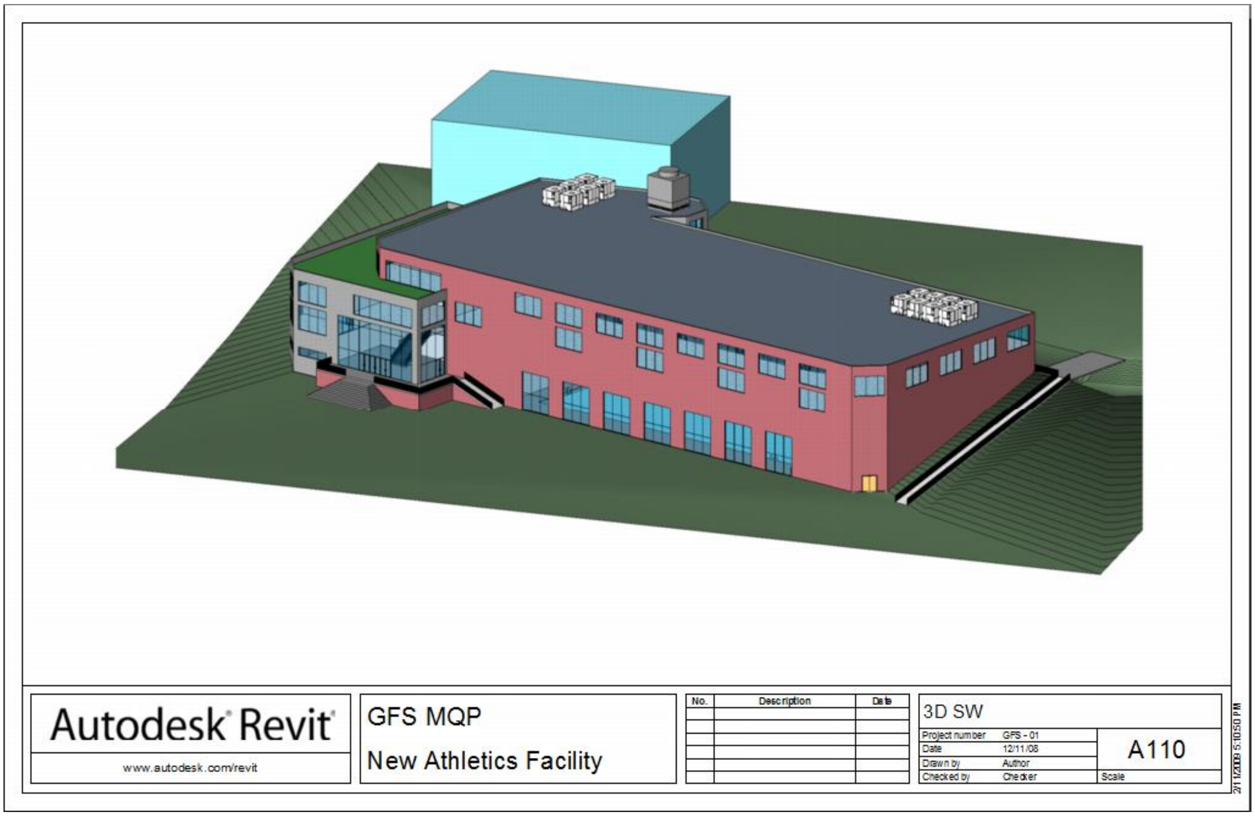

Figure 27: MQP Architectural Revit Model, 2/11/09

The process that was used to create the BIM model followed closely to the usual process of design firms. The first stage is a conceptual model with loose definitions on the global floor space, basic shape, and orientation on site. This model utilized very basic forms to gain a perspective on what to expect in future phases, illustrated in Figure 26. The model then progressed into defining the outer shell, exterior windows, and doors in order to gain a better understanding of how the building will look in comparison to the site it is situated on. With the shell completed, the construction of the BIM model moved to the interior of the building. Loose definitions of floor space and partitions were added to understand how the building will function. This phase of the model required large amounts of input from other team members as well as stakeholders in the project. This BIM model was created to closely reflect the parameters made by Sasaki's preliminary design in terms of floor space, programs, basic layout and site orientation. It was extremely important to retain the functionality of the facility while keeping costs and structural changes to a minimum. Figure 27 illustrates how the Revit Model has evolved throughout the conceptual design phase up till February 11, 2009. Lastly, the BIM model included structural steel, basic finishes, equipment, and unique fixtures in order to fully grasp the layout of the building and how foot traffic will flow. The difficulty of modeling structural steel is the number of steel members required for such a large facility. Figure 28, Figure 29, and Figure 30 give a rough three step process, starting with columns, then beams and girders, and finally floor and ceiling joists. It is important to note that the trusses designed in section 7.4 were directly imported into the structural model. However, structural members that were not specifically addressed, such as columns and floor joists, were chosen from typical designs of similar facilities. While the BIM model created is a useful tool for the clients and designers, it is important to note that this particular model is still considered in the conceptual stage of design.

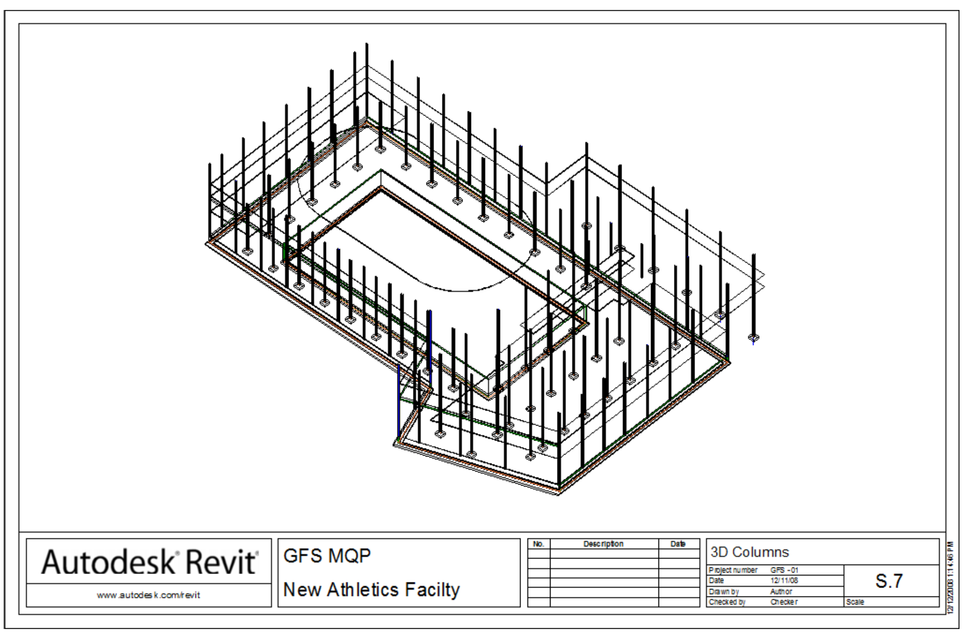

Figure 28: MQP Revit Model, Structural Columns 12/11/08

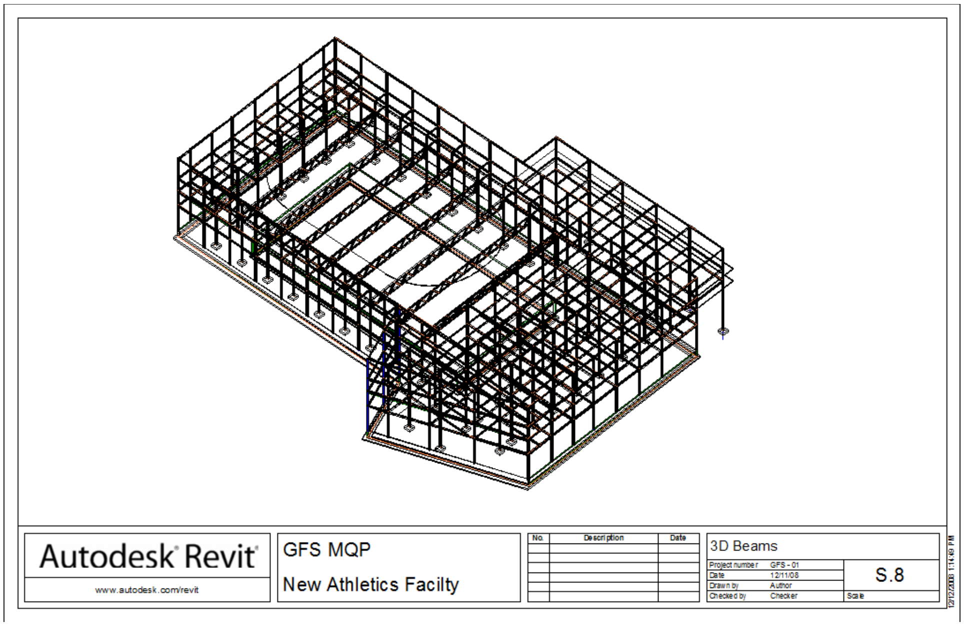

Figure 29: MQP Revit Model, Structural Beams 12/11/08

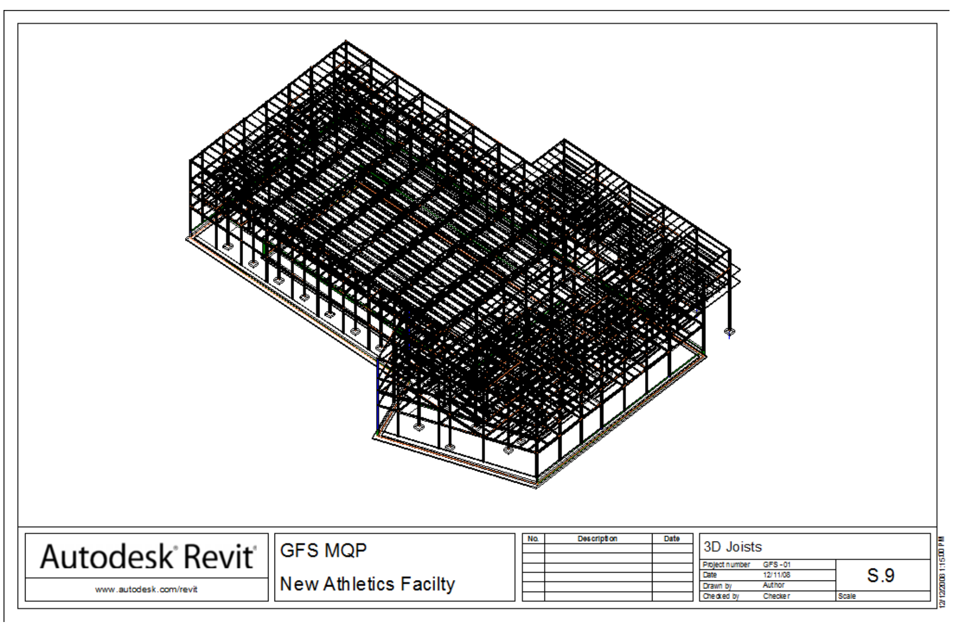

Figure 30: MQP Revit Model, Structural Joists 12/11/08

Making changes to a design becomes increasingly difficult as a construction project progresses. However with the incorporation of Project Integration these design changes can be made earlier in the process and save enormous amounts of money. In the Figure 31, created by

Patrick MacLeamy, it is clearly shown that earlier in the design process the ability to make changes, illustrated by the white line, is less costly than the later stages of design. In a normal design process, illustrated by the black line, most design changes occur after the “break even” point where it becomes more costly to make design changes than to actually implement them. The incorporation of Project Integration, illustrated by the red line, helps determine the necessary changes earlier in the design process which allows for less costly changes and more savings.[47]

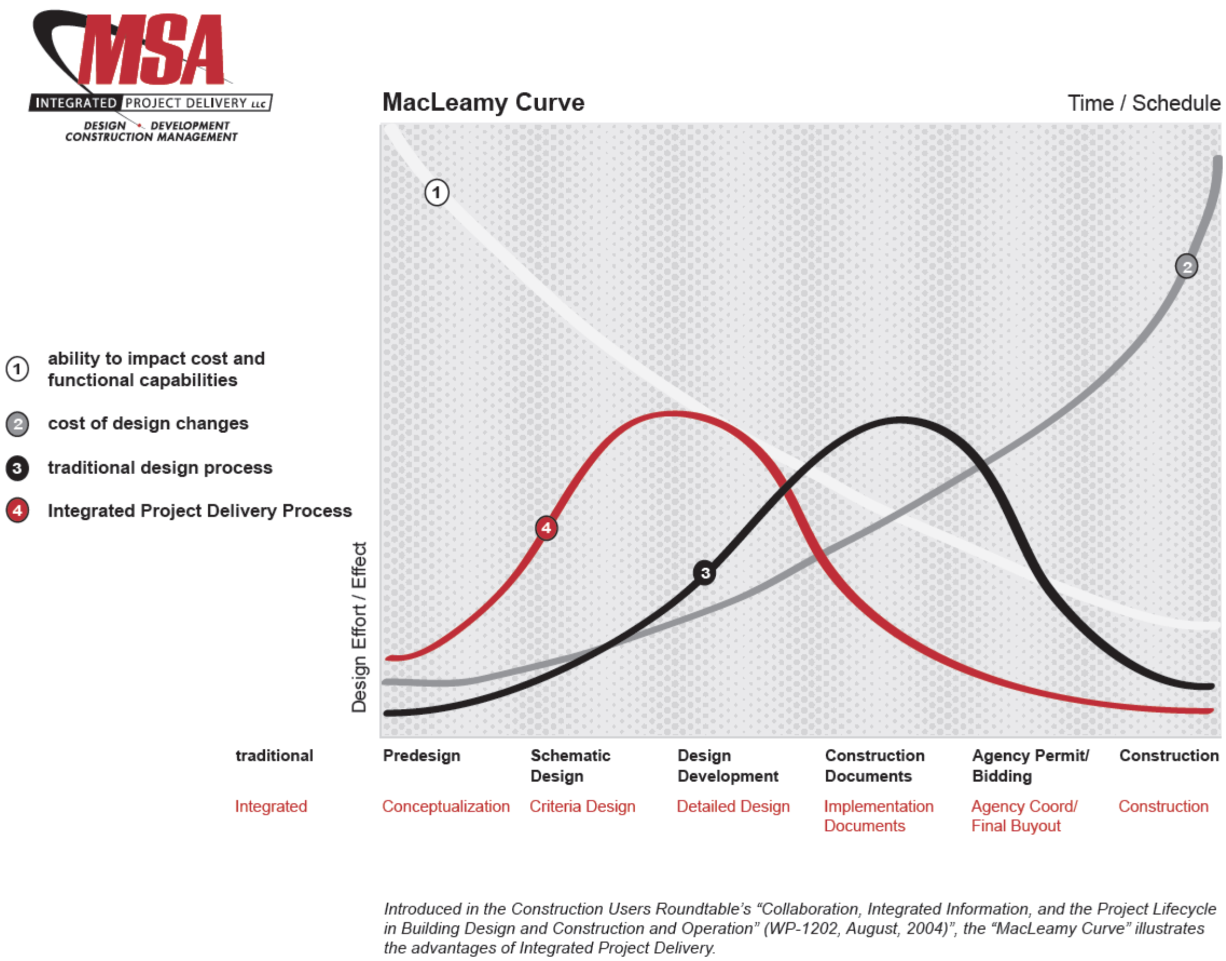

Figure 31: Advantages of Project Integration in the Pre-Construction Phases

[47] MacLeamy, P. (2004). MacLeamy Curve. *Building Design and Construction*, WP-1202.

7.2 Conceptual Design Issues

At the start of the MQP the master plan document from the Sasaki Architecture Firm provided a basic breakdown of the necessary areas for the new athletics facility. From this master plan, a conceptual design was modeled in Revit that produced several important design considerations. It is crucial to address these conceptual design issues in the pre-construction phase because as the project goes on, the cost to make changes rises. However, through the use of Project Integration these changes can be identified and addressed earlier than usual.

Firstly, WPI's new athletics facility called for 130,000 to 150,000 Global Square Feet (GFS) of space to adequately house the necessary facilities and systems. While this number may seem to be adequate, there were several concerns from all disciplines about the size of the facility. The conceptual model designed by this project team, classified as MQP1, was a basic shell of four floors, with one level being a mezzanine adjacent to the natatorium. This design was calculated to be approximately 135,000 square feet which was within Sasaki's master plan. The specific changes to the plans can be viewed in Appendix K: Program Area Changes in Conceptual Phase.

After the design committee for the actual WPI project met on Jan 22, 2009, it was clarified that with the current recession and the possible soil condition complications, that the size of the facility should be shrunk by about 10,000 to 15,000 square feet. Through what is known as construction value management the value added by each functional area of the proposed design to the ultimate use of the building is assessed in terms of its monetary value, and decisions to cut, shrink, or move these functional areas are made.

Some of the particularly important facility functions were the natatorium, fitness center, multi-court gymnasium, indoor track, rowing tank, and office space. The natatorium, multi-purpose gym, and indoor track are the driving factors behind the design of this facility. Not only are they the largest areas, but the dimensions for each are regulated by international standards. From the perspective of this study, this meant that these areas were basically off limits to size reductions, and due to their size, placement of these areas was complicated. Their dimensions are respectfully 200 feet by 100 to 120 feet for the indoor track[48], 84 by 164 for the pool by Olympic Standards[49], and 220 by 100 feet for the multi-court gymnasium. From these dimensions it is clear that the limiting factors are the gymnasium and the track areas. However, it was pointed out by the structural engineer that these areas can be placed on top of each other if there is proper support. This led to the structural analysis of the truss system under the gym courts which quickly became an important topic of design.

The rowing tank is an interesting addition to the facility because of a generous donation. As a request, if WPI decided to incorporate a rowing tank into the new facility, the donation would pay for the construction cost. While many suggestions for the new facility, such as a Jacuzzi, were made with good intentions, most were eliminated due to impracticalities. However, the rowing tank was an exception because it would be fully utilized by WPI students. After this generous offer was made, any new designs incorporated a rowing tank.

One major design issue that arose was the height of the building and after brainstorming Cannon Design created three concepts for the building. The driving factor for this

[48] Amburst, W. (n.d.). *Track Calculator.* Retrieved September 25, 2008, from North American Racewalking Foundation: http://philsport.com/narf/atrack.htm
[49] Cannon Design. (2008). *Student Opinions on New Athletics Facility.* Student Survey.

issue was the layout of the building. In essence the facility would stack the track on top of the gymnasium and the gymnasium on top of the natatorium. After a geological survey was conducted it was determined that the bedrock was found to be at an elevation of 504 feet, a full 17 feet under the football field. The stacking of the three major components of the building leads to a building height of almost five stories, a daunting spectacle on a college campus.

Cannon's first concept was to separate the pool from the main facility and attached it to the side. However this creates problem with foot traffic paths and disturbs the natural flow of the building. This concept was quickly done away with by the design team. Also the site plan analysis made by this MQP determined that a facility under this design would impact the surrounding soccer and baseball fields greatly and reduce the accessibility of the site.

The next concept was called "stacked-down", illustrated in Figure 32, which entailed the facility to be excavated into the bedrock. From the south eastern face of the building, facing WPI's Quad, the facility would appear to be only one story tall. While this concept allows for a better view of Boynton Hill to the north, it drastically increases costs and makes the facility appear less important when situated between the four story buildings of Harrington and Morgan Hall. The infeasibility behind the "stacked-down" concept is derived from the excavation into the bedrock. A meeting with Neil Benner, project manager from Gilbane, explains that in a project of this size the foundations into the bedrock need to be blasted, which in itself is expensive, then the holes made need to be loosely filled so the crane can traverse the site, and finally the holes need to be re-excavated to lay the foundation footings. In essence this concept requires the foundation to be excavated twice.

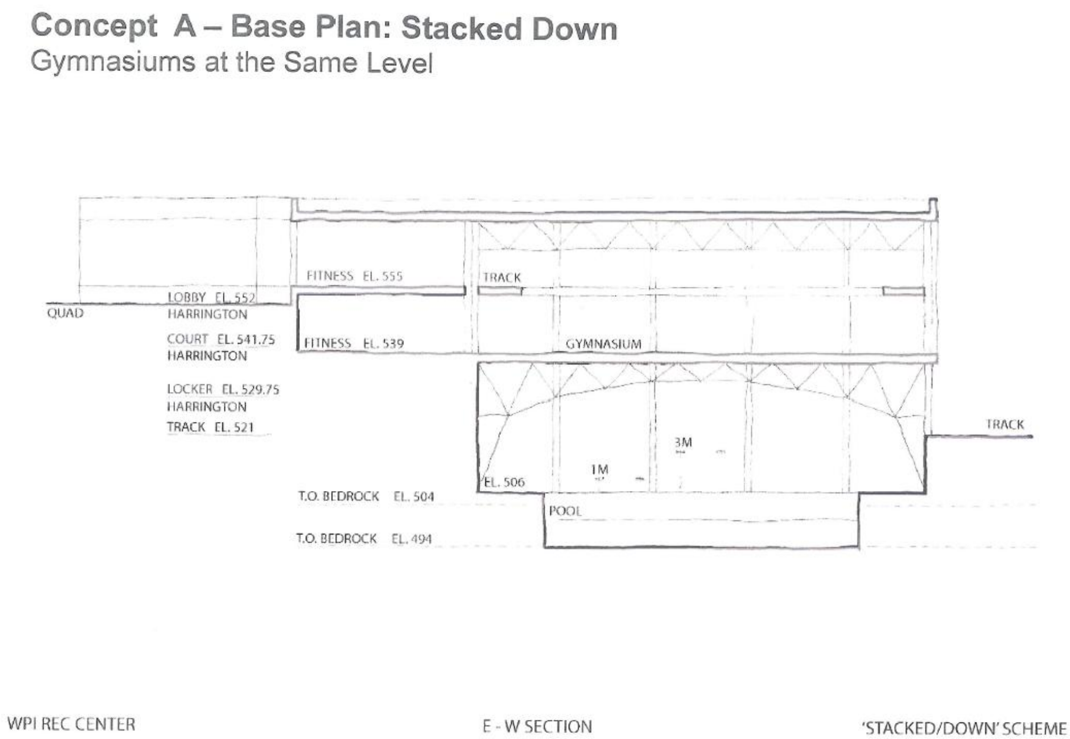

Figure 32: Stacked-Down Section[50]

The "stacked-up" design concept has a lower cost than the "stacked-down" concept and has a two-story face along the Quad, but it also came with a few downsides. This concept did not have a connection to Harrington's gymnasium floor and the design also required a massive twenty-five foot plus retaining wall. In a project meeting, the management team of this MQP determined that the difference between a twenty foot and twenty-five foot retaining wall was tens of thousands of dollars because of the use of tie-backs.

With these design concepts in mind, the MQP team decided to build upon the "stacked-up" version of the facility with a few alterations. Structurally it would be difficult, but not impossible, to design a truss system to carry the gymnasium and tracks above the natatorium.

[50] (2008, December 11). WPI Design Committee Meeting. (T. Grant, & B. Blanck, Interviewers)

Also, the savings made by not excavating into the bedrock would allow for better use of the available funds. A major breakthrough was made when a floor plan analysis of the conceptual model led to the creation of a mezzanine level, Figure 33, between the natatorium floor and the gymnasium floor along the southeastern and northeastern faces. This mezzanine level, in later models labeled as Office Floor, was adjacent to the actual natatorium space which did not impact the design of the truss system; instead it broke up the height of the retaining wall which will save drastically save on construction costs, and is located at the same elevation as Harrington gymnasium for easy access between the two facilities. This is a prime example of how integrated practice can produce solutions to complex problems. It is not to say that a designer would not develop a solution such as this, but with the input from all the various disciplines the advantages and disadvantages were explored quickly and efficiently.

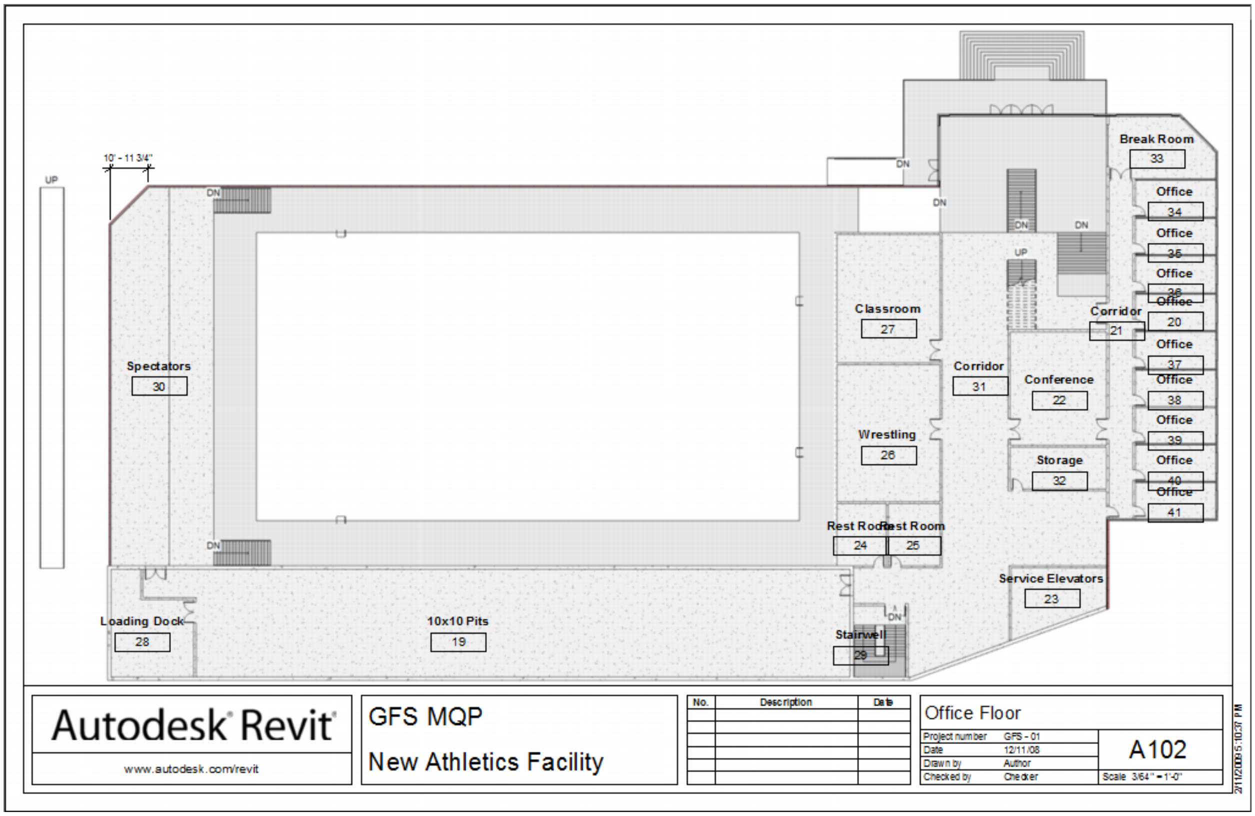

Figure 33: MQP Design, Mezzanine (Office) Level, Elevation at 540 ft

In a later design committee meeting, Cannon also discovered and implemented this mezzanine level, illustrated in Figure 34. Even though the Revit model of this MQP differs from the designs made by Cannon, the basis for the designs and feasibility of various aspects remain the same. Even though Cannon Design and Gilbane Construction Co. have sufficient professional resources to flush out the problems and solutions in designing WPI's new athletics facility, the use of project integration by this MQP can produce less accurate but comparable results.

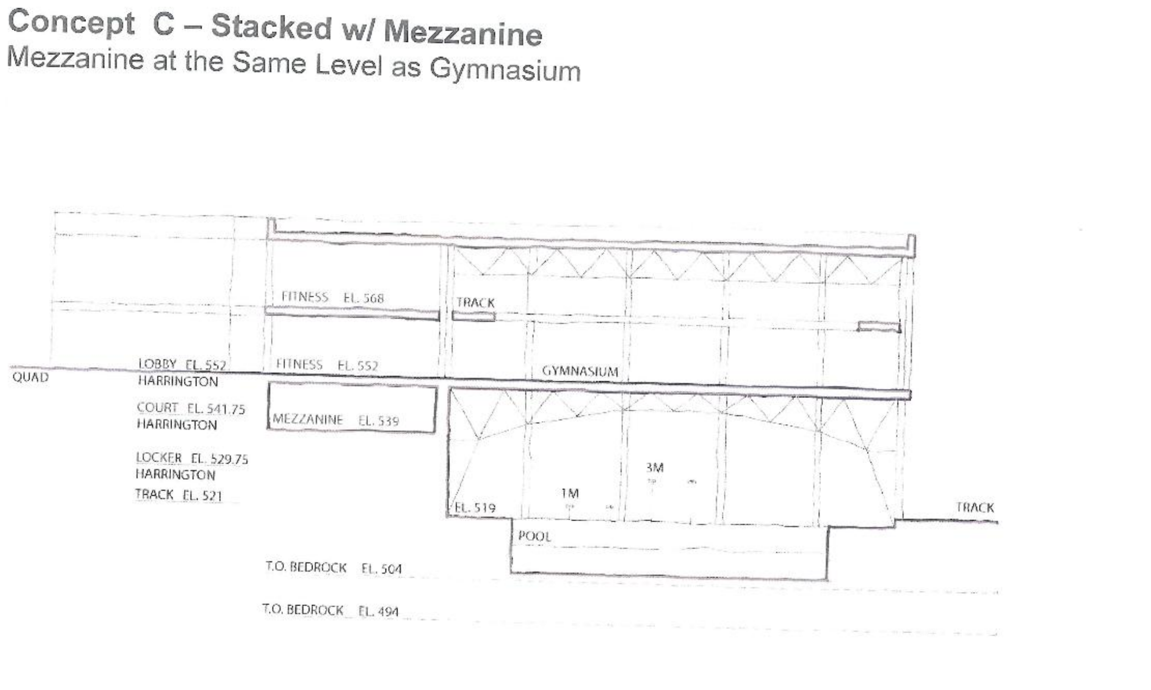

Figure 34: Stacked w/ Mezzanine[51]

In the creation of the Revit model based upon the "stacked-up" concept the MQP team discovered the difference between professional surveys and third party information. In a document provided by Neil Benner and Cannon Design, the ground floor of the new Facility would be located at an elevation of 521 feet above sea level. This elevation was said to match that of the existing track and field. However, after importing topographical data from the U.S. Geological Survey, displayed in GoogleEarth, the track and field were displayed at an average of 525 feet above sea level. In order to verify this difference the elevation on the southeast, or Quad side, was checked and found to match. Normally a one foot difference in elevations is normal because of soil expansion and water content. However, a four to five foot difference in

[51] (2008, December 11). WPI Design Committee Meeting. (T. Grant, & B. Blanck, Interviewers)

elevations is extremely high and could present disastrous results. It was stated that the U.S. Geological Survey is only accurate within five feet, and the results given by Gilbane were made by doing on-site surveys which are accurate within an inch. This situation shows that with good communication, disastrous design mistakes can be easily avoided.

7.3 Schematic Design Issues

After the introduction of a mezzanine level to the "stacked-up" concept it was nearly a unanimous decision to start development of several schematic design aspects of the new athletics facility. These designs are not as detailed as the final documents that will be used for construction, but they allow for closer inspections of the programs and systems that the new facility will include.

Originally it was planned for the new athletics facility to be attached to Harrington along the north eastern face on all levels and the Revit Model developed by this MQP followed suit. However, Cannon and Gilbane presented the case that connecting the two buildings on every level would lead to various complications. If both buildings were attached, then the fire safety codes of Harrington would change and the building would need immediate renovation, which would make the gymnasium inaccessible for a large amount of time and negatively impacting WPI's athletics program. Also attaching the buildings would lead to issues concerning foot traffic from the future parking lot to the upper levels of the campus. After the January 22, 2009 Design Committee meeting, Cannon Design stated that it was in WPI's best interest to not connect Harrington and the new facility at least on the upper levels. Later designs, Figure 35, showed that the two buildings were connected on lower levels to provide access to and from existing locker rooms. This issue shows that while project integration helps create solutions to complicated problems, our status as students without much field experience led us to overlook such an important design concept.

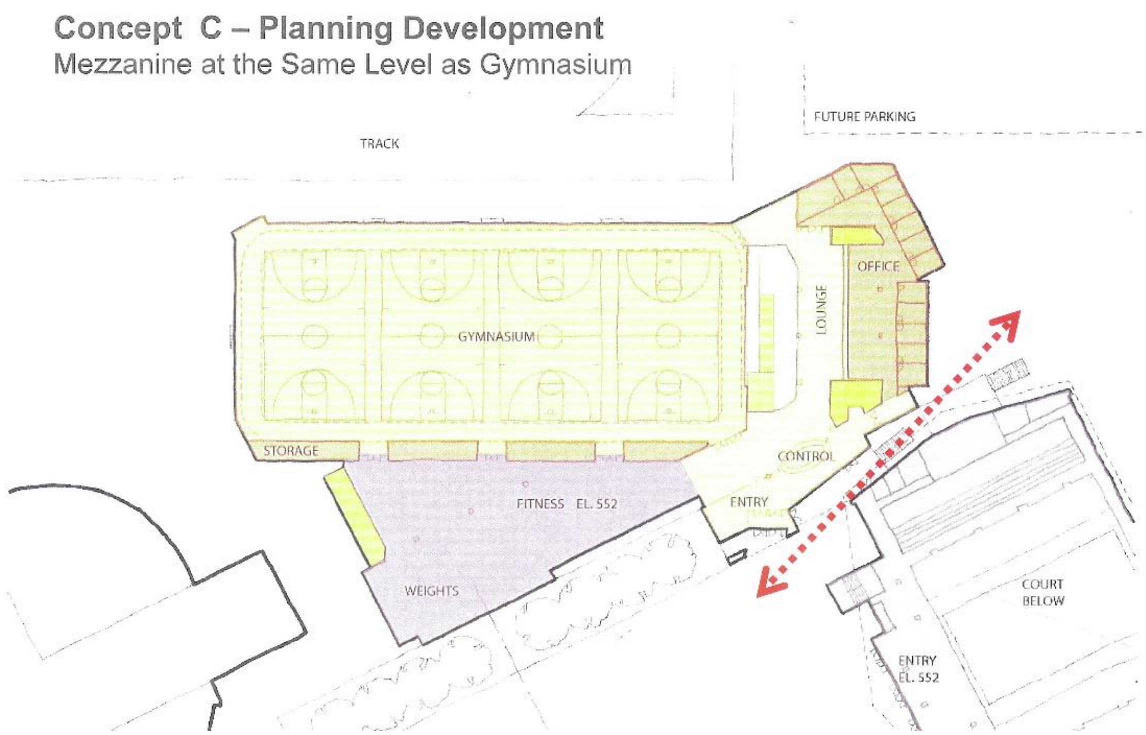

Figure 35: Red Arrow Indicates Separation of New Facility and Harrington

Building upon the gap of experience between us as students and the professionals assigned to this project, there were several design issues that the first Revit model overlooked. In comparison, the first Revit model developed was much more of a conceptual design aid while the second model produced incorporated various schematic design issues discussed. A facility as large and complicated as the new athletics facility has several design requirements that must be met in order for it to function properly. These items include service elevators, a loading dock, HVAC equipment, a cooling tower, electrical access, sewer access, and available natural lighting. The importance of each of these issues varies but they all must be addressed for the facility to function.

The location of the service elevators and loading dock were particularly complicated. When discussed by the MQP team, two options for the location of the loading dock and requirements for the placement of the service elevators were developed. Since the building would be approximately four stories tall the MQP team assumed that is that the service elevators would be operated by pneumatics rather than a cable system. This removes the need to mount additional mechanical systems on the roof and makes the placement simpler. However, it was determined that the service elevators should be in close proximity to the gymnasium in order to better support events hosted by WPI.

In private MQP meetings the location of the loading dock was determined to either be on the northwestern face near the Higgins parking lot or the southwestern face utilizing the already existing service road. During a design committee meeting Cannon showed that it had the loading dock located at the southwestern face. Without much explanation as to the reasoning behind this location, the MQP team investigated the pros and cons between the two locations in order to see if our reasoning was comparable to Cannon's. The northwestern location would allow for a less hilly terrain for vehicles but would ultimately infringe on the future parking lot and would utilize the service elevators extensively. After deliberation the MQP team decided on the south western choice, despite that it would be along a hill and would require reworking the existing roadway to the proper elevation. This location was more feasible because WPI planned to remove that service road after construction and it was on the same level as the mezzanine which allows for easy access from the new facility in Harrington. While Cannon's exact reasoning behind the location was not confirmed, it was confirmed by Gilbane that our reasoning was similar to that of the professional design team.

Other smaller but still important design issues were discussed in the design committee meetings that the first Revit model did not address. Firstly, the electrical access of the new facility was coming from the Quad and it was much more feasible to have the electrical rooms along the southern walls in order to avoid running large power cables through the facility. Sewer access for the facility is located along the northwestern corner of the site, running from the Quad to the sewer main along Park Avenue. This lead to the designing the facility with restrooms and locker facilities located close to the sewer access. It is entirely possible to locate restrooms on the opposite side of the building. However such a design would require piping to run along the walls or under the grade further increasing costs and possibilities of maintenance problems. Lastly, WPI's new athletics facility is so large and unique that is requires a large number of mechanical systems. It was fairly simple to locate the pumps and filters for the natatorium on the ground floor in a relatively less accessed area. However, the HVAC and cooling tower equipment were decided to be on the roof. It is possible to locate said systems on the site and attached to the facility, but after consultation with the management team it was explained that locating them on the ground would drastically increase costs. This cost increase comes from pumping air and water up into the building instead of using the aid of gravity to pump it down into the facility. Although it was decided by the pre-construction teams to place the mechanical systems on the roof, the aesthetics of the facility would be greatly affected as shown in Figure 36, and this schematic design issue was fervently discussed by WPI's design committee.

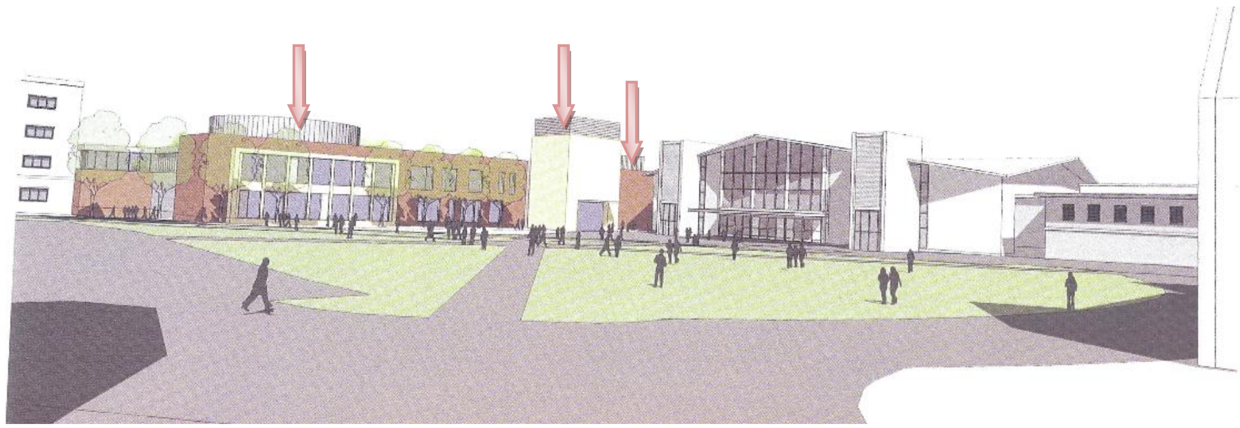

Figure 36: Stacked Up Rendering - Arrows Indicate Mechanical Housing[52]

The involvement of WPI's design committee provided a strong feedback on the basic schematic design concepts developed as well as the programs located within the facility. One major requirements of the new athletics facility was the interaction between Harrington and the ability to host events. With the introduction of the mezzanine level the robotics competitions' intentions were preserved while keeping the primary use saved for athletics. Other concerns for the facility were the location of the locker rooms and the distinction of the new facility from Harrington.

The current locker room situation at WPI has been a major concern of the staff for several years. It was planned that the new facility would accommodate the needs of the students and staff. Preliminary designs have fallen short of supporting this need and the design committee adamantly requested that this issue be addressed. This is a prime example of addressing the clients' needs and should be solved before designs extend further. It is difficult to evaluate whether or not the Revit model produced by this MQP fully addresses this issue,

[52] (2009, February 2). WPI Design Committee Meeting. (T. Grant, Interviewer)

but it is important to note that in the design of the model the locker rooms quickly took precedence over other minor facilities.

Even though this MQP performed pre-construction designs to a lesser extent than those of the actual design firms, without project integration it would have been difficult for the designs made by the MQP team to be so similar to the designs produced by the professionals who have years of experience. By incorporating different disciplines several design issues were discovered and addressed quickly and efficiently.

7.4 Truss Analysis

When this project began the actual athletic facility project by WPI was still in the early stages of design. The only available documents to base our building from were partial designs done by the Sasaki design company as part of an overview of WPI's long term plan for campus renovation. It was important to ensure that the part of the building selected for structural analysis would still be a part of the WPI project at the end of the MQP. A major driving factor for the new athletic facility was the construction of a competition sized pool to replace the undersized pool in Alumni Gymnasium. Therefore, the team decided that the natatorium would be a good starting point for structural analysis. Upon further inspection of the proposed natatorium it was decided that the focus should be on the overhead trusses because of the wide span they would need to have.

To accommodate the competition sized pool the overhead trusses would need to span a length of 110 feet as shown in Figure 37. Through discussions between the REVIT design and structural design members of the team it was decided that the most viable building design was to have the natatorium on the bottom floor of the building with the gymnasium directly above it, similar to the Sasaki design. With this decision the wide span truss system needed to be designed strong enough to support the gymnasium.

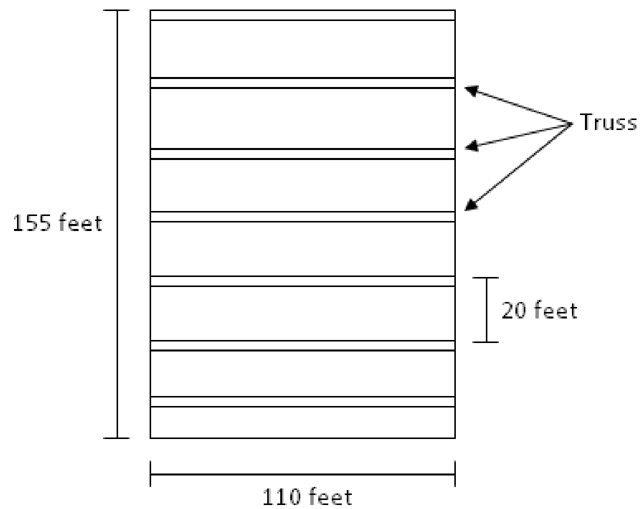

Figure 37: MQP Natatorium Dimensions

Truss design began with finding the correct loading patterns. The applicable vertical loads in this situation were just the dead and live loads. Other load types, such as snow load, did not apply to this truss while others, including vibration loading, were considered but eventually disregarded after consulting with the group's structural advisor. To calculate the dead and live loads, the following sources were used. The American Concrete Institute code Table 9.5(a) was used to determine the necessary thickness of the floor slabs for the gymnasium. The 1997 edition of the Massachusetts State Building Code was then used to find the appropriate dead loads applied by the reinforced concrete floor slabs and hardwood flooring. The given loading was then multiplied by the tributary area of each truss to find the unit weight per unit length the trusses were responsible for. The weight of the supporting truss system was also included in the dead weight calculations. This was determined later in the design process as other unknowns, including the amount of steel, the number of trusses, the size of the steel members, and the joist sizes, were needed to be determined first. To determine the live loads, the 2008 edition of the Massachusetts State Building Code was used. The load combination equations used to incorporate the dead and live loads together were also found in this edition of the MSBC. The most applicable equation used for this project was equation number 16-9 in the MSBC.

When the loading was determined different truss shapes were analyzed initially using the ANSYS software. Different truss types were analyzed with the same loading to determine which type was most effective at resisting a generic distributed load. This was applied as concentrated loads at the joints. Some of the common truss orientations tested included the Pratt Truss, the Warren Truss, the Sub-divided Warren Truss, and the K-Truss. As shown in Figure 38ANSYS was able to calculate and display the deflection of a truss with the defined loading.

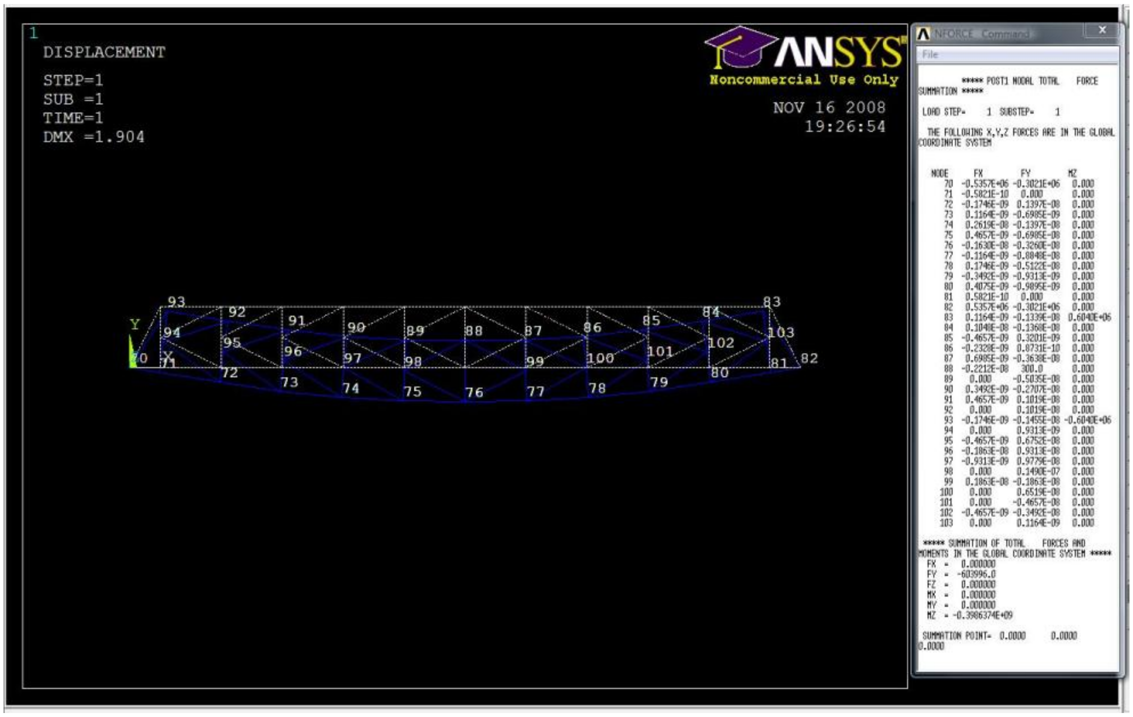

Figure 38: K-Truss Deflection in ANSYS Software

However, since none of the team members were familiar with ANSYS, it was soon discarded as an analysis tool. However, A few items of value did come out of this procedure. It provided deflections that were referenced when making an educated selection of truss types for analysis using the method of joints. It also gave a visual aid early in the project that allowed the group to understand the type of deflection being experienced.

After attempting ANSYS the structural member of the team decided to proceed with analysis on paper using hand calculations. These were then inserted into Microsoft Excel for easier alteration when changes were deemed necessary. The trusses analyzed this way included the Warren Truss and an inverted version of the Warren Truss. These calculations can be found in Appendix H.

During the ANSYS analysis the most effective truss seemed to be the K-Truss. It supported the generic load with less deflection than any of the other truss shapes. However, after consulting with other members of the team this truss option was later eliminated from consideration. The team decided that this style of truss was simply too complicated to fabricate repeatedly, and included more steel than the other options making it a less economical option. After the conversion to the joint method of analysis, the most effective truss type was found to be the Warren Truss. It was much simpler than the K-truss and used less linear feet of steel per truss. The Warren truss, shown in **Error! Reference source not found.**Figure 38, was selected to be used for this project.

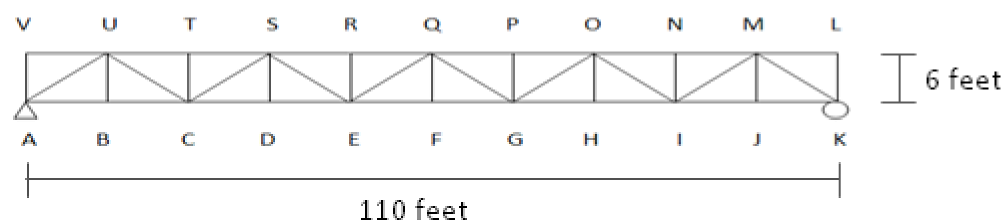

Figure 39: Selected Warren Truss

Integrated practice was important to this part of the project. Working directly with the REVIT design member of the team it was found that the design parameters of the natatorium conflicted. The REVIT model had been designed with a natatorium that was approximately 147 feet long and 130 feet wide. The trusses had been designed assuming the natatorium to be 155 feet long and 110 feet wide. The easiest way to rectify the issue was to include interior columns at the ends of the 110 foot trusses and add extra truss panels or beams to span from the columns to the walls. However, later in the project the natatorium was changed back to the original dimensions of approximately 155 feet by 110 feet negating the need for the additional interior columns. If integrated practice had not been utilized and the problem addressed early on, this problem may have compounded causing much more work for the entire team.

During this meeting the issue of having a three meter diving board in the natatorium was also discussed. Enough clearance had to be given to the divers between the top of the diving board and the bottom of the truss. The two design members of the team decided that with a 30 foot high room a truss height of six feet should be short enough to provide enough room for the divers. This new change required the truss system to be reanalyzed. The initial trusses had been designed with ten 11 by 11 foot panels. The new design required the panels to be reduced to dimensions of 11 by 6 feet.

This modification caused the angle of the diagonal members to change along with the force patterns on each truss member. In the previous design the panels were made square with the diagonal members at a 45 degree angle, making the forces applied in the horizontal and vertical directions identical. The new design reduced the angle of the diagonal members to 28.6 degrees, as shown in Figure 40**Error! Reference source not found.**, creating a greater horizontal force and lower vertical force using the same initial loading.

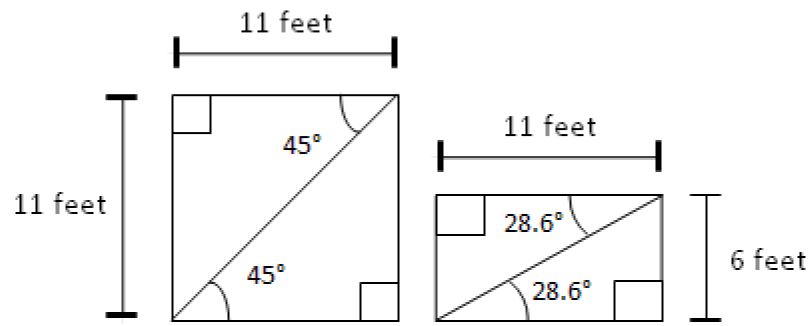

Figure 40: Panel Size Alteration

Another aspect that was important during the truss design was the spacing between the trusses. A larger spacing would result in a higher load demand on each of the members as the tributary area each truss would be responsible for would increase, but a smaller spacing would mean more linear feet of steel needed, and more trusses to be manufactured, connected, and installed. After calculating the applied loads on a few different spacing configurations, a spacing of 20 feet on center was decided upon as a good compromise between cost and stability.

To complete the truss analysis, lateral loading was also considered. The western and southern facing walls could be subjected to either wind or earthquake loading. The eastern wall was projected to be against a hill causing lateral soil pressure as well as seismic loading. The northern face of the natatorium was still located inside the building so lateral forces were not considered in this direction.

As the trusses are horizontal members they were not expected to resist the lateral forces. These loads were carried by the vertical components, including the columns and the load bearing walls. The trusses were needed, however, to facilitate load translation to the appropriate vertical resisting members. To assist with the translation, bracing may be added between the trusses.

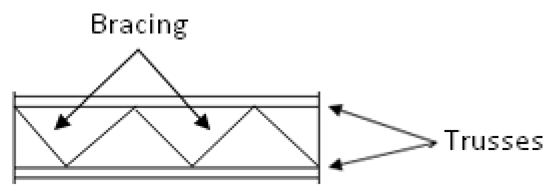

Figure 41: Suggested Bracing Placement (Overhead View)

The bracing systems would need to be designed to effectively translate the lateral loading to the resisting members. It would also need to be decided what the lateral load resistance members will be. Two of the most commonly used options are to use load bearing walls or to utilize the columns already in place. The designer should be cautioned that if the columns are selected that they will be subjected not just to the lateral loading but to the vertical loading of the building as well. Although lateral loading was found using the Massachusetts State Building Code and ASCE 7, the bracing system for the trusses was not designed due to time constraints.

The simplest method of choosing truss members would be to use a consistent steel size throughout the truss. However, this would lead to a gross overdesigning for the members experiencing less force. Therefore, to make the trusses more economically viable, different sized members were used depending on the forces experienced. To avoid overcomplicating the fabrication of the truss, only three different member sizes were used. These sizes, as seen in Appendix H, are wide flange members W12x79, W12x45, and W6x12. The member sizes used were found in Table 1-1 of the 13th edition of the American Institute of Steel Construction Steel Construction Manual.

Once the initial truss design was completed, the floor joists needed to be designed to help support the floor slab above. This was done using the Vulcraft Steel Joists and Joists Girders catalogue made in conjunction with the Steel Joist Institute as a guide. The joists experienced the same dead and live loads as the trusses except only had to support their own dead weight instead of both theirs and the trusses. After analysis it was found that Double 18LH09SP joists would be needed. The loads were too excessive for a normal double joist size. Therefore, a joist designed for long spans was selected, but would need to be fabricated shorter for the smaller actual length. This modification would need to be communicated to the manufacturer to ensure it is met.

In the future girders and columns will need to be designed to transfer the load into the foundation. An important decision to be made concerning these two components will be the distribution of columns. If the choice is made to place columns at the ends of each truss then the girders will be needed mostly to add lateral support to the columns as shown in Figure 43.

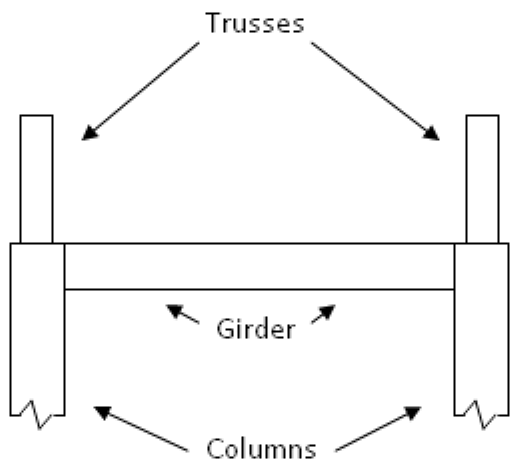

Figure 42: Column Configuration A (Side view)

However, if it is decided to use fewer columns, as shown in Figure 43, it will be the responsibility of the girders to collect the end loads from the trusses and translate them to the nearest columns. This will mean that the girders must be large enough to support the loads coming off the trusses.

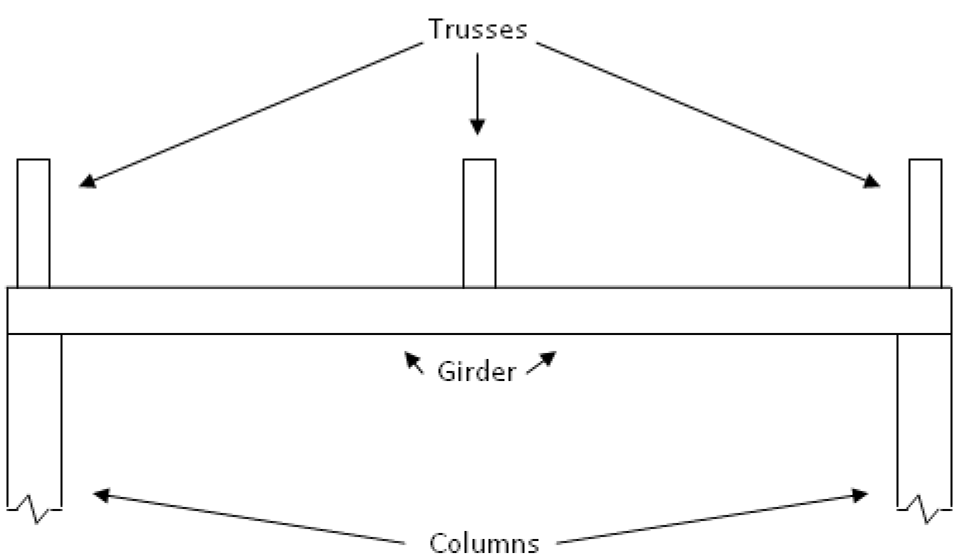

Figure 43: Column Configuration B (Side view)

The use of Integrated Practice had an overall beneficial effect on the truss design. The main advantage was the ease of communicating changes with other members of the group. This process would have been much more tedious if common construction practices of today were used and the changes had to go through one or more middle men.

7.5 Green Building Analysis

Green Buildings and High Performance Buildings have become a staple choice for new construction for institutions around the country, and WPI determined that the new athletics facility needed to be LEED certified. There are many advantages to develop a LEED certified green building, and there a few disadvantages to this process as well. Green buildings promote more publicity, lower maintenance costs, lower utility costs, and help reduce the impact on the environment. The main opposition to a green building is the high front end cost. Typically a green building will cost 5-10% more than a similar building that is not "green".[53] However the money saved on utilities and maintenance are so high that green construction often returns the investment in three to five years.

WPI's new athletics facility has the potential to be a shining example of a LEED project. The LEED accreditation system grants points for various aspects of the building that promote sustainability and reduce environmental impacts. From these points a rating of platinum, gold, silver or certified is awarded to the building. With such a large facility and the early involvement from Gilbane, who is knowledgeable of LEED accreditation, the potential to achieve higher LEED ratings such as gold or platinum is possible.

[53] Kibert, C. J. (2007). *Sustainable Construction: Green Building Design and Delivery.* John Wiley & Sons..

There may be hundreds of ways to apply the LEED accreditation system to the new facility but some of the major aspects that should be considered are the use on natural lighting, solar energy, and water conservation. While there may be easier LEED points to achieve from buying local materials to recycling all waste generated, some of the more difficult to obtain but more profitable systems deal with energy conservation.

The athletics facility is situated on site in that it has exposure to western sunlight past noon, little eastern sunlight exposure, has a large roof space, and will consume large amounts of water. This western sunlight exposure can make designing controls for glare and reflection for this light source complicated and expensive, but it also allows for a large amount of natural light and heating. The design team should also consider the more expensive but better insulated double pane glazing. While these panels of glass are much more expensive than traditional single pane glass, they have been proven to greatly reduce the amount of heat lost through windows.

Since the facility will be situated on a relatively open site with little tree cover, the large roof space allows for the installation of solar energy panels with an average of fifteen square feet in area. With current designs the facility could possibly utilize over 30,000 square feet of roof space for solar panels. While this area can support over 2000 panels, it is up to the design team to determine the best use of solar panels versus skylights. Figure 44 depicts the possible roof space allowable for solar panels.

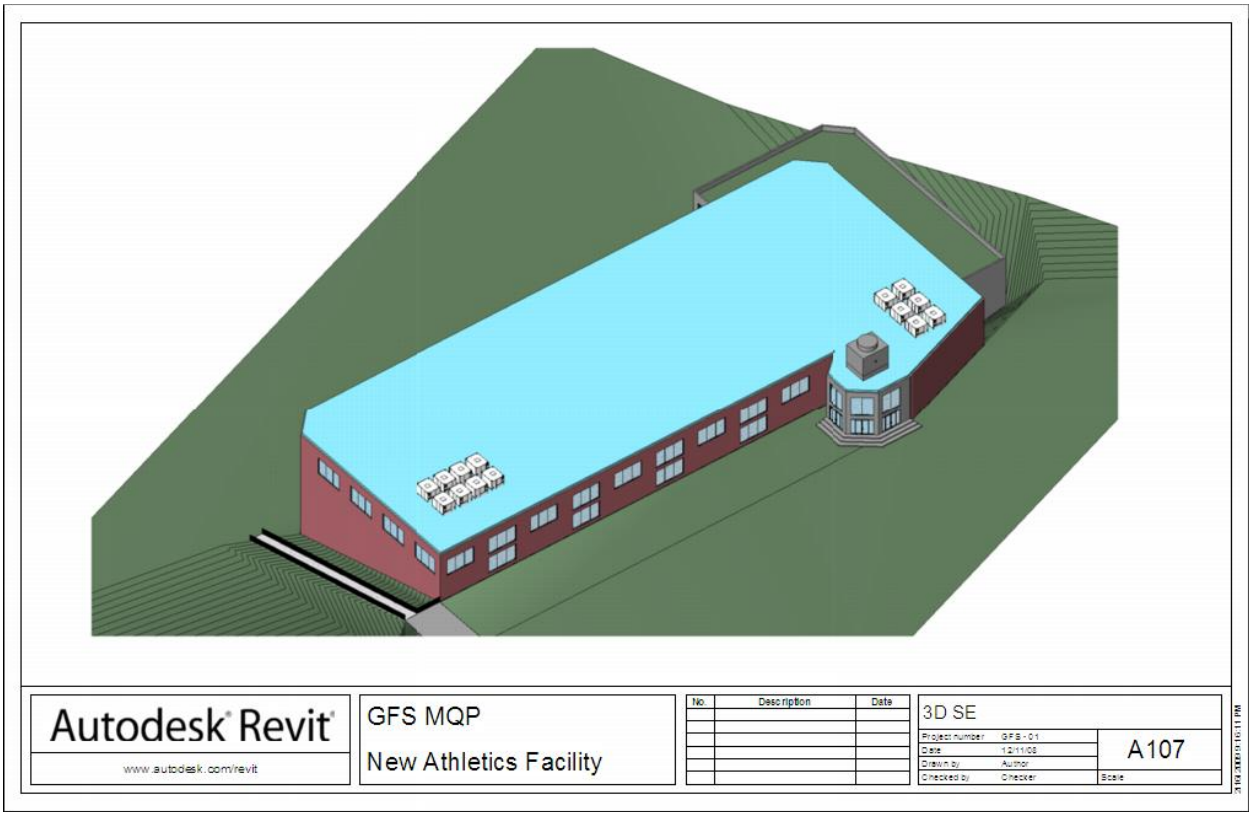

Figure 44: Solar Panel Roof Space (Highlighted in blue)

Currently Massachusetts law only permits solar energy units to produce seventy percent of non-residential units' electricity consumption. Even if WPI installed enough solar panels to only generate up to seventy percent of the facility's electricity consumption, that seventy percent would represent an enormous amount reduction in utility costs which will allow the saved money to be applied elsewhere. Legislation is currently under consideration to remove this restriction which would allow WPI to produce as much electricity as it saw fit.

The various systems and programs housed by the new athletics facility will consume large amounts of potable water, and if the project team can make improvements to the water uses, then significant savings can be achieved. The facility is planned to include an Olympic sized swimming pool, shower stalls, training facilities, rest room and a rowing tank.

Tremendous savings can be made by finding a way to recycle water either from storm water or wastewater, and the impacts on local water sources will be reduced.

Another minor but important green building concept under consideration is the implementation of a green roof system as illustrated in Figure 45. This system would act as a filter for storm water, add to the aesthetics, and act as an insulator for the facility. Simple systems like these can greatly reduce the environmental impact this facility has on the environment.

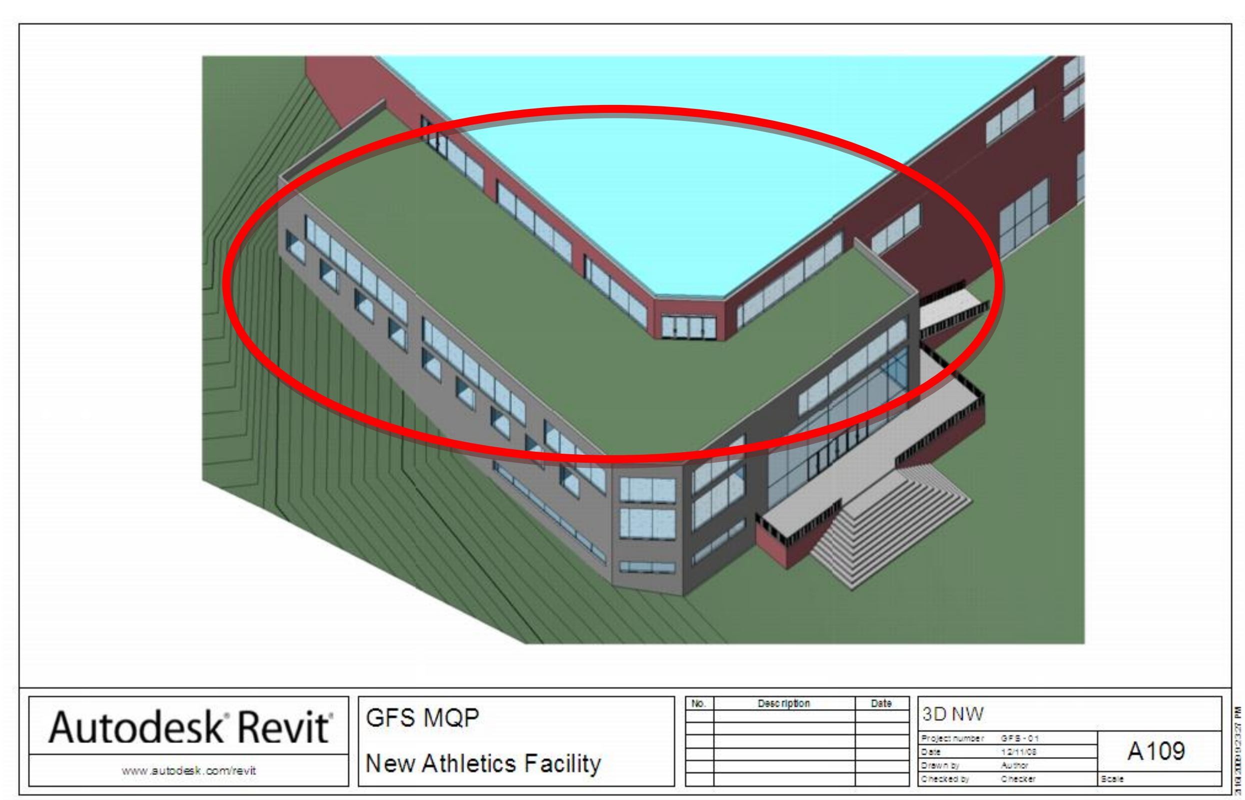

Figure 45: Proposed Green Roof Space (Circled in Red)

By following integrated design processes, the design team has the potential to save on maintenance costs, and show that WPI is dedicated to reduce its impact on the environment. Constructing a green building requires higher front end costs, roughly 10% higher than traditional building methods, for the non-traditional systems but in the long run these investments pay for themselves.[54] With the constant interaction between the LEED Accredited Professionals from Gilbane and the design team from Cannon, this project should be able to identify many available LEED points and lead to a high rated green building. Without integrated practices incorporating LEED certification into the design process would be difficult and more time consuming than necessary.

8 Community, Investment and Cost Estimation

One of the major driving factors behind the athletic facility and most of the changes being made to WPI come from its students and faculty. Everyday people from both areas voice their opinions and desires to WPI trustees as well as administrators. The construction of a new athletics facility is one such desire stakeholders have expressed for several years. In order to gain a better understanding the driving factors behind the construction of a new athletics facility and the funding for such a large project, the MQP team performed various interviews with key personnel as well as consulted Cannon Design on an open survey for students on October 1, 2008.

The MQP team also performed two major cost estimations and a green building analysis for WPI's new Athletics facility within the limitations of time and information. It is important to note that these analyses were conducted with portions of information and various assumptions were made.

[54] Kibert, C. J. (2007). *Sustainable Construction: Green Building Design and Delivery.* John Wiley & Sons.

8.1 Community

The MQP team's first interview was with Janet Richardson, the Vice President of Student Affairs. Janet Richardson is responsible for the delivery of services to all undergraduate and graduate students at WPI. She also oversees the office of undergraduate admissions, enrollment management, financial aid, student life, the Career Development Center, the department of Physical Education. Essentially, Richardson is responsible for Student-Institution relations. Richardson informed the team of the basic funding of the Athletic Facility, as well as the impact she expects the new facility to have on campus life. Richardson stated that unlike the funding for most new facilities, the new Athletic Facility would be funded entirely through the Capital Campaign.[55] Normally, bonds are issued for funding construction but Richardson believes this will be difficult in today's economy. Construction can only begin once 90% of the funding has been acquired. Richardson informed the team that LEED certification is a requirement for the building, though the school is not targeting any specific level at this time. She was excited about the new Facility and believes that it will cause a positive impact on both the students and faculty. Janet Richardson referred us to Dexter Bailey, Vice President for Advancement and Alumni Relations, for further information regarding the funding of the new facility

According to Janet Richardson many of the WPI students have felt that a new athletic facility could become a key selling point to attract students in the future. The qualities of the current facilities have been described as minimal at best. One of the major problems WPI

[55] Richardson, J. (2008, December 3). (B. Sealund, & B. Blanck, Interviewers)

students have is the lack of a regulation size pool as well as a substandard weight room. These two problems would be solved by the addition of a new athletic facility to the WPI property.

In the information survey coordinated by Cannon Design on October 1, 2008 the MQP team investigated results of the survey in order to understand the demand for specific programs in the proposed facility. The survey consisted of various posters that depicted the larger proposed programs that would be found in the facility; such as racquetball courts and a climbing wall, and students would place votes for the programs they thought were most important to them. WPI administrators believed that the most popular programs would be competition sized pool and indoor track. Surprisingly it was discovered that the student body placed the most votes in the fitness center.[56] Results such as this helped voice the demands of the student body and define the scope of the project clearer for Cannon Design.

WPI also held a student town meeting on December 6, 2008 in order to report upcoming changes, accomplishments, goals, and further gain an understanding or students' concerns. Various topics were discussed between faculty and students at the meeting. When the discussion turned towards the new athletics facility the program gave an overview of the current design considerations but limited the amount of specifics such as budgeting information. Further investigation into the topics of funding and the budget were conducted in interviews WPI administration.

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[56] Cannon Design. (2008). *Student Opinions on New Athletics Facility.* Student Survey.

8.2 Investment

From these interviews it was discovered that investment in this project will come from a combination of alumni donations and the creation of new debt. To collect specific information on how WPI sees the development of the new facility as an investment and then to conduct an investment analysis the project team conducted interviews with both Dexter Bailey and Jeff Solomon.

Dexter Bailey is the Vice President for Advancement and Alumni Relations. His mission is to raise funds for WPI primarily from donations and gifts from Alumni and other donors. Dexter explained to the team how the WPI budget works and how the school funds specific projects. The total estimated cost of the facility is $50 million dollars, $20 million to be financed by the university and $30 million to be raised from gifts from Alumni or corporate sponsors. Dexter Bailey went on to describe how the school goes about trying to get $30 million in donations from Alumnus.[57]

Dexter, along with other staff from his department, routinely goes through the list of WPI graduates, and finds those that have shown interest in WPI. Dexter finds those with a history of revisiting the university and possibly some past philanthropic actions. He then finds any public financial information such as bonds or stocks and decides whether or not they are worthy of contacting for a donation. For instance, if an alumnus that was on the football team is now the CEO of a highly successful firm, he or she will most likely be contacted for funding the new Athletic Facility. Anyone can donate money to name a specific area or room of the

[57] Bailey, D. (2009, February 5). (B. Blanck, & B. Sealund, Interviewers)

new Facility and even the naming of the Facility itself. The price of each area is determined not by their actual value or size but by their value to the project. A list of the available gifts for the Athletic Facility is presented in Appendix L: Donation Gift Opportunities for reference.

The plan for the new Athletics Facility is to raise money into the year 2014, approximately $2.5 million from 2008-2009 and anywhere from $5 to $6 million received each following year until the goal of $30 million is reached. These numbers refer to money that is raised solely for the Athletic Facility, not including donations for other areas or projects. Donations are considered at 100% of their value as soon as a contract has been signed agreeing to give "X" amount of money over "Y" amount of time, regardless of when the total is received.

According to Dexter, on average 90% of the donations received are from 10% of the donors. For example, so far the university has received the following five gifts for the Athletic Facility: one $1 million dollar, one $400 thousand, one $120 thousand, and two $100 thousand. Most gifts are given in the form of large stock transfers given to WPI which are subject to market fluctuations. Dexter explained that finding these large gifts is primarily achieved through networking skills. As described earlier, Dexter does considerable research and sifting through past Alumni to find those who have both the ability and possibly the will to donate large sums of money to the university.

The next person the project group interviewed was Jeff Solomon who is the Executive Vice President for Finance and Operations. He is also known as the Chief Financial Officer (CFO). His job is to prepare and oversee the WPI budget as well as oversee finance operations. His role in the new athletic facility is to find a way to fund the roughly 20 million dollars not being funded through alumni donations. The way in which he plans to raise this money is through the creation of new debt. He plans to sell tax exempt bonds to accomplish this. Tax exempt bonds are favorable to NPF organizations due to low interest. WPI will plan to issue fixed-rate bonds; this will insure that they will pay the same amount of interest on the bonds through the useful life of the bonds which in this case will most likely be 40 years to mirror the useful life of the debt. The use of a fixed rate will result in a higher interest rate; however it will provide insurance that the rate will never change.

The interest on these bonds will be paid through the operating budget for WPI. This is the master budget WPI uses to determine costs and spending for the fiscal year. The interest payments on this new debt would become a new expense line on the budget. The main source of revenue for the operating budget comes from research conducted by the faculty, student tuition, room and board of the undergraduate population, as well as interest generated by the WPI endowment (currently reported at around 300 million down 25% due to the economic situation). The trustees have allowed a 5.5% spending to come from this endowment. Unless there is another approved increase of spending, then the money will need to either come from higher tuition or a decrease in salary and benefits to staff or a combination of both. One problem faced by Jeff Solomon and his staff is that if room and board are continually increased to pay for this debt, then enrollment could go down, and alumni could start giving more money to fund scholarships to keep undergraduates coming to WPI. This is something that Jeff Solomon will need to determine as the bonds are issued and the interest rate received.

8.3 Cost Estimation

The MQP team performed basic cost estimation on the construction of the new Athletic Facility based upon Cannon Design's estimates of market price values given to us by Brent Arthaud. Brent is the construction manager for WPI's new Athletic Facility.[58] He represents WPI on all issues related to the management of development of the new facility and he is essentially the official communication line between WPI and Cannon. Brent is employed by Cardinal Construction, Inc. a local civil engineering consulting firm. He was given our conceptual building design and early cost estimation values from RS Means calculations for review and comment, which he then recommended a few changes to the general design of the building. The changes he recommended were items that only an experienced employee such as himself would have known. For one, he noticed that we had the second floor of the building overhanging the Alumni field with open space below it. He recommended changing this open space into additional room(s) since there will already be foundation below. The added cost of simply adding walls would improve the general cost efficiency of the facility. Another helpful design cue he gave the team was about the placement of the HVAC (Heating, Ventilation and Air Conditioning) system. We decided together that the only placement option would be on the roof, but the large units would have to be hidden from view. A faux sloped-roof could then be constructed to be more aesthetically pleasing to the eye and match the other buildings around the quad.

The unit prices obtained from Brent were then multiplied by the gross square footage of the entire building, giving a somewhat rough estimate of the cost of the building. The square

[58] Arthaud, B. (2009, December 16). (B. Blanck, & B. Sealund, Interviewers)

footage is that of our own conceptual building design, not that of Cannon's. The cost estimation gives both a maximum and minimum possible cost for the facility in its entirety. The values obtained, including approximate inflation and management costs are a maximum of $47.88 million and a minimum of $44.03 million. Both of these numbers are higher than Cannon's basic estimate for the facility due to the fact that our conceptual building design has nearly 20,000 square feet more area than Cannon's. Considering this fact**,** by comparison our facility is a more cost efficient alternative, as the cost per square foot of our building is actually lower than Cannon's. The complete cost estimate can be seen in Appendix J below.

Once the team was able to work with more specific information given from a completed conceptual Revit model the cost estimate became more exact. This can be seen in Appendix J: Cost Estimate for Group's Model. Although not all values have been fully incorporated into the model, the team estimated as many feasibly possible values within the limitations of time and experience. This is the reason for the difference of approximately $20 million dollars between the original estimate and the final version. Specific items such as window count are not included in the estimate. The initial estimate contained in Appendix J also does not include a specific area, volume, or quantities for trades; it merely uses the buildings gross square footage. In areas where information was insufficient in the Revit model to create a detailed cost estimate, we simply used the total square footage of the building along with Gilbane's unit costs from the original estimate. Such selections were the MEP systems, conveying systems, finishes, etc. The cost of each type of trade was determined by an excel spreadsheet output by Revit. This sheet contained tabs entitled: Mass Floor, Walls, Roof, Doors, Floors, Panels, Rooms, Structural Framing, Structural Column, Structural Foundations, Ramps, and Stairs. Each section was used to determine the area, volume, or quantity of items to be incorporated. For this work the cost estimators met with the team member doing Revit design to confirm results. The grand total provided is an estimate that only includes data the team was able to complete in the short time frame. Had a fully completed model been used including items such as heating, A/C, Electrical, plumbing, and furnishings the total would be far higher.

In an actual construction management firm prices are obtained through historical values and actual supplier quotes. The price for removing and filling soil was determined by asking a local contractor for an approximation on the excavation costs of the site. A few details were provided and appropriate unit costs were given. We performed this cost estimate under the assumption that Gilbane obtained their costs in this same manner.

The unit prices for most items are quite different than the prices offered by Gilbane. With our level of experience we chose what seemed to be an appropriate price using the RS Means estimation book as well as general price knowledge. For a few trades an approximate average was determined by taking various types materials or systems, for example doors, and averaging those prices together. Other unit prices, such as concrete, are not necessarily comparable. This is because Gilbane gave a price per square foot where as concrete is priced per cubic yard in actuality. Some of our costs such as concrete include labor costs because they are fairly static while others do not due to the project's limitations.

8.4 Life-Cycle Financial Analysis

Through working with the WPI department of plant services the project group was able to obtain operating budgets as well as cost of staffing for East Hall as well as Gateway Park, the new life sciences building at WPI, these numbers are show in Figure 46. The operating budget for Gateway takes into account all utilities, janitorial supplies, repair and maintenance as well as plumbing, roofing, glass, elevator, HVAC, electrical, carpentry, locksmith, snow removal, fire protection systems and the staffing takes into account union wages, overtime and benefits. The operating budget for East Hall takes into account all utilities, licenses & fees, recycling, snow removal, tree care, maintenance and grounds supplies while the staffing takes into account union wages and benefits.

	Gateway	East Hall
Square Footage	120,00	105,000
Operating Budget	$1,428,325.00	$234,200.00
Staffing	$267,275.97	$166,629.43

Figure 46: Costs for Gateway and East Hall maintenance

These numbers were then compared to their total squared footages and averaged together to create a final average operating budget per square foot as well as average staffing costs per square footage. Once these numbers were compiled the project group compared them to the square footage of our building and calculated estimates for the annual operating budget and staffing costs for our building.

	Gateway	East Hall
Average Operating Budget per square foot	$11.90	$2.23
Average Cost of Staffing per square foot	$2.23	$1.59

Figure 47: Cost of maintenance per square foot

	Student Design Maintenance Cost
Square Footage	133,000

Operating Cost	$939,856.77
Staffing Costs	$253,647.41

Figure 48: Student Design maintenance costs

As shown in the above figures our estimated operating cost for the recreation center would be $939,856.77 which is much higher than East Hall. This is a good reflection because there should be much higher maintenance cost in a recreation center for things such as operating a competition sized pool and a weightlifting facility. These areas will require not only more electricity, they will also require constant maintenance and supplies. In addition our building is much larger than both Gateway and East Hall. The staffing costs for the recreation center are also higher due to the buildings large size and the fact that the building has more rooms that will require intricate cleaning, such as locker rooms and conference rooms. These numbers will help to play into the life cycle cost due to the fact that they will show an additional $1,193,504.18 in annual costs for the recreations facility. As the building ages these costs could be become much larger due to constant use. WPI has specifically requested that the new Athletics Facility must be LEED certified which entails higher front end construction costs, but lower maintenance costs in comparison to older buildings like Alumni Gymnasium.

The benefits revealed by a green facility obtaining LEED certification are far beyond simple decreased pollution. A study performed by Greg Kats in 2003 demonstrates the decreases in facility maintenance and energy costs obtained by LEED certification.[59] The greener a building is, the higher its certification level and the faster the financial benefits are

[59] Kats, G., Alevantis, L., Berman, A., Mills, E., & Perlman, J. (2003). *The Costs and Financial Benefits of Green Buildings.* California.

realized. A chart showing the 20-year Net Present Value of a building organized by category and certification levels is shown in Figure 49 below.

Summary of Findings (per ft^2)

Category	20-year NPV
Energy Value	$5.79
Emissions Value	$1.18
Water Value	$0.51
Waste Value (construction only) - 1 year	$0.03
Commissioning O&M Value	$8.47
Productivity and Health Value (Certified and Silver)	$36.89
Productivity and Health Value (Gold and Platinum)	$55.33
Less Green Cost Premium	($4.00)
Total 20-year NPV (Certified and Silver)	**$48.87**
Total 20-year NPV (Gold and Platinum)	**$67.31**

Source: Capital E Analysis

Figure 49: Financial Benefits of Green Buildings

With a building as large as WPI's new Athletic Facility the savings earned will be worth their initial investment long before twenty years is over. For example, our final conceptual building design has approximately 133,000 square feet. If it is to earn Silver LEED certification it translates to savings of $6 million dollars over a period of twenty years. If the building were to get Gold or Platinum certification, a savings of over $8 million dollars would be realized. Understandably, a large percentage of these savings are calculated by increased human productivity and health value. These values are determined from expenditures during construction, close out activities, and operation phases. For example, typical spray-on foam insulation produces fumes and particulate matter which need time to be cycled out of the facility's ventilation. This period of waiting costs time, money, and requires various tests throughout the facility's life cycle to ensure safety for occupants. Insulation materials with low to no emissions usually cost more up front than typical insulation but they do not require a wait time to settle and less testing for safety is needed. Productivity does not make much sense to use as a benefit for the Athletic Facility, though health value is also a part of this calculation. Considering still, there will be several offices for the Athletic department that will benefit from the increased productivity rates. Health value is important to consider in this facility, as it will be used mainly for exercise. Cleaner, healthier air leads to easier breathing during exercise.

9 Conclusions

This project encompassed various limited pre-construction tasks concerning Worcester Polytechnic Institute's new athletics facility within the context of integrated practice. Since Integrated Practice is still young in the construction industry and proper implementation of its practices has not been clearly defined, this student project team incorporated integrated practices into the various tasks of design, construction management, and cost analysis. The construction of any building is an interdisciplinary process and with that understanding the project team collaborated on those areas of construction that overlapped or required input from multiple disciplines.

Since construction is interdisciplinary, the project team advocates the incorporation of Integrated Practice into any construction project. It is notably easier in smaller projects such as homes, but much more difficult in large projects such as WPI's new Athletics Facility. Even so, the project team determined that in comparison to standard practices, such as those performed by the actual design team of the new athletics facility, integrated practices reduce construction time and costs. In several cases, within the limitations of the project, the student team discovered and addressed various issues of design at the same time or even before the actual design team who had much more experience. With this knowledge that a group of students, with little time or experience, can find these issues early in the pre-construction phases, it is simple to conclude that incorporation of integrated practice into the real pre-construction activities would make these changes even sooner and more efficiently.

With the advantages of Integrated Practice the student team also discovered various areas of communication that must be addressed prior to implementation. Through exploration of meetings, email, website submittals, and other communication devices, the project team encountered situations where communications either broke down or became confusing. Concerning submittals and collaborating reports, posting information became disjointed and resulted in vital information being lost and required resubmission. Other areas of confusion resulted in the conflicting schedules between students. Playing games of phone tag or not reporting absence from meetings led to confusion and wastes of time and energy.

After examination of these issues the three following recommendations were developed. Clear objectives must be defined early and updated constantly during the entire process. Without a clear definition of goals and objectives work can become scattered and disjointed, thus losing the overall scope of the project. Mandatory weekly meetings proved to be the best method of communication. In these meetings discussions were conducted to maintain project objectives, divide up future work, and report findings to teammate. The student project team eventually progressed into biweekly and tri-weekly meetings towards the end of the project, however it was agreed that more than two meetings a week can become cumbersome. Lastly the project team recommends the creation of a well defined timeline and structure for the project. Deadlines, collaboration, and communication tools should be discussed within the group and agreed upon before implementation.

The project team hopes that that recommendation will proves useful for any construction company seeking to implement Integrated Practice into a project of their own.

While Integrated Practice is still young in the construction industry companies that can afford to risk trying a new approach to construction should find its advantages invaluable. By understanding the limitations of this project and applying the lessons learned from it, the student team believes that Integrated Practice will eventually become the standard practice of construction in the future.

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Appendices

Appendix A: Project Proposal

Project Proposal

As Worcester Polytechnic Institute (WPI) continues its long term goals of expanding both its student body and facilities, the need for a new and state-of-the-art athletics facility is now a top priority for the institution. The current facility is barely adequate for the current student population, which is increasing faster than predicted, and this issue that has been voiced by both the students and the faculty.[60]

WPI has proposed the construction of a new athletics facility located on the hill between the Quad and the athletics field. The proposed facility will fully enclose the Quad and will also attach to the current athletics building of Harrington. This facility will allow WPI to renovate Harrington into an academic center which falls into place with the continued plans of expansion.[61] Studies have shown that students highly regard a place of recreation and a new facility will likely increase student enrollment. However not every plan is perfect and the construction of the new facility will create several issues. This facility will take several years to construct and some issues already being discussed are the allocation of funding, construction traffic and equipment, and the safety of the students.

Our project will parallel the responsibilities performed by a construction management firm, develop our own solution to the construction project, and incorporate all activities with

[60] Richardson, J. (2008, December 3). (B. Sealund, & B. Blanck, Interviewers)
[61] *Revised Strategic Plan.* (2009, April 8). Retrieved February 2, 2009, from Worcester Polytechnic Institute: http://www.wpi.edu/Admin/president/strategicplan.html

project integration techniques. Due to the long schedule of this construction project our MQP will take place in the pre-construction phases. We plan to develop an architectural solution to the accuracy of a schematic design through the use of Autodesk's Revit®, structural analyses and designs of the intended Olympic sized pool, cash flow analyses, schedules, and several cost estimates. We also will take the input from the student body and staff into our intended solution. Also we will seek to exemplify integrated practice by centralizing information for all parties to work with. All throughout the development of this MQP we will shadow the current construction management firm to compare and learn about the development of such a large construction process further improving the quality of our work.

Appendix B: Meeting Minutes

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #1 – September 4th, 2008 @ 2:00 pm
Kaven Hall 111

Members Present:

Anthony Petrocchi
Timothy Grant
Robert Bernard
Brian Sealund
Benjamin Blanck
Professor Salazar
Professor Elmes

Minutes:

-Team members formally introduced themselves.
-The overall project description and scope was discussed and details were brought up.
-Each team member presented the group with what their expectations were for the MQP and what they could personally offer.
-Meeting closed at 3:00 pm

Assignments: Project Proposal

Next Meeting: Thursday, September 11, 2008 @ 3:00 pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #2 – September 11th, 2008 @ 2:00 pm
Kaven Hall 111

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Robert Bernard
- Brian Sealund
- Professor Salazar
- Professor Elmes

Members Absent:
- Benjamin Blanck
- Professor El Korchi

Minutes:

- Bobby opened up the meeting and discussed the project proposal highlighting the points made about the duties of the group members
  - Next time: Need meeting agenda
- Tim discussed the involvement of Revit within the project and its capabilities, which includes:
  - Cost estimating take-offs
  - Quantification schedules
- Brian discussed the financial outlook of the project
- Professor Elmes makes points about project proposal:
  - What are we doing in this project?
  - Why are we doing it?
  - Methodology
  - What data is going to be collected and analyzed?
- Professor Salazar discusses project organization
  - teamwork
  - submittals
    - (Elmes) Literature Review – each member does their own literature review, the group reviews all the work done and revises as needed, then the work is submitted.
  - There are several parts to the proposal stage. The next stage is to go into more detail on what we are doing in this project as it relates to our personal contributions, and then as a group
  - myWPI website
    - Added links to the the "external links" tab
    - Get rid of the unneeded side tabs
    - Add folders for separate parts rather than just submittals
    - Add folder for Advisor reviews of work
- WPI will be launching a website for the athletic facility. Open to the entire WPI community and the public.
- Salazar discusses where the project currently stands
  - Architectural programming – very conceptual
    - Discussing what functional rooms are needed and how much space these rooms take up
    - Cost per square foot for each room
    - What is the objective of this building in terms of the Owner (WPI)

            - What does WPI want out of this building?
        - Approximate total space ~ 124,000 sq. ft
- What can we do now?
    - Look at and analyze similar facilities that have already been built
        - See what they did in terms of architecture
        - How did they fit their students needs, is it similar to WPI?
        - Can get an estimate of cost by knowing the total square feet of the building and how much it cost to built
    - Funding mechanisms and strategies
        - Interview Jeff Solomon?
        - Bonds and Rates
        - Talk to people in Finance dept.
        - Loans
        - Revenue from within?
            - Raise student tuition?
            - Grants
    - Cost of Maintenance and Operation over 50 years
        - Don't forget to use interest rate
    - What is the organization of the parties involved (owner, designer, CPM, etc.) and what are their roles? When do they come into play?

- Reference Material to look at:
    - CE 3020 Project Management Book
    - RS Means Cost Estimating Book
    - Engineering News Record (ENR)

MEETING ENDED AT 4:00 pm

Assignments:

- Enhance project proposal
- Review similar facilities
- Preliminary cost estimate
- Start thinking about how we are going to use Revit
- Literature Review
    - What are we going to look at and why/What do we need to learn?

Next Meeting: Thursday, September 81, 2008 @ 3:00 pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #2 – September 18th, 2008 @ 3:00 pm
Kaven Hall 111

Members Present:

Anthony Petrocchi
Timothy Grant
Robert Bernard
Brian Sealund
Benjamin Blanck
Professor Salazar
Professor Elmes

Members Absent:

Professor El Korchi

Minutes:

- Anthony started the meeting discussing the various updates to the myWPI site including:
    - Reorganization of materials on site
    - Advisors want a link in the side bar for their suggestions to various pieces
    - RS Means links were added to the External links section
- Tim brought back the rough blueprints for the facility from Janet Richardson
- The students discussed their updated Proposal, explaining which parts they will be overseeing.
    - Advisors want title changed to explain that this is not part of the Report.
- Professor Salazar mentioned that there could possibly be focus groups asking faculty & staff what they want in a new athletic facility.
    - Preliminary dates of October 1st & 2nd
- Three construction management firms have been short listed as possibilities.
- Advisors suggested the following
    - Ben and Brian interview Danna Harmon, the Athletic Director.
    - Interview Dexter Bailey, the V.P. of annual giving
    - Examine case studies from similar schools to WPI and their project's benefits.
- For next week:
    - There should be a timeline setup for the rest of the term.
    - Possible questions for future interviews
    - A range of possible prices for the athletic facility
    - Write an introduction explaining the problem statement

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #4 – September 25th, 2008 @ 3:00 pm
Kaven Hall 111

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Robert Bernard
- Brian Sealund
- Benjamin Blanck
- Professor Salazar
- Professor Elmes

Members Absent:
- Professor El Korchi

Minutes:

- Brian began the meeting by reviewing the agenda and then moved to the bar chart
    - Use the MyWPI survey as part of the student survey
- To get more background information Prof Salazar suggested the students attend Q&A session being held on the new facility on Oct. 1st 10-2 and 7-8.
    - Will be lead by Danna Harmon
- Bob asked a few questions regarding the structural analysis aspect of the project
    - What design to use for analysis
        - Wait for official drawings?
        - Students come up with rough design based on square footage of desired components?
- Professor Elmes commented on the interview questions prepared by the students
    - Dexter Baily (funds raiser not funds allocator)
        - Capital Campaign
            - How much is given toward the new athletic facility?
        - How does the new athletic facility fit in the overall plan?
    - Jeff Solomon
        - (First learn how universities budget themselves.)
        - How does the WPI budget work?
        - How will the new athletic facility be paid for *and* maintained?
    - Janet Richardson
        - How do colleges compete with one another?
            - How will having a new athletic facility help WPI compete?
    - Danna Harmon
        - Question/Interview at the Info Session on 10/1
    - President Dennis Berkey

        - How is the new athletic facility in WPI’s best interest?
        - Whay build a new athletic facility over the other options?
            - i.e. parking, green space, etc.
- Lit Review
    - Structural
        - Prof Salazar suggested looking into the CE trade magazines available at the library
        - Prof Elmes suggested looking into the history of building athletic facilities
    - CPM
        - Doesn’t need to be too extensive
        - Focus on what is relevant
        - What is happening today (CMAA) and how that is relevant
    - Cost Est.
        - Quantitative -> Context
        - Net Present Value

Next Meeting: Thurs. October 2 @ 3:00pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #5 – October 2nd , 2008 @ 3:00 pm
Kaven Hall 111

Members Present:
Anthony Petrocchi
Timothy Grant
Robert Bernard
Brian Sealund
Benjamin Blanck
Professor Elmes

Members Absent:
Professor El Korchi
Professor Salazar

Minutes:

- Robert led this week's meeting with Tim recording the minutes
- First we discussed our findings from the Open House session with Cannon design on Wednesday, October 1st
    - Results from the voting process showed that fitness center was the highest interest to the student body, followed by the swimming pool and private rooms
    - Robert gained some valuable information about the pool design specs
    - The architects plan to model the building in Revit because the structural analyses are being performed by Revit Structure
- Lit Review
    - Ben and Brian met with Prof. Salazar to review Net Present Value topics
    - Tim extended the Revit section to encompass how this project exemplifies Revit's capabilities
    - Anthony remarked that he is working on not getting bogged down by the details of the CPM section
    - Prof. Elmes suggested that the structural section be tailored more towards this project
        - He also suggested research in earthwork
    - *Talk to librarians about finding literature on athletics facilities
- Revit Tutorial
    - General overview of the documentation that Revit produces and how it can bring the various aspects of the industry together
    - Next week more information should be provided
- Structural Design
    - Robert presented a rough sketch of the swimming pool based on information from Cannon Design and personal research
- Interview Questions Updated
    - Jeff Solomon and Dexter Bailey
        - What do you hope to raise for the new facility?
        - How is WPI different from the basic budgeting of other universities?
        - Don't be adversarial in questioning

- How did you decide to build the rec. facility first instead of academic space or parking?

Next Meeting: Thurs. October 9 @ 3:00pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #6 – October 9nd , 2008 @ 3:00 pm
Kaven Hall 111

Members Present:
Anthony Petrocchi
Timothy Grant
Robert Bernard
Brian Sealund
Benjamin Blanck
Professor Elmes
Professor Salazar

Members Absent:
Professor El Korchi

Minutes:

- Tim led this week's meeting with Ben recording the minutes
- First we discussed the student town hall meeting on 10/6
    - At this meeting we learned that the part of the facility on the quad will be one or two stories while the part on the field will be three or four stories.
    - After the completion of the recreation center the focus will switch to a renovation of alumni gym and Harrington
        - Alumni gym will be turned into an academic center
        - Harrington will have the basketball court lowered to possibly accommodate for a robotics competition.
    - Pool will have space for scuba lessons as well as a possible shallow end for aquatic fitness.
    - President Berkey said this will be a three year project while Professor Salazar said this project is already about three months behind with a target completion of august 2011.
    - President Berkey discussed how the parking structure will be level with Park Avenue and accommodate around 600 cars with an estimated cost of $10Million.
- Literature Review
    - All parts are being finalized this week.
    - Once each part is completed Tim will compile the works and edit them.
    - 3 major parts and will be done by:
        - Construction Management and BIM (Tim and Anthony)
        - Structural (Rob)
        - Cost Estimating (Brian and Ben)
    - Professor Salazar informed Tim that BIM should be called integrated practice and place it under the CM section
    - Professors can expect rough drafts by Monday or Tuesday.
- Revit
    - Professor Salazar said OK to use the master plan to make conceptual model.
    - Rob is to use Revit structure to make his analysis
    - Team learned at open house that cannon will be making the design in Revit
- Structural Sketch

- Based around the bottom floor with the pool.
- Pool will be a “stretch 25” model.
- Rob revised his sketch to include everything on the floor include the squash courts.
- Rob took extra space in his diagram and assigned them to closet space.
- Rob also requested that Professor Salazar sends him the results of the boring samples.
- Using the projected square footing from the master plan since no legitimate footprint has been set forth.
- Professor Salazar reminded the team that the size of the pool floor will affect the size of the entire building.

- Interviews
  - The interviews will be conducted B term
  - Professor Salazar said that some of our questions will be already answered in the coming weeks.
  - Professor Elms said to change the Berkey question to ask “how does this facility fit into the strategic plan” and not ask about best interest to make the question les adversarial.
- Methodology
  - Will be in three sections
    - Data collection (interviews, master plan data)
    - Literature review (books and internet)
    - Case Studies

Next Meeting: Thurs. October 30@ 3:00pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #7 – October 29th , 2008 @ 3:00 pm
Kaven Hall 111

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Robert Bernard
- Brian Sealund
- Benjamin Blanck
- Professor Salazar

Members Absent:
- Professor El Korchi
- Professor Elmes

Minutes:

- Ben was initially supposed to lead this week's meeting, but showed up late. Anthony recorded the minutes.
- Discussed project objectives and goals – what we need to do as a team
    - Create a mode
    - Create an estimate
    - Create a schedule
- We need to be a step ahead of the actual WPI-Gilbane process
    - We do the work
    - We check out own work and improve it
    - We compare our work to the actual process, and continue to improve
- What Ben and Brian are doing:
    - What are the effects of the building once it goes into operation?
        - Happier WPI community?
        - Enrollment?
        - Athletics Program and success of it?
        - WPI Look and Feel?
        - Job Benefits?
        - WPI Reputation?
    - Funding of the project – continue to work on this
        - How and why
- Discussed the actual ongoing project with details from Prof. Salazar
    - Gilbane has been chosen as the CPM
        - They know the area of Worcester and WPI well
        - Cannon is the current architect
- Discussed more of what we need to do as a team for this MQP
    - Come up with a structural design and a geotechnical design (Bobby)
    - We should define our pieces within the project more specifically and detail what we are actually going to do – improved project proposal
    - This extends what we are going to talk about and analyze, it's what we are actually doing within the project

- THINGS TO DO:
  - Site Plan (Anthony)
  - Constructability Report (Anthony)
  - Schedule (Anthony)
  - Model (Tim)
  - Cost Estimate (Ben and Brian w/ Anthony)
  - Cash Flow Analysis (Ben and Brian)
  - Structural Design and Analysis (Bobby)
  - Analyze and use Soils Report (Bobby)
  - Preliminary Design (Tim)
- For Next Meeting:
  - Improved project proposal and what each group member is doing specifically (for next meeting)

Next Meeting: Monday November 3rd, 2008 @ 3:00 pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #9 – November 10th , 2008 @ 3:00 pm
Kaven Hall 202

Members Present:
Anthony Petrocchi
Timothy Grant
Robert Bernard
Benjamin Blanck
Professor Salazar
Professor Elmes (remotely)

Members Absent:
Professor El Korchi
Brian Sealund

Minutes:

- Card Trick
  - We began the meeting with a discussion of our timeline for B term which was conducting using a card trick method.
  - The colors in the resulting excel spreadsheet symbolize who will lead each part.
- Interviews
  - Professor Salazar discussed how the cost estimating should be done with a life cycle analysis and then a lazy s curve.
  - Professor Salazar discussed how the focus for the interviews should be broken down:
    - Richardson: represents students at large and could help discuss how process has grown. Also questions should be approved by her for other interviews.
    - Solomon: Represents the money and could help give rough estimates of how money is being spent on the project.
    - Morrow: Represents construction coordination
    - Harmon: Represents users of the facility.
  - Tim Grant also posed we ask Janet Richardson why Sasaki design was let go and Cannon was used.
  - Additional information needs to be collected on life cycle of Harrington and Alumni.
- Site Plan discussion
  - Anthony posed two different designs for the site plan

        - The first plan maintains use of baseball and football fields however it blocks off direct access to Daniels and Morgan.
        - This plan however is considered less safe since traffic will be around the quad.
        - Both plans make use of offices in Harrington to as to free up the room that would be used by a trailer.
        - The second plan uses the baseball field instead of the quad for a work site.
        - This plan is safer however it interferes with use of the baseball field.
        - Possible traffic study on the second option and its effect on Salisbury.
- Truss Design
    - Robert presented some models for truss stress and design.
    - Analysis done initially by hand but will be done by software soon.
    - Needs geo technical data to finish.
    - Research into effect of chlorine on the beams.

Submitted by Benjamin Blanck

Next Meeting: Monday November 17rd, 2008 @ 3:00 pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #11 – November 24th, 2008 @ 3:00 pm
Kaven Hall 202

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Robert Bernard
- Benjamin Blanck
- Professor Salazar
- Professor Elmes (remotely)

Members Absent:
- Professor El Korchi

Minutes:

- Announcements
  - Meeting with Neil Benner moved to Wednesday 10AM
  - December 4th we are permitted to attend design meetings from 1-3
  - December 11th design meeting canceled
  - President has given a "go" for design process but is withholding from giving construction a "go"
- Structural
  - Analysis sheets updated on myWPI
  - K truss design removed, changed to Warren truss design based of analyses
    - New Excel sheets allow easy modifications and checking
  - Added more design topics
    - Floor system
    - Beams/Joists
  - Pool area/ Building height discrepancy
    - Lower set costs more because of excavating into bedrock
    - Higher set costs less money but may be less ascetically pleasing
- Architectural
  - Model update
    - Floor heights changed to reflect specs
    - Gross floor area slimmed to 125,000 sf
      - Net floor area reduction factor is 68-70%
    - Specific rooms and areas defined for refined cost estimates
- Cost Estimating
  - Life span of Harrington and Alumni Gym found to be 60+ years
    - Check IQP on Alumni Gym layout
  - Alumni has been renovated twice while Harrington has only had one floor renovation
  - Funding
    - Harrington Gym was 90% paid by the Harrington Brothers
    - Alumni Gym was paid almost fully by class gifts
  - Interview times have been set
- Site Plan
  - Alternative 2 has been chosen
    - Write up on decision process is on myWPI
    - Talk to Neil Benner about Church Parking lot use

        - Baseball field will be changed to a soccer field and underground parking lot when construction is finished
    - Discussion of the open lot near Gateway park that can be used as a construction yard
    - Scheduling
        - Use of Primavera
        - Lazy S curve to be based off Primavera schedule
- Integration
    - We document our decision making and work processes
        - Write up of how we work together as an example of Integrated Practice
        - Compare ourselves to the work processes of Gilbane
    - We should document current conditions, i.e. economy

Submitted by Tim Grant

Next Meeting: Monday December 1st, 2008 @ 3:00 pm

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #12 – December 1st, 2008 @ 3:00 pm
Kaven Hall 111

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Robert Bernard
- Benjamin Blanck
- Professor Salazar
- Professor Elmes (remotely)

Members Absent:
- Professor El Korchi

Minutes:

- **ROBERT**showed his updated structural analysis sheet using excel
  - Added in loads
  - Used building code
- Professor Salazar recommended that Rob add in 15% of load for bolts, plates, etc.
- Topic of vibrations of the gym floor and proper support came up
  - Rob mentioned it wasn't large enough a factor to consider
    - Salazar is OK with that, but wants proper background information on why
- Rob plans to have done by the end of the term:
  - Finish trusses
  - Include joists
  - Walls
  - Roof?
- **TIM** used his Revit models to create quantity take-offs to continue the cost-estimation process.
    - Door schedule
    - Square footage of rooms
  - Cost estimate is currently in process with help from Brian
- **BRIAN AND BEN** are conducting and interview with Janet Richardson on Wednesday, December 3rd, 2008 at 2:00 pm.
  - Has questions for her specifically
  - Also looking for insight on who to go to next and what to ask
- They plan on going to President Berkey's office hours on December 8th pending approval from the advisors
- **ANTHONY** is currently writing material for the final report.
  - Topics include:
    - Site Plan Analysis/Meeting with Neil Benner
    - Actual project development and the effects of the economic situation
      - Union vs. Non-Union Labor w/ cost effects
        - Davis Bacon Act
- Anthony is also currently working on:
  - Site plan into Civil 3D/Revit
  - Helping with the Cost Estimate… plans to incorporate "Lazy S" curve into schedule

IMPORTANT NOTES:

- The project team needs to decide on a design solution, including:
  - Footprint of building
  - Stacked-down or stacked-up version?
  - How excavation will be done based on design
    - Blasting... how does this also effect cost?!?
- The project team needs to document the decision making process and our integration process.
  - This is VERY important to our project! We need to do it, and document it properly
- END OF TERM:
  - Literature Review completed and polished
  - MANY writing submittals
    - Must almost be in a state to be in the final report
  - Flow charts explaining the decision making process and steps taken for large portions of the project, such as:
      - Revit Models
      - Schedule
      - Cost Estimate
      - Site Plan
    - These flow charts should show personal work, as well as integration done
  - Table of Contents
  - Final Report Outline
  - Need to work on methodology

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #14 – January 22, 2009 @ 3:15 pm
Kaven Hall 111

Members Present:
Anthony Petrocchi
Timothy Grant
Robert Bernard
Benjamin Blanck
Professor Salazar
Professor Elmes (remotely)

Members Absent:
Professor El Korchi

Minutes:

ABOUT REPORT:

- Post updated report by Thursday 1/29/09

ABOUT REPORT FORMAT:

- Chapters represent categories of work, i.e. Background, Lit. Review, Integration, Methodology, CM, Revit, Structural, Cost Estimation/Life Cycle, Data, Results, Analysis
- Most important chapter → Integration
    - Use Diagrams!
- Use more diagrams throughout report

Ben and Tim are the editors

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #15 – January 29, 2009 @ 3:15 pm
Kaven Hall 111

Members Present:
Anthony Petrocchi
Timothy Grant
Benjamin Blanck
Professor Salazar
Professor Elmes

Members Absent:
Professor El Korchi
Robert Bernard

Minutes:

ABOUT REPORT:

- Post updated report tomorrow (1/30/09)
- Professor Salazar suggested making each Results subject its own chapter in order to keep chapters approximately equal length.
- The writing on solely integration should have its own chapter
- Make sure Introduction has the 5 rhetorical moves
- Rename the Background to "WPI New Athletics Facility" or similar
- Should have one title page with both Project ID numbers

ABOUT INTERVIEWS:

- Discussed how WPI is funding the project, that is the gap we shall write about
- Ask interviewees not how they feel about the Capital Campaign but how they will supplement it

Make sure information we are told can be shared publicly to others interviewee's as well as on the report

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #16 – February 5, 2009 @ 3:00 pm
Kaven Hall 111

Members Present:
- Anthony Petrocchi
- Timothy Grant
- Benjamin Blanck
- Robert Bernard
- Professor Salazar
- Professor Elmes

Members Absent:
- Professor El Korchi

Minutes:

- Dexter Bailey
    - How the Athletic Facility is actually being funded.
        - About $42 mill total needed
        - $30 mill from donations ($90 mill split with Salisbury and Gordon)
            - From organizations, past athletes
                - Mutual funds, endowments
        - 7 year campaign
- Thoughts on Alumni
    - "The Projectory"
        - House the Project Center, the Writing Center, IGSD
- Report
    - Beef-up write up about interview
        - Utilize S-curve
        - Analyze interview
    - Use past buildings built recently as examples
        - What is the money spent?
        - Is there a trend?
        - How does it tie in with WPI's master development plan?
    - Why put money into buildings instead of other options?
    - WPI Master Plan and Strategic Plan
    - Integrated Practice
        - Pull back a bit
        - Be honest about both good and bad aspects
    - Methodology
        - Pulled back too much
        - Needs a bit more
    - A chapter on the major steps of the project?
    - Background

    - Dump material about the actual WPI project here?
- Redo Introduction
    - 5 Rhetorical moves

WPI NEW ATHELTICS FACILITY MQP, 2008-2009

Meeting #19 – February 27, 2009 @ 10:00 am
Kaven Hall 111

Members Present:

Timothy Grant
Benjamin Blanck
Robert Bernard
Professor Salazar
Professor Elmes

Members Absent:

Anthony Petrocchi
Professor El Korchi

Minutes:

- Report Additions
    - CM
        - Explain that CMs are fee based not hourly costed, thus it is not in the CMs best interest to make a project longer
    - Integrated Practice
        - Identify to the reader that each section will reference how it was affected by integrated practice
        - Talk about the narrow mindset of the current industry
    - 5 Rhetorical moves for Intro
        - Project Integration
        - Challenges with PI
        - WPI's new athletics facility and not using PI
        - Why doesn't the whole industry adopt PI
        - Our objectives of this MQP
    - Conclusion
        - Relate to the Intro
    - Abstract
        - Forcing collaboration through BIM practices and by adopting integrated practice there is a reduction in construction time and the amount of RFIs
- Report Editing
    - Explain limitations in each analysis section
    - Structure and Flow
    - Minor Grammar
    - Finish References

Finish Appendices

Appendix C: Cannon Design Information Session Report

The Info Session event for the new athletic facility at WPI provided Canon Design with an interesting way for student to give them feedback on their design plans. Canon had set up pictures of multiple different facilities' sections they had completed in the past along the wall of the campus bookstore. They had provided pictures of an elevated track, an Olympic sized swimming pool, free weight areas, exercise areas with machines, a lobby, multi use rooms, squash/racket-ball courts, a rock climbing wall, and of course the gym floor itself. Each of these example photos were placed on cardboard and plenty of space was left around them for comments. Students walking by were asked to vote with colored dots for which area meant the most to them. Surprisingly, while we were there, the swimming pool did not receive the most attention. It was actually the free weight area that most students seemed to vote for. From briefly speaking with a few of the Canon employees I learned that they were getting results they did not expect either. Students were voting for areas of the gym they had not believed would be very popular.

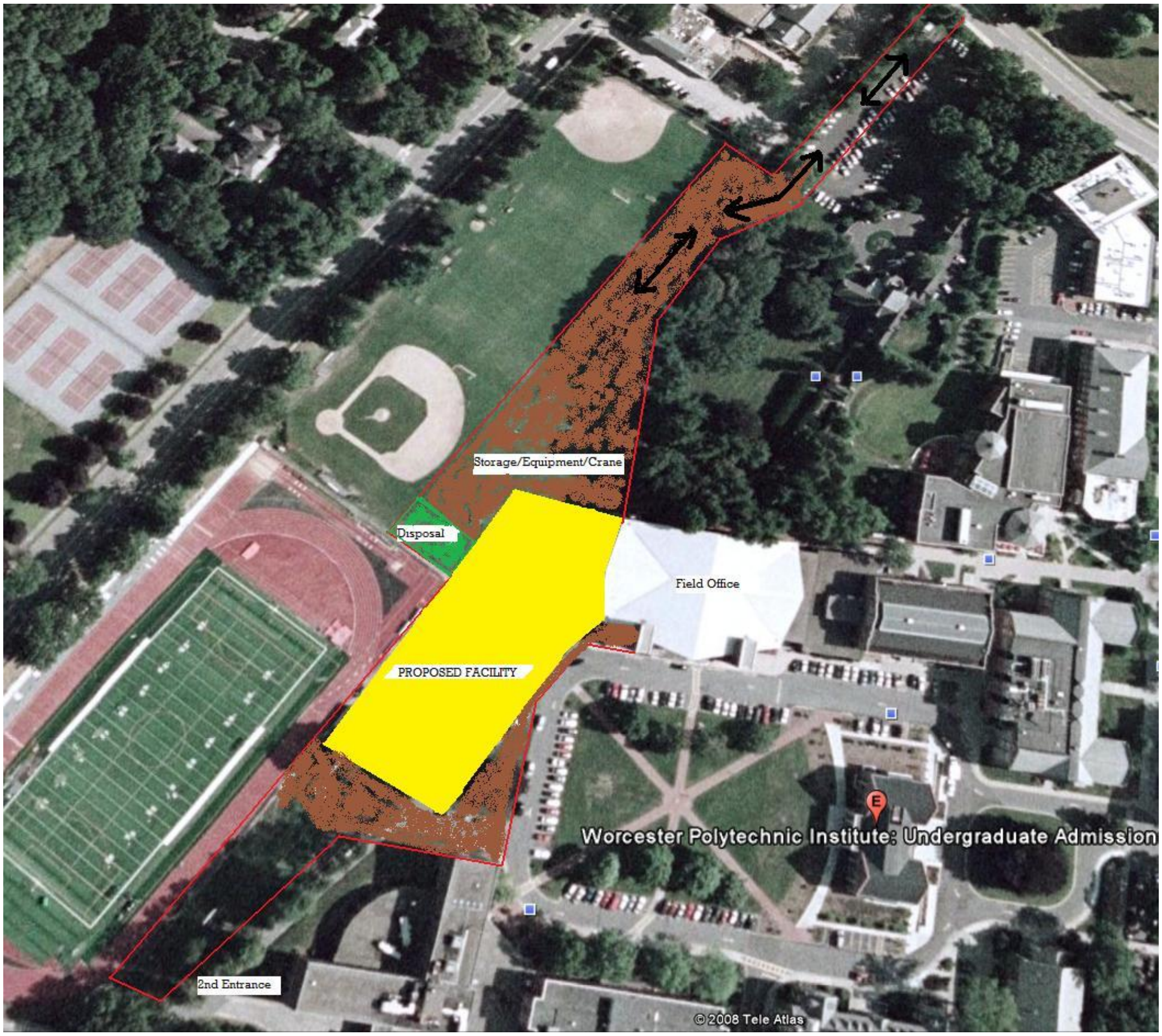
The purpose of this event was to give the Architectural Design firm an idea of what the student body wants in their new facility in general. Though it is not the most accurate way to judge the entire student body it is good start on getting to know the community. I thought that this was a very good and unique idea that Canon had come up with for getting real opinions straight from the WPI student body. This way people can be truthful and do not have to voice their wants through student ambassadors and the like to try and get their opinions through. Janet Richardson was not present at the event while our team was there so we did not have a chance to speak with her.

Appendix D: WPI Student Town Meeting Report

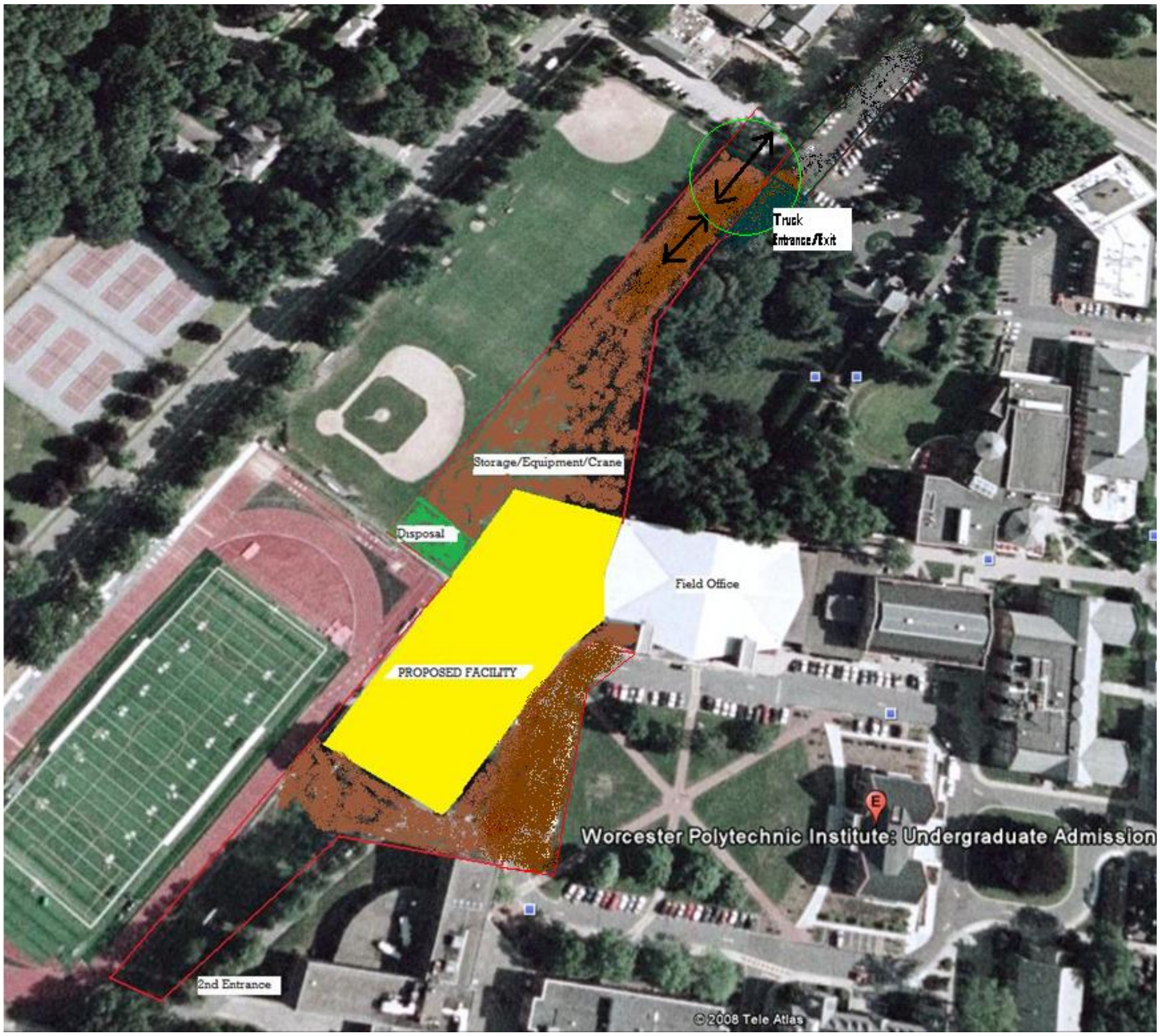
- New Rec. Center
    - Confirmed – the new facility will complete the quad, enclosing it
    - Approximately 3 to 4 stories since it will be built into the hill
    - Harrington Gym floor and the new gym floor will be at the same elevation
        - The size of the multipurpose gym area will be dependant on the area of the pool
        - Confirmed – There will be an elevated track around the outside of the gym
    - Soil sampling for the hill needs to be done
    - Better fitness center topped the voting charts at the open house
    - The pool is recognized to be a large reason to build the new facility
        - 8-10 lanes, 1-2 meter diving boards, possible shallow areas for recreation activities
    - Confirmed – Racquetball and Squash Courts
    - Construction aspects
        - 3 years till opening
        - WPI requires a loan to fund the project
        - After the rec. center opens renovations on Harrington into an academic center will begin
        - Due to a generous gift there will be a rowing tank in the new facility
        - Estimated to be 40 million for construction and another 10 million for other expenditures
        - 600 new parking spaces planned to be built where the athletic fields are located
            - The fields are planned to sit on top of the parking facility

Appendix E: Site Plans

Site Plan 2.1

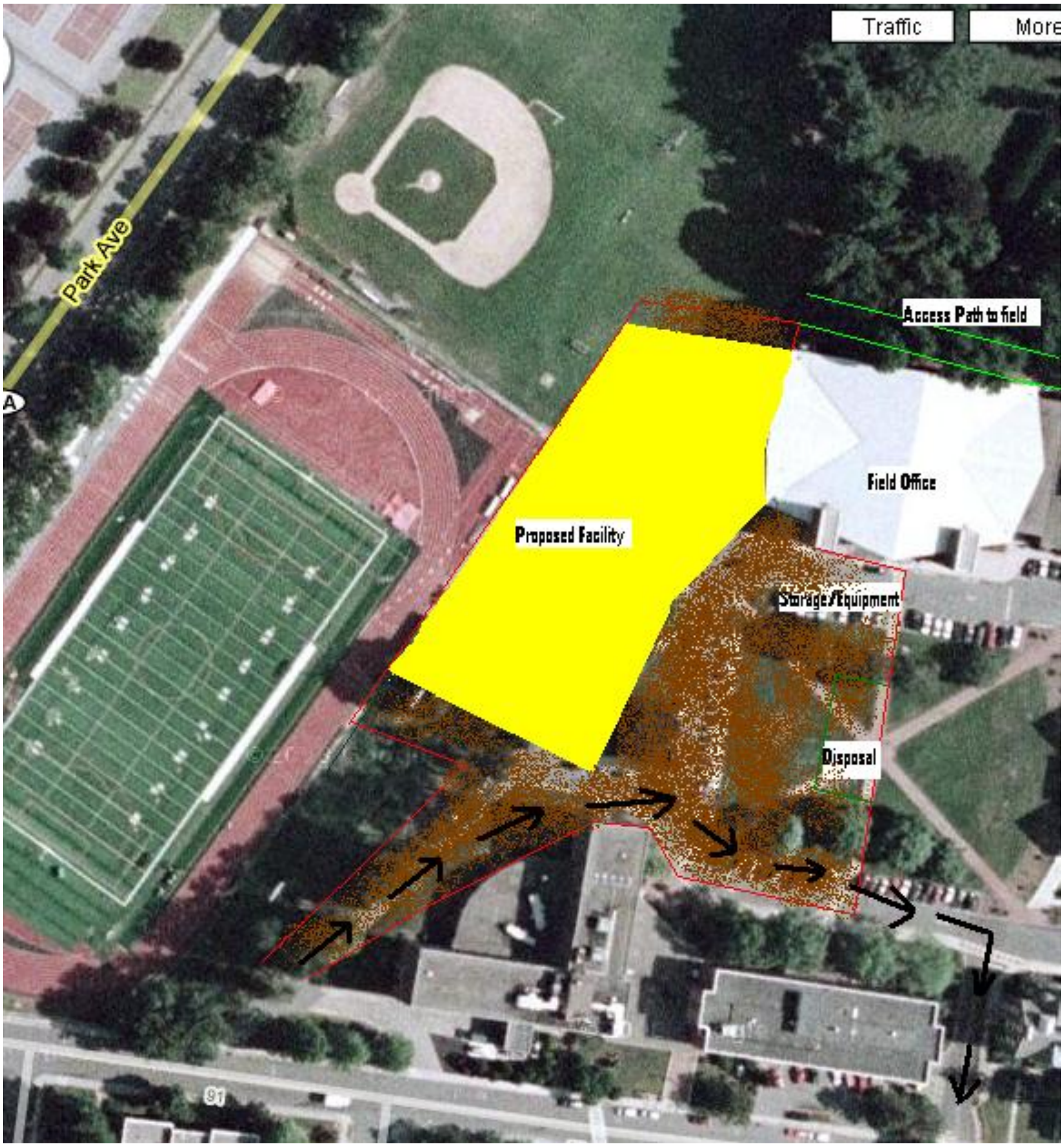


Site Plan 2



Truck
Entrance/Exit
Storage/Equipment/Crane
Disposal
Field Office
PROPOSED FACILITY
Worcester Polytechnic Institute: Undergraduate Admission
2nd Entrance
© 2008 Tele Atlas

Site Plan 1


Traffic
More
Park Ave
Access Path to field
Field Office
Proposed Facility
Storage/Equipment
Disposal
91

Appendix F: Schedules

WPI new Athletics Facility Schedule provided by Gilbane

WPI REC CENTER
ELEVATIONS

(QUAD)	LOBBY HARRINGTON	EL 552
	COURT "	EL 541.75
	LOCKER	EL 529.75
	TRACK	EL 521.00
	T.O. BEDROCK (1)	EL 504.00
	(2)	EL 494.00

MASTER SCHEDULE:

DES. SELECTION 3/21/08 - 5/15/08

DESIGN PHASE

PROGRAMMING & CONCEPTUAL	7/1/08 - 12/18/08
SD	10/1/08 - 3/25/09
DD	2/23/09 - 6/4/09
CD	5/6/09 - 9/17/09
PERMITTING	3/26/09 - 8/14/09
BID & AWARD	5/18/09 - 8/19/09
CONSTRUCTION	9/18/09 - 1/18/12

(Fall 2011 Occupancy)

Substantial Completion	10/19/11
Occupancy	11/16/11

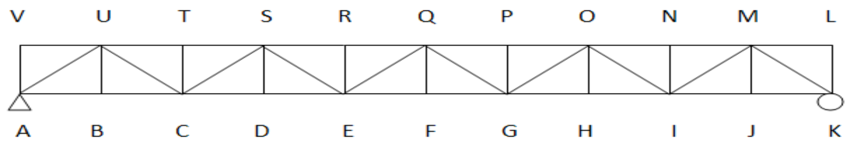
WPI Barlett Center Schedule

Construction of the WPI Bartlett Center

Milestone	Start Date
Excavation	24-Feb-05
Structural	18-May-05
Exterior Envelope	27-Jun-05
Interior	02-Aug-05
Finishes	06-Jan-06
Close - Out	31-Mar-06
End Project	26-May-06

Appendix H: Truss Analysis Sheet

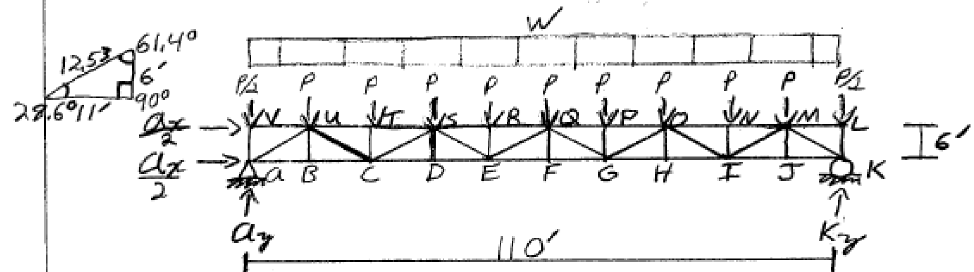
Warren Truss Analysis Sheet						
Panel Height	6.00	ft				
Panel Width	11.00	ft				
Quantity	10					
Truss Length	110.00	ft				
Trusses Spaced	20.00	ft o.c.				
# of Trusses	7					
Steel per truss	411.30	lf				
Total Steel	2879.10	lf				
Joists	42.00	plf				
Double 18LH09SP						
Vertical Loading						
Dead Load						
Concrete	51.75	psf =	1035.00	plf		
Hardwood Flooring	4.00	psf =	80.00	plf		
Truss	215.96	plf				
Joists	0.84	kips				
Total Dead Load	1330.96	plf				
Live Load	100.00	psf =	2000.00	plf		
Snow Load	0.00	psf				
Seismic Load	0.00	psf				
Wind Load	0.00	psf				
Load from Soils	0.00	psf				
Load from Fluids	0.00	psf				
Vertical Load Combinations						
1.)	1330.96	plf				
2.)	3330.96	plf				
3.)	3330.96	plf				
4.)	2398.10	plf				
5.)	798.57	plf				
6.)	798.57	plf				
Greatest Load	3330.96	plf				
Force per Truss		3330.96	plf	Factor of Safety Target		
Loading	Point	37.48	kips	1.75-2.00		
	Point/2	18.74	kips	A36 Steel Allowable Stress		
Forces	Ay	187.40	kips	36	ksi	
	Ax	0.00	kips	Member Cross Sectional Area		
	Ky	187.40	kips	W12x79	23.20	si
	Kx	0.00	kips	W12x45	13.10	si
				W6x12	3.55	si



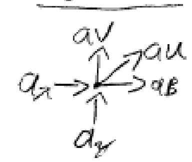
Section	Force		Member Length (ft)	Member Type	Weight (lbs)	Stress	FoS	
va	(18.74)	kips	6.00	W6x12	72.00	(5.28)	6.82	
vu	0.00	kips	11.00	W6x12	132.00	0.00	n/a	
au	(352.34)	kips	12.53	W12x79	989.87	(15.19)	2.37	
ab	309.35	kips	11.00	W12x79	869.00	13.33	2.70	
bu	0.00	kips	6.00	W6x12	72.00	0.00	n/a	
bc	309.35	kips	11.00	W12x79	869.00	13.33	2.70	
ut	(68.74)	kips	11.00	W6x12	132.00	(19.36)	1.86	critical
uc	(274.04)	kips	12.53	W12x79	989.87	(11.81)	3.05	
ts	(68.74)	kips	11.00	W6x12	132.00	(19.36)	1.86	
tc	(37.48)	kips	6.00	W6x12	72.00	(10.56)	3.41	
cs	352.34	kips	12.53	W12x79	989.87	15.19	2.37	
cd	(240.60)	kips	11.00	W12x45	495.00	(18.37)	1.96	critical
ds	0.00	kips	6.00	W6x12	72.00	0.00	n/a	
de	(240.60)	kips	11.00	W12x45	495.00	(18.37)	1.96	critical
se	430.64	kips	12.53	W12x79	989.87	18.56	1.94	
sr	(137.49)	kips	11.00	W12x45	495.00	(10.50)	3.43	
re	(37.48)	kips	6.00	W6x12	72.00	(10.56)	3.41	
rq	(137.49)	kips	11.00	W12x45	495.00	(10.50)	3.43	
eq	(352.34)	kips	12.53	W12x79	989.87	(15.19)	2.37	
ef	446.83	kips	11.00	W12x79	869.00	19.26	1.87	critical
fq	0.00	kips	6.00	W6x12	72.00	0.00	n/a	
fg	446.83	kips	11.00	W12x79	869.00	19.26	1.87	critical
qg	(352.34)	kips	12.53	W12x79	989.87	(15.19)	2.37	
qp	(137.49)	kips	11.00	W12x45	495.00	(10.50)	3.43	
pg	(37.48)	kips	6.00	W6x12	72.00	(10.56)	3.41	
po	(137.49)	kips	11.00	W12x45	495.00	(10.50)	3.43	
go	430.64	kips	12.53	W12x79	989.87	18.56	1.94	
gh	(240.60)	kips	11.00	W12x45	495.00	(18.37)	1.96	critical
ho	0.00	kips	6.00	W6x12	72.00	0.00	n/a	
hi	(240.60)	kips	11.00	W12x45	495.00	(18.37)	1.96	critical
oi	352.34	kips	12.53	W12x79	989.87	15.19	2.37	
on	(68.74)	kips	11.00	W6x12	132.00	(19.36)	1.86	
ni	(37.48)	kips	6.00	W6x12	72.00	(10.56)	3.41	
nm	(68.74)	kips	11.00	W6x12	132.00	(19.36)	1.86	critical
im	(274.04)	kips	12.53	W12x79	989.87	(11.81)	3.05	
ij	309.35	kips	11.00	W12x79	869.00	13.33	2.70	
jm	0.00	kips	6.00	W6x12	72.00	0.00	n/a	
jk	309.35	kips	11.00	W12x79	869.00	13.33	2.70	
mk	(352.34)	kips	12.53	W12x79	989.87	(15.19)	2.37	
ml	0.00	kips	11.00	W6x12	132.00	0.00	n/a	
lk	(18.74)	kips	6.00	W6x12	72.00	(5.28)	6.82	
Peak Tension	446.83	kips						
Peak Compression	(352.34)	kips						

Hand Calculations

Warren



Joint a



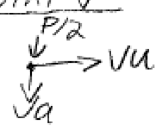
$\Sigma F_y = 0 = aV + a_y + aU\cos(61.4)$

$aU = (-aV - a_y)/\cos(61.4)$

$\Sigma F_x = 0 = a_x + aB + aU\sin(61.4)$

$aB = -aU\sin(61.4) - a_x$

Joint V



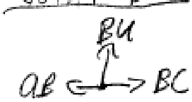
$\Sigma F_y = 0 = -P - Va$

$Va = -P/2$

$\Sigma F_x = 0 = VU$

$VU = 0$

Joint B



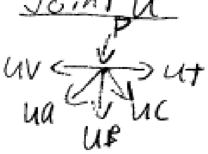
$\Sigma F_y = 0 = BU$

$BU = 0$

$\Sigma F_x = 0 = -aB + BC$

$BC = aB$

Joint U



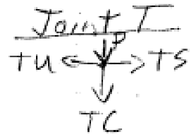
$\Sigma F_y = 0 = -P - UB - Ua\cos(61.4) - UC\cos(61.4)$

$UC = (P + UB + Ua\cos(61.4))/\cos(61.4)$

$\Sigma F_x = 0 = -UV + UT - Ua\sin(61.4) + UC\sin(61.4)$

$UT = UV + Ua\sin(61.4) - UC\sin(61.4)$

Joint T



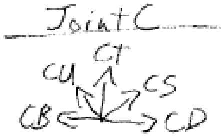
$\Sigma F_y = 0 = -TC - P$

$TC = -P$

$\Sigma F_x = 0 = -TU + TS$

$TS = TU$

Joint C



$\Sigma F_y = 0 = CU\cos(61.4) + CT + CS\cos(61.4)$

$CS = (-CU\cos(61.4) - CT)/\cos(61.4)$

$\Sigma F_x = 0 = -CB + CD - CU\sin(61.4) + CS\sin(61.4)$

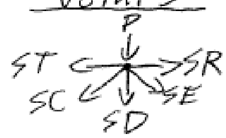
$CD = CB + CU\sin(61.4) - CS\sin(61.4)$

Joint D

$$\Sigma F_y = 0 = DS$$
$$DS = 0$$

$$\Sigma F_x = 0 = -DC + DE$$
$$DE = DC$$

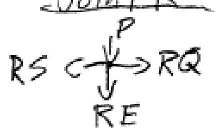
Joint S



$$\Sigma F_y = 0 = -P - SC\cos(61.4) - SD - SE\cos(61.4)$$
$$SE = (P + SC\cos(61.4) + SD)/\cos(61.4)$$

$$\Sigma F_x = 0 = -ST + SR - SC\sin(61.4) + SE\sin(61.4)$$
$$SR = ST + SC\sin(61.4) - SE\sin(61.4)$$

Joint R



$$\Sigma F_y = 0 = -P - RE$$
$$RE = -P$$

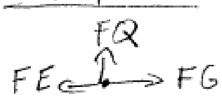
$$\Sigma F_x = 0 = -RS + RQ$$
$$RQ = RS$$

Joint E

$$\Sigma F_y = 0 = ES\cos(61.4) + ER + EQ\cos(61.4)$$
$$EQ = (-ES\cos(61.4) - ER)/\cos(61.4)$$

$$\Sigma F_x = 0 = -ED - ES\sin(61.4) + EQ\sin(61.4) + EF$$
$$EF = ED + ES\sin(61.4) - EQ\sin(61.4)$$

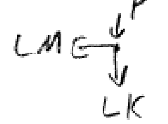
Joint F



$$\Sigma F_y = 0 = FQ$$
$$FQ = 0$$

$$\Sigma F_x = 0 = FG - FE$$
$$FG = FE$$

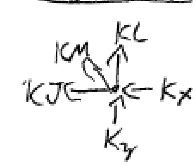
Joint L



$$\Sigma F_y = 0 = -P - LK$$
$$LK = -P/2$$

$$\Sigma F_x = 0 = LM$$
$$LM = 0$$

Joint K



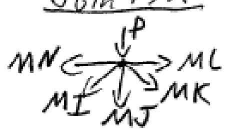
$$\Sigma F_y = 0 = K_y + KL + KM\cos(61.4)$$
$$KM = (-K_y - KL)/\cos(61.4)$$

$$\Sigma F_x = 0 = -KJ - KM\sin(61.4) - K_x$$
$$KJ = -KM\sin(61.4) - K_x$$

Joint J

$$\Sigma F_y = 0 = JM$$
$$JM = 0$$
$$\Sigma F_x = 0 = -JI + JK$$
$$JI = JK$$

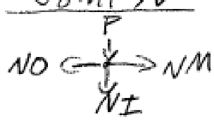
Joint M



$$\Sigma F_y = 0 = -P - MJ - MI\cos(61.4) - MK\cos(61.4)$$
$$MI = (P + MJ + MK\cos(61.4))/\cos(61.4)$$

$$\Sigma F_x = 0 = -MN - MI\sin(61.4) + ML + MK\sin(61.4)$$
$$MN = -MI\sin(61.4) + ML + MK\sin(61.4)$$

Joint N



$$\Sigma F_y = 0 = -P - NI$$
$$NI = -P$$

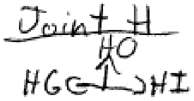
$$\Sigma F_x = 0 = -NO + NM$$
$$NO = NM$$

Joint I

$$\Sigma F_y = 0 = IO\cos(61.4) + IN + IM\cos(61.4)$$
$$IO = (-IN - IM\cos(61.4))/\cos(61.4)$$

$$\Sigma F_x = 0 = -IH - IO\sin(61.4) + IM\sin(61.4) + IJ$$
$$IH = IJ + IM\sin(61.4) - IO\sin(61.4)$$

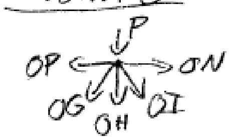
Joint H



$$\Sigma F_y = 0 = HO$$
$$HO = 0$$

$$\Sigma F_x = -HG + HI$$
$$HG = HI$$

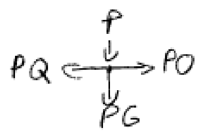
Joint O



$$\Sigma F_y = 0 = -P - OG\cos(61.4) - OH - OI\cos(61.4)$$
$$OG = (P + OH + OI\cos(61.4))/\cos(61.4)$$

$$\Sigma F_x = 0 = -OP - OG\sin(61.4) + OI\sin(61.4) + ON$$
$$OP = -OG\sin(61.4) + OI\sin(61.4) + ON$$

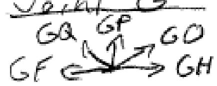
Joint P



$$\Sigma F_y = 0 = -P - PG$$
$$PG = -P$$

$$\Sigma F_x = 0 = -PQ + PO$$
$$PQ = PO$$

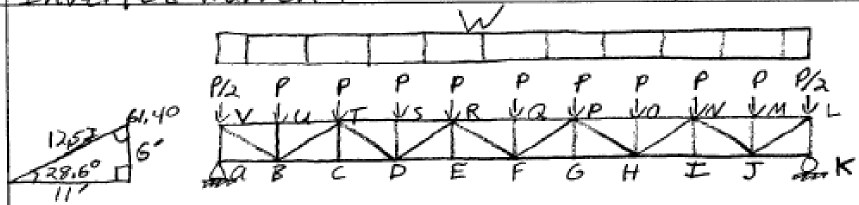
Joint G



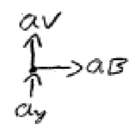
$$\Sigma F_y = 0 = GQ\cos(61.4) + GP + GO\cos(61.4)$$
$$GQ = (-GP - GO\cos(61.4))/\cos(61.4)$$

$$\Sigma F_x = 0 = -GF - GQ\sin(61.4) + GO\sin(61.4) + GH$$
$$GF = -GQ\sin(61.4) + GO\sin(61.4) + GH$$

Inverted Warren



Joint a

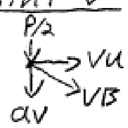


$\Sigma F_y = a_y + aV = 0$

$aV = -a_y$

$\Sigma F_x = 0 = aB$

Joint V



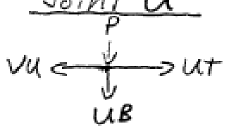
$\Sigma F_y = 0 = -P/2 - aV - VB\sin(28.6)$

$VB = \dfrac{-P/2 - aV}{\sin(28.6)}$

$\Sigma F_x = 0 = VU + VB\cos(28.6)$

$VU = -VB\cos(28.6)$

Joint U



$\Sigma F_y = 0 = -P - UB$

$UB = -P$

$\Sigma F_x = 0 = -VU + UT$

$UT = VU$

Joint B

$\Sigma F_y = 0 = UB + VB\sin(28.6) + BT\sin(28.6)$

$BT = \dfrac{-UB - VB\sin(28.6)}{\sin(28.6)}$

$\Sigma F_x = 0 = -aB - VB\cos(28.6) + BT\cos(28.6) + BC$

$BC = aB + VB\cos(28.6) - BT\cos(28.6)$

Joint C

$\Sigma F_y = 0 = CT$

$\Sigma F_x = -BC + CD$

$CD = BC$

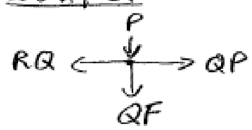
KL = va
MJ = UB
NI = TC
OH = SD
PG = RE

LJ = VB
JN = BT
NH = TD
HP = DR
PF = RF

LM = VU
MN = UT
NO = TS
OP = SR
QP = RQ

KJ = aB
JF = BC
IH = CD
HG = DE
GF = EF

Joint Q

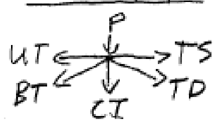


$$\Sigma F_y = 0 = -P - QF$$
$$QF = -P$$

Joint F

$$\Sigma F_y = 0 = RF\sin(28.6) + QF + FP\sin(28.6)$$

Joint T



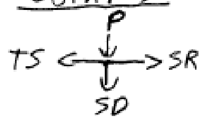
$$\Sigma F_y = 0 = -P - CT - BT\sin(28.6) - TD\sin(28.6)$$

$$TD = \frac{-P - CT - BT\sin(28.6)}{\sin(28.6)}$$

$$\Sigma F_x = 0 = -UT - BT\cos(28.6) + TD\cos(28.6) + TS$$

$$TS = UT + BT\cos(28.6) - TD\cos(28.6)$$

Joint S



$$\Sigma F_y = 0 = -P - SD$$

$$SD = -P$$

$$\Sigma F_x = 0 = -TS + SR$$

$$SR = TS$$

Joint D

$$\Sigma F_y = 0 = TD\sin(28.6) + SD + DR\sin(28.6)$$

$$DR = \frac{-TD\sin(28.6) - SD}{\sin(28.6)}$$

$$\Sigma F_x = 0 = -CD - TD\cos(28.6) + DR\cos(28.6) + DE$$

$$DE = CD + TD\cos(28.6) - DR\cos(28.6)$$

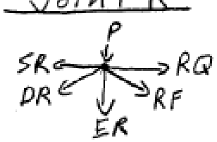
Joint E

$$\Sigma F_y = 0 = ER$$

$$\Sigma F_x = 0 = -DE + EF$$

$$EF = DE$$

Joint R



$$\Sigma F_y = 0 = -ER - DR\sin(28.6) - RF\sin(28.6) - P$$

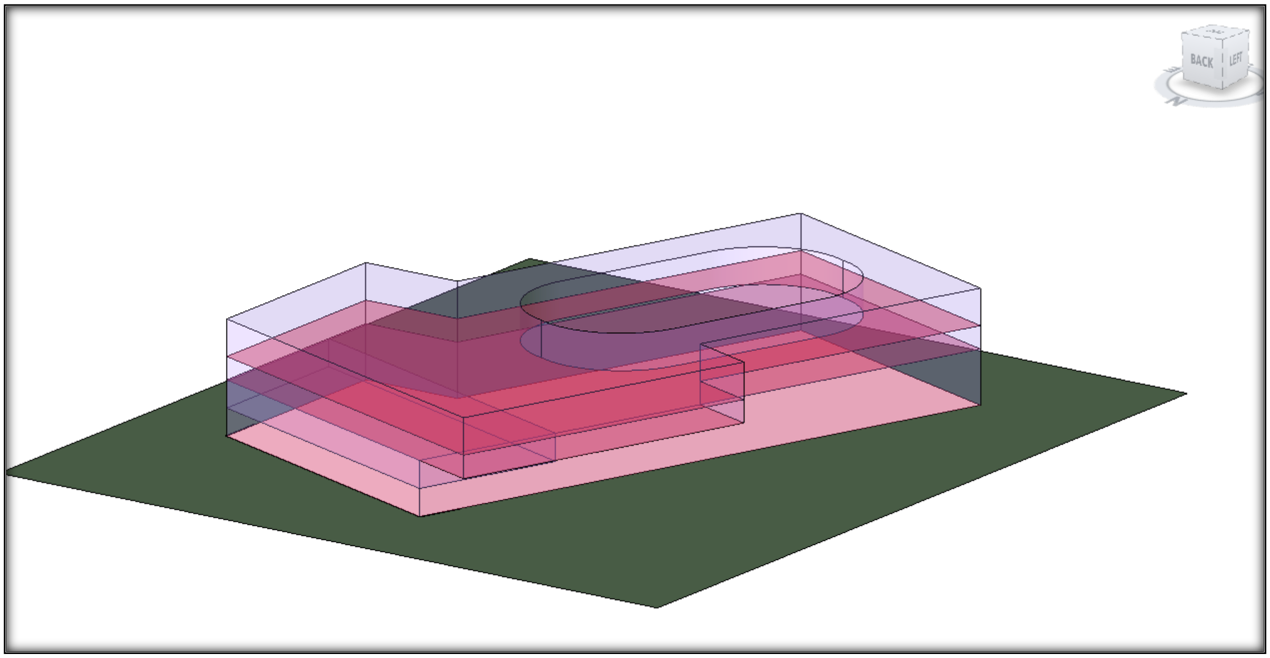
$$RF = \frac{-ER - DR\sin(28.6) - P}{\sin(28.6)}$$

$$\Sigma F_x = 0 = -SR - DR\cos(28.6) + RF\cos(28.6) + RQ$$

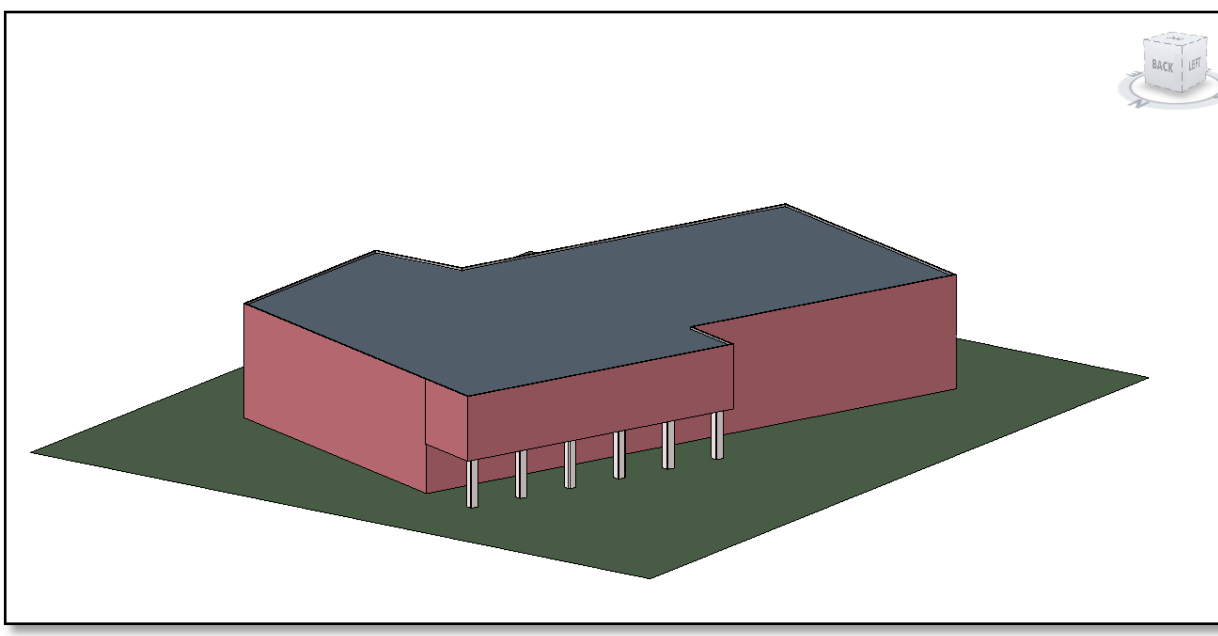
$$RQ = SR + DR\cos(28.6) - RF\cos(28.6)$$

Appendix I: Revit Model Progression

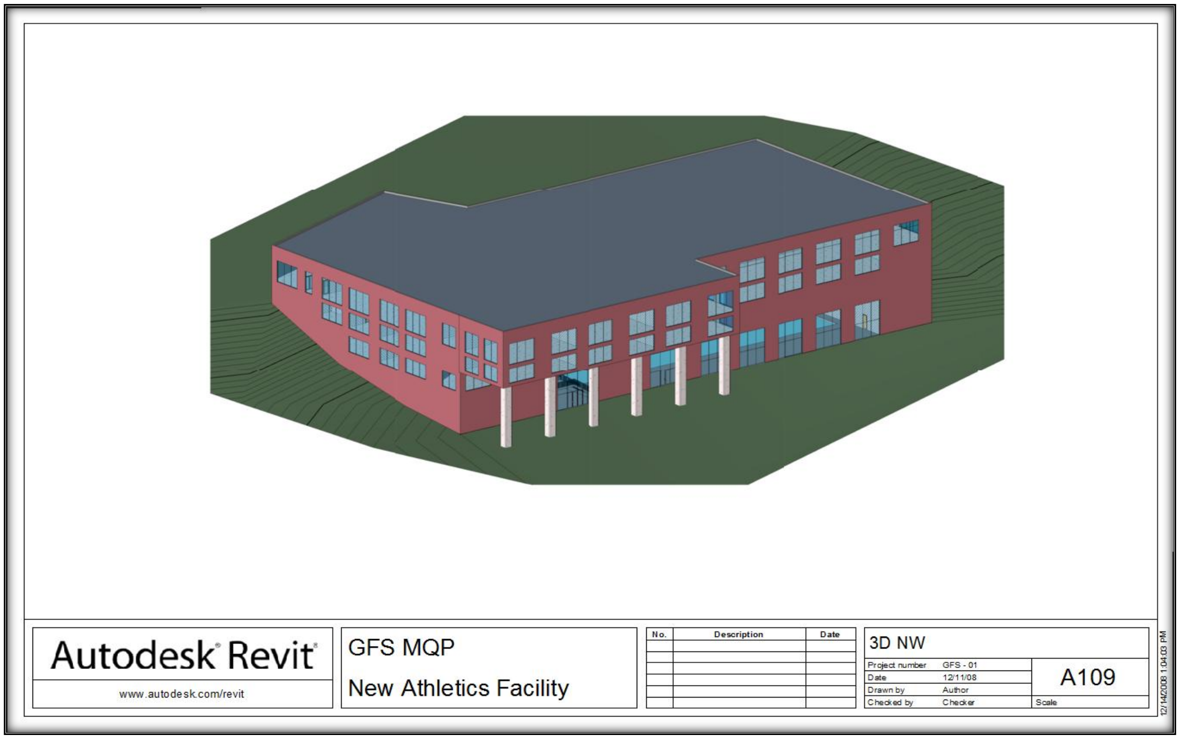
11/26/08



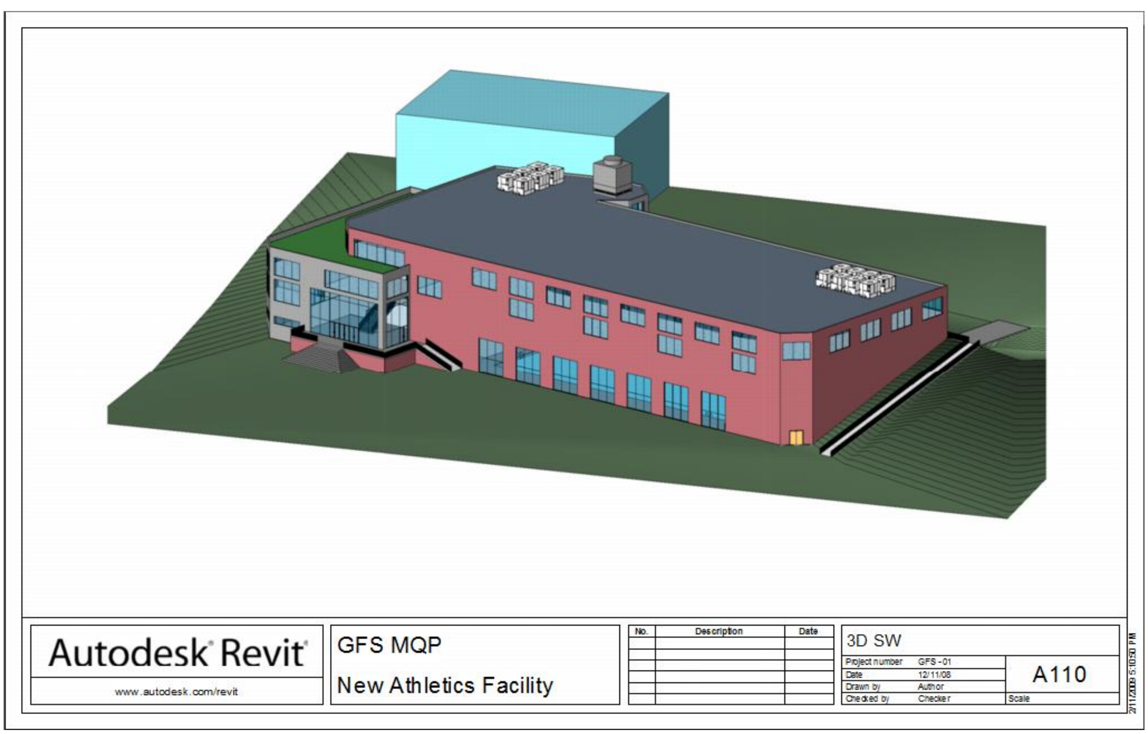
12/10/08



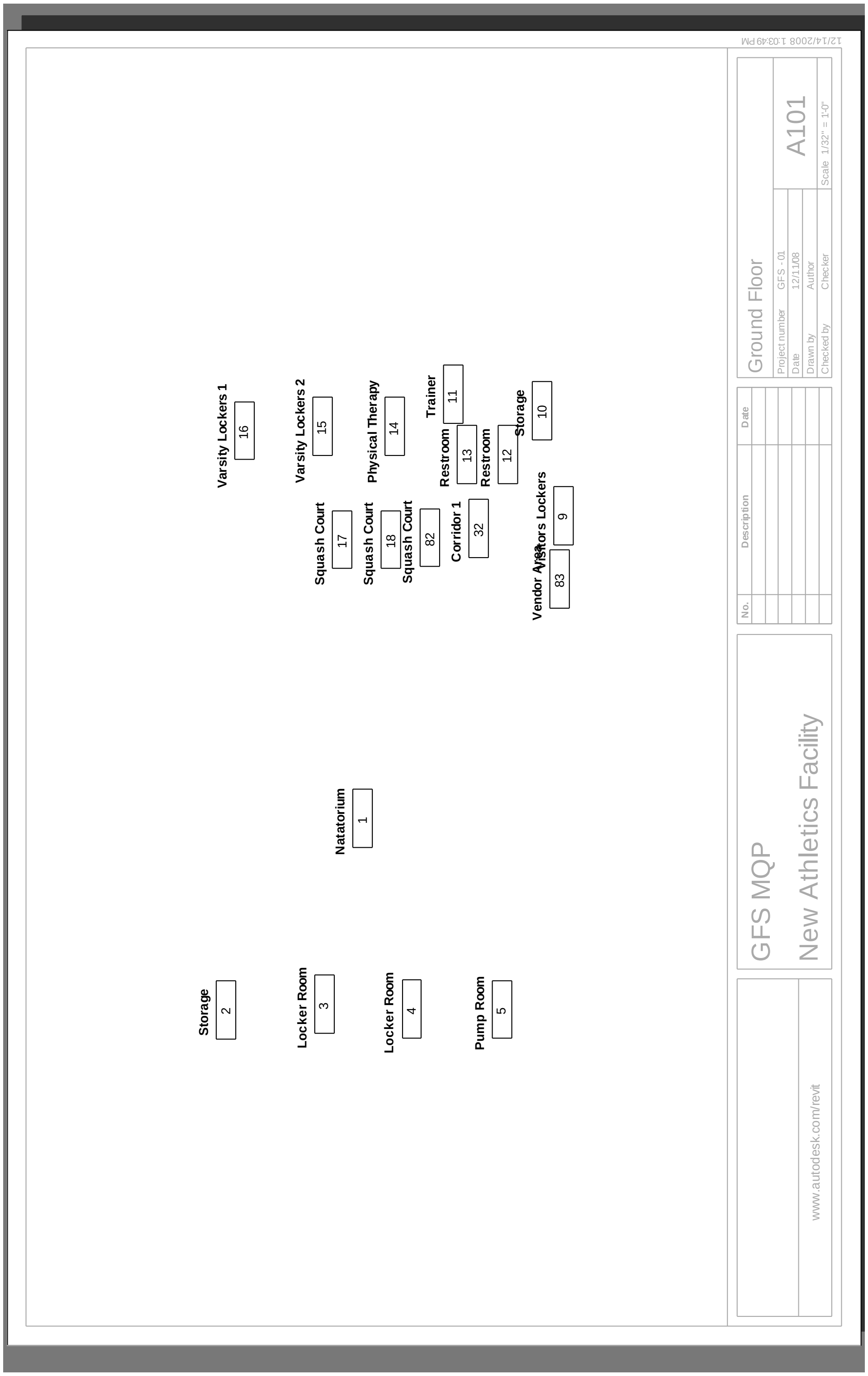
12/16/08

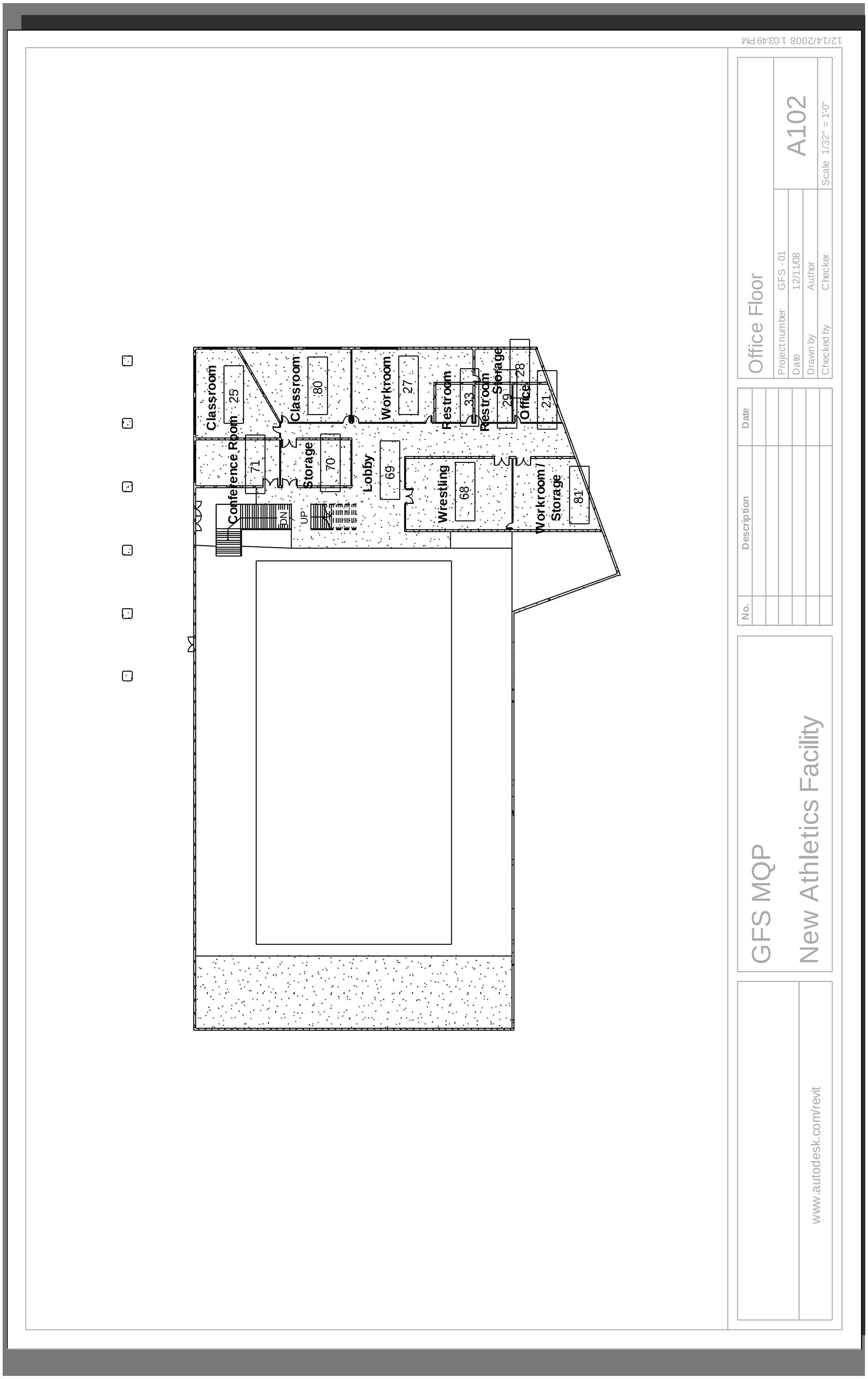


2/11/09



Design Plans 12/6/08

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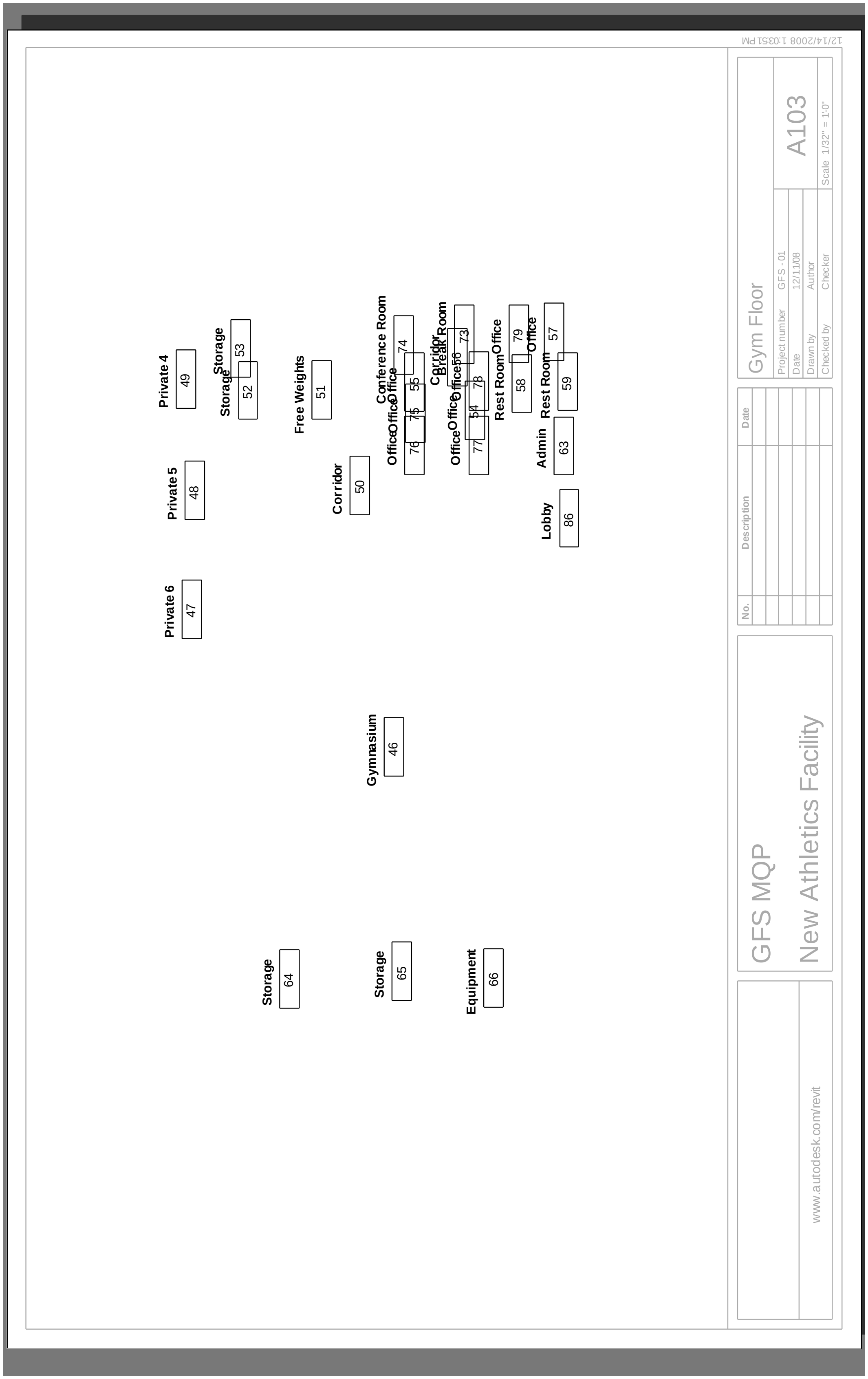
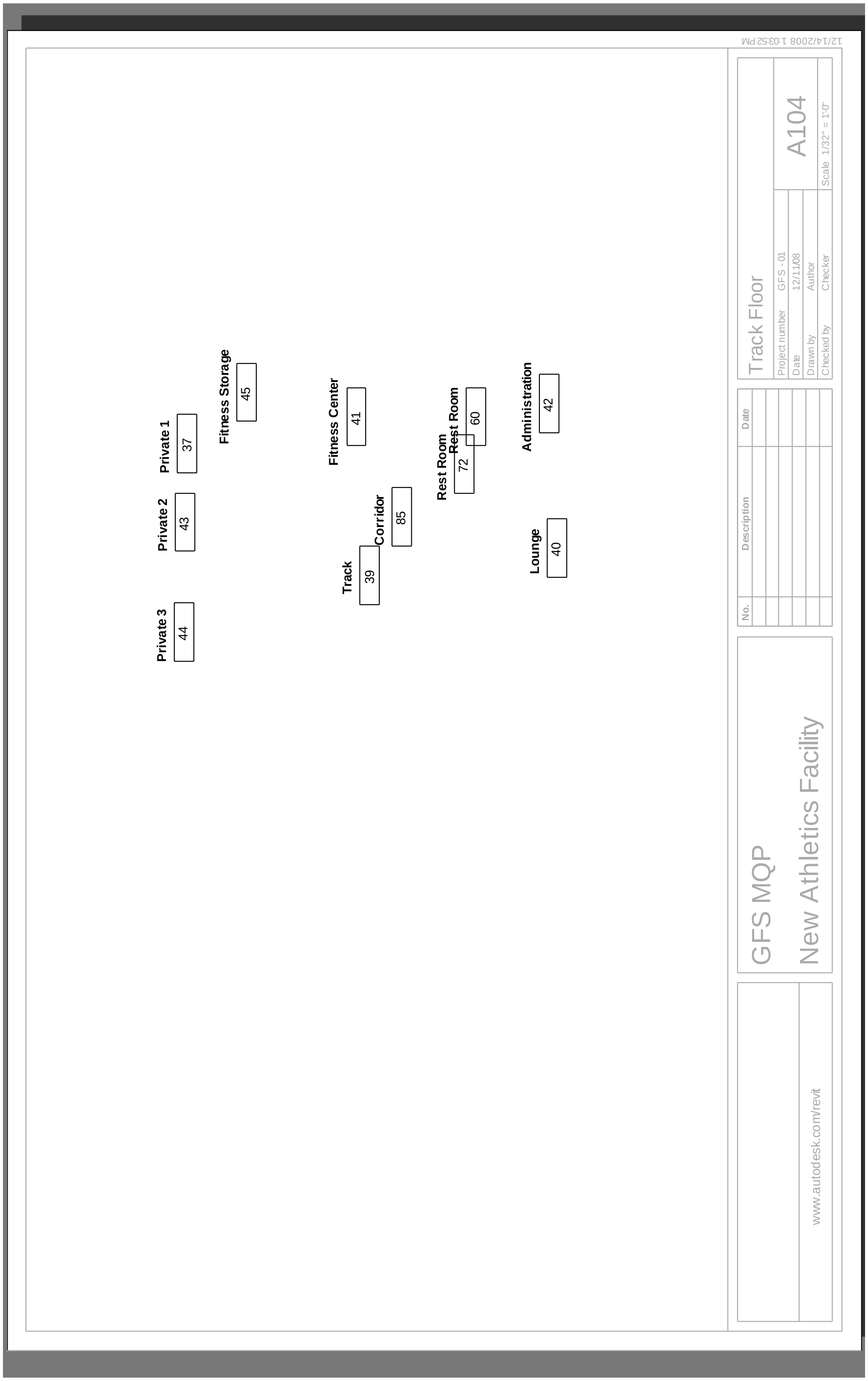
Classroom
25
Classroom
80
Workroom
27
Restroom
33
Restroom
29
Storage
28
Office
21
Conference Room
71
Storage
70
Lobby
69
Wrestling
68
Workroom / Storage
81
DN
UP
Office Floor
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
A102
Scale 1/32" = 1'-0"
No.
Description
Date
GFS MQP
New Athletics Facility
www.autodesk.com/revit



Private 4
49
Private 5
48
Private 6
47
Storage
53
Storage
52
Free Weights
51
Corridor
50
Gymnasium
46
Storage
64
Storage
65
Equipment
66
Conference Room
74
Office
55
Office
75
Office
76
Break Room
73
Corridor
56
Office
78
Office
54
Office
77
Office
79
Rest Room
58
Office
57
Rest Room
59
Admin
63
Lobby
86
12/14/2008 1:03:51 PM
Gym Floor
A103
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
Scale 1/32" = 1'-0"
No.
Description
Date
GFS MQP
New Athletics Facility
www.autodesk.com/revit


Private 3
44
Private 2
43
Private 1
37
Fitness Storage
45
Fitness Center
41
Track
39
Corridor
85
Rest Room
72
Rest Room
60
Administration
42
Lounge
40
www.autodesk.com/revit
GFS MQP
New Athletics Facility
No.
Description
Date
Track Floor
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
A104
Scale 1/32" = 1'-0"
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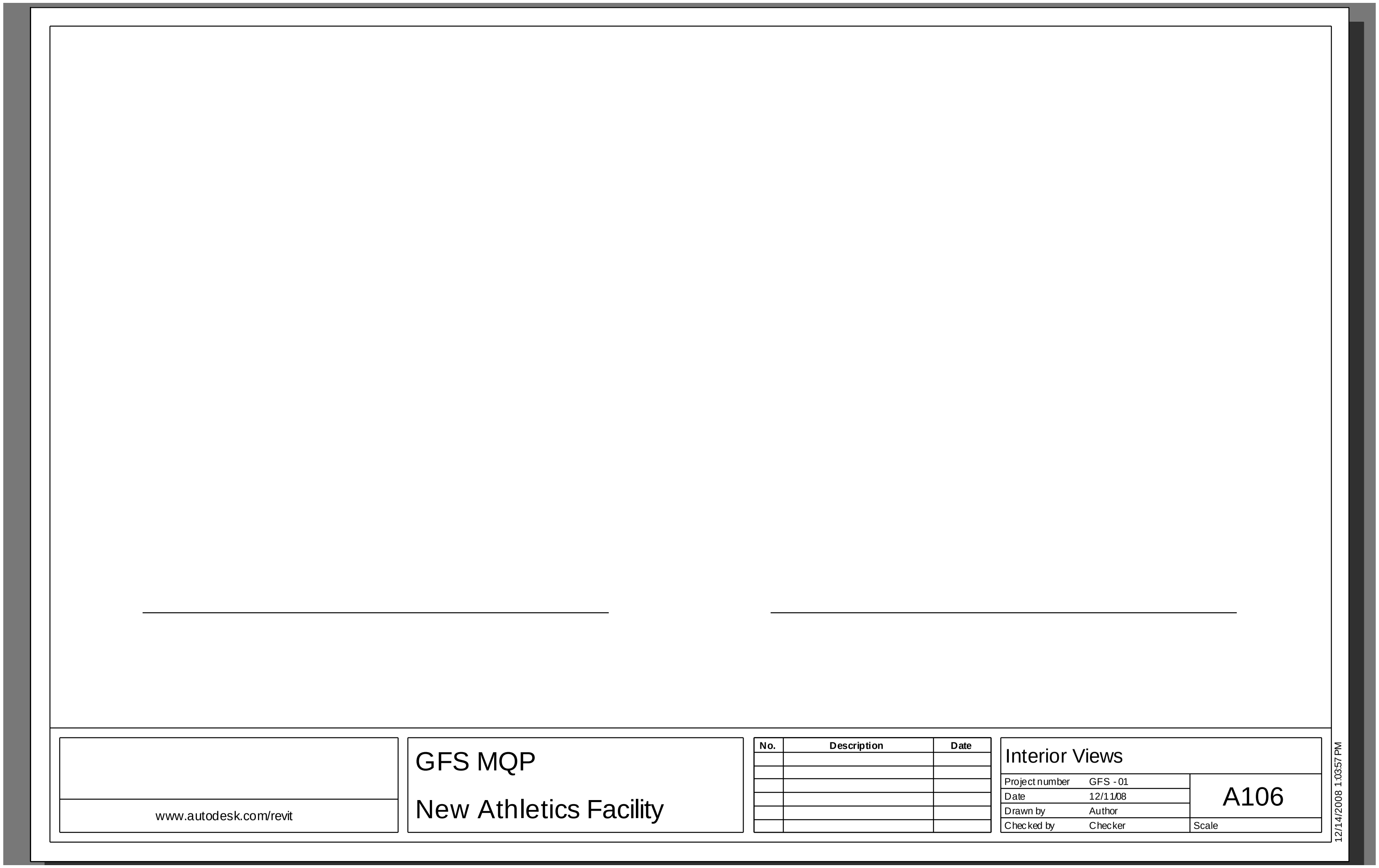
www.autodesk.com/revit
GFS MQP
New Athletics Facility
No.
Description
Date
Interior Views
Project number
GFS - 01
Date
12/11/08
Drawn by
Author
Checked by
Checker
A106
Scale
12/14/2008 1:03:57 PM

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GFS MQP

New Athletics Facility

No.	Description	Date

3D SE

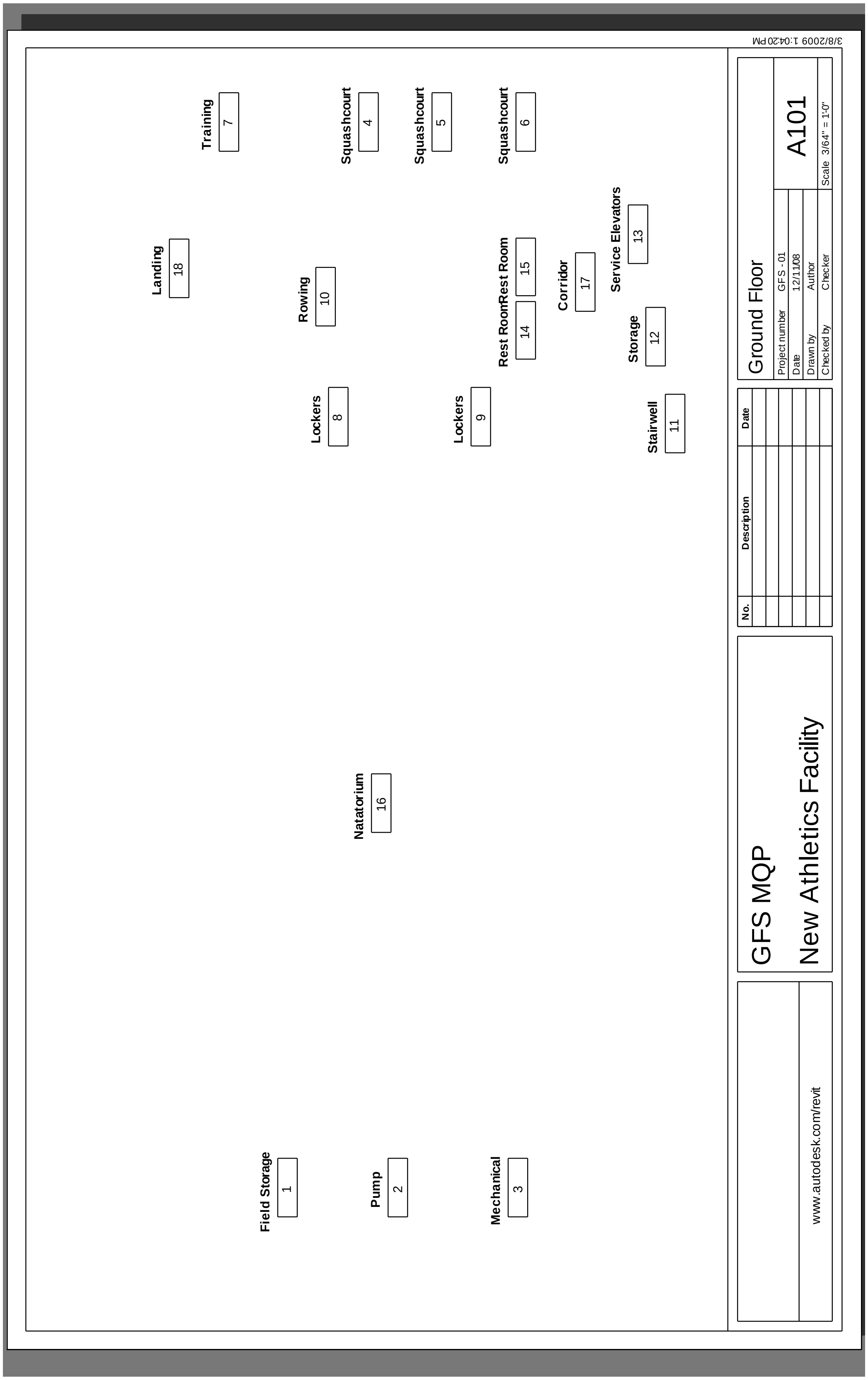
Project number	GFS - 01
Date	12/11/08
Drawn by	Author
Checked by	Checker

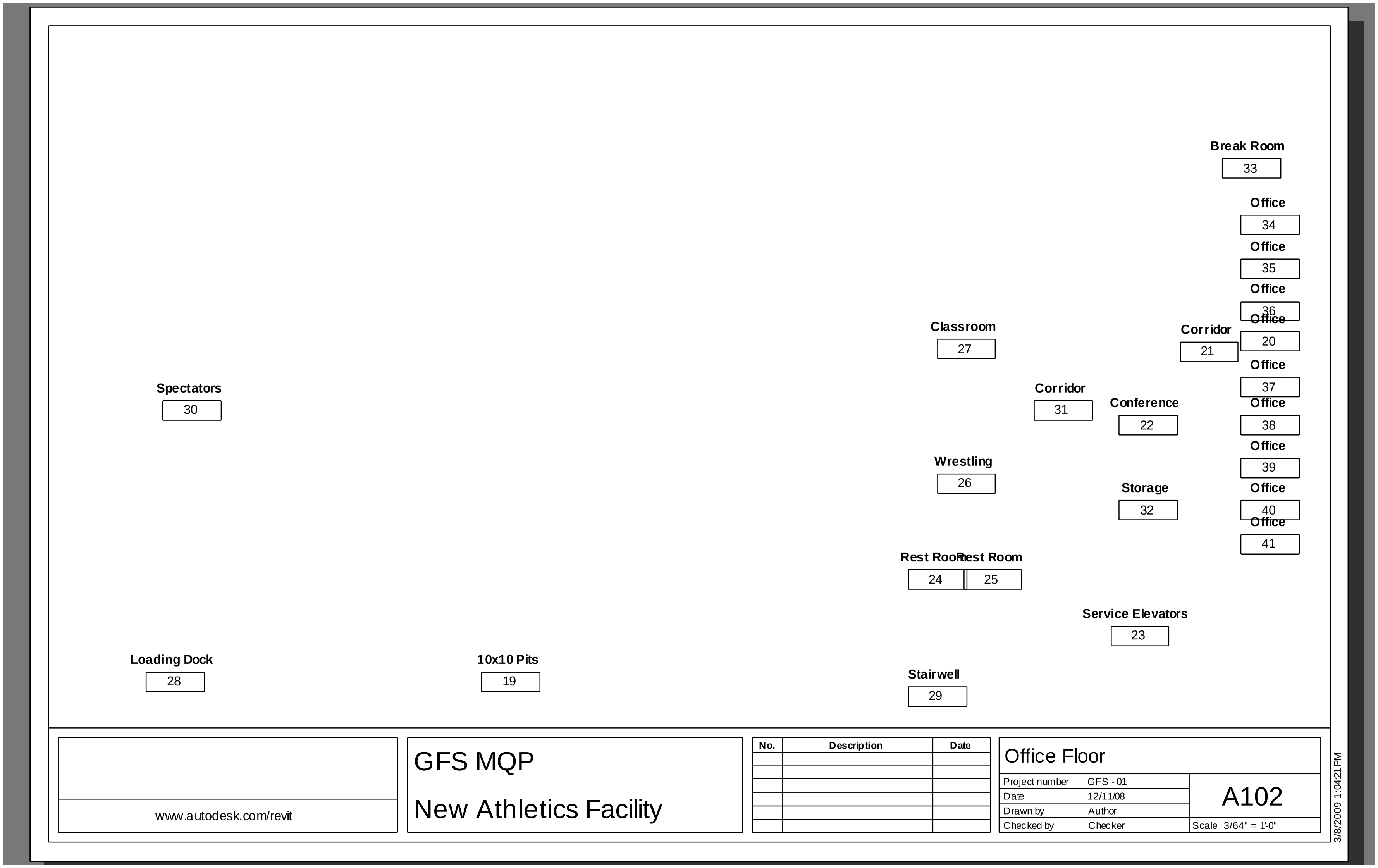
A107

Scale

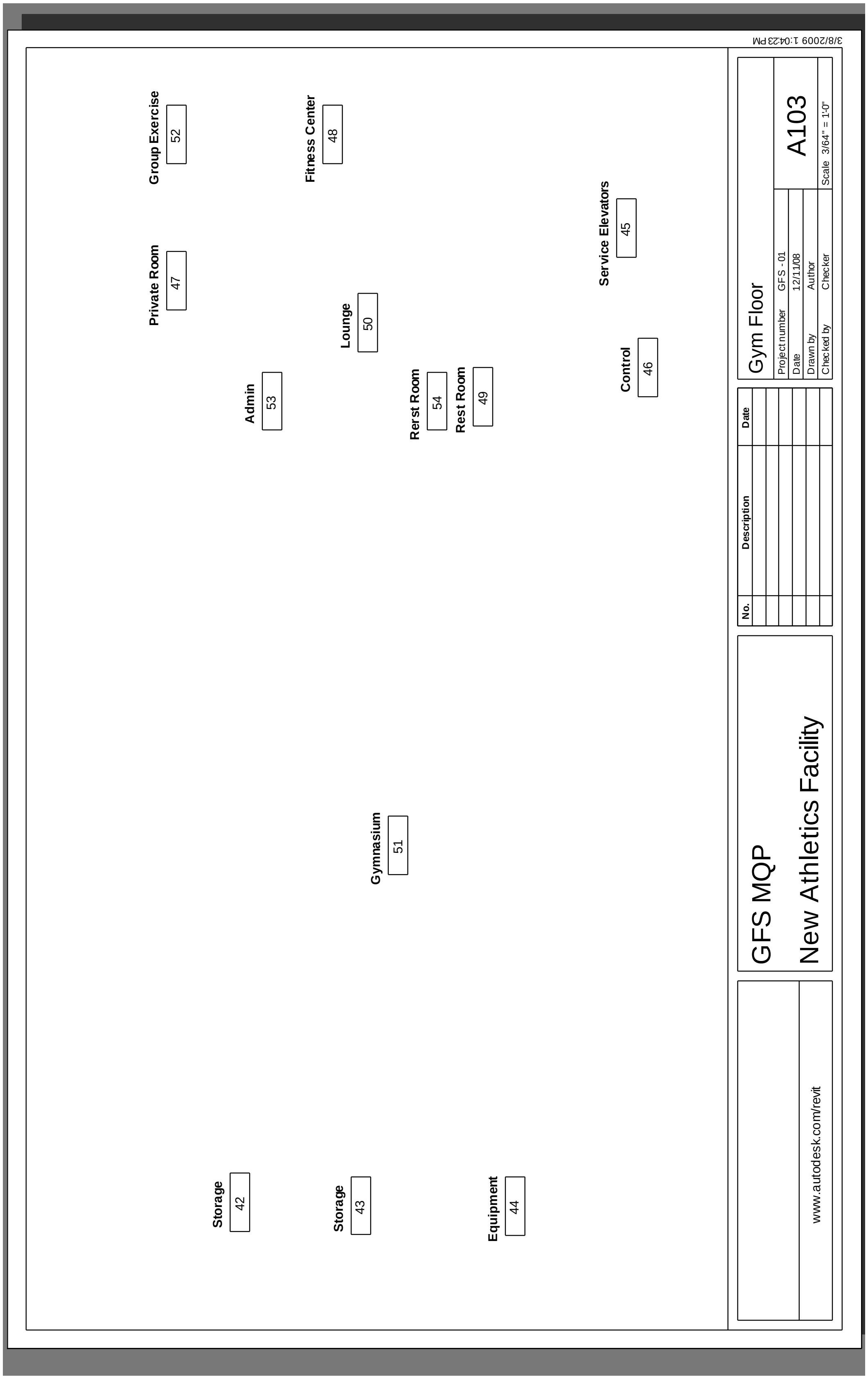
12/14/2008 1:03:59 PM

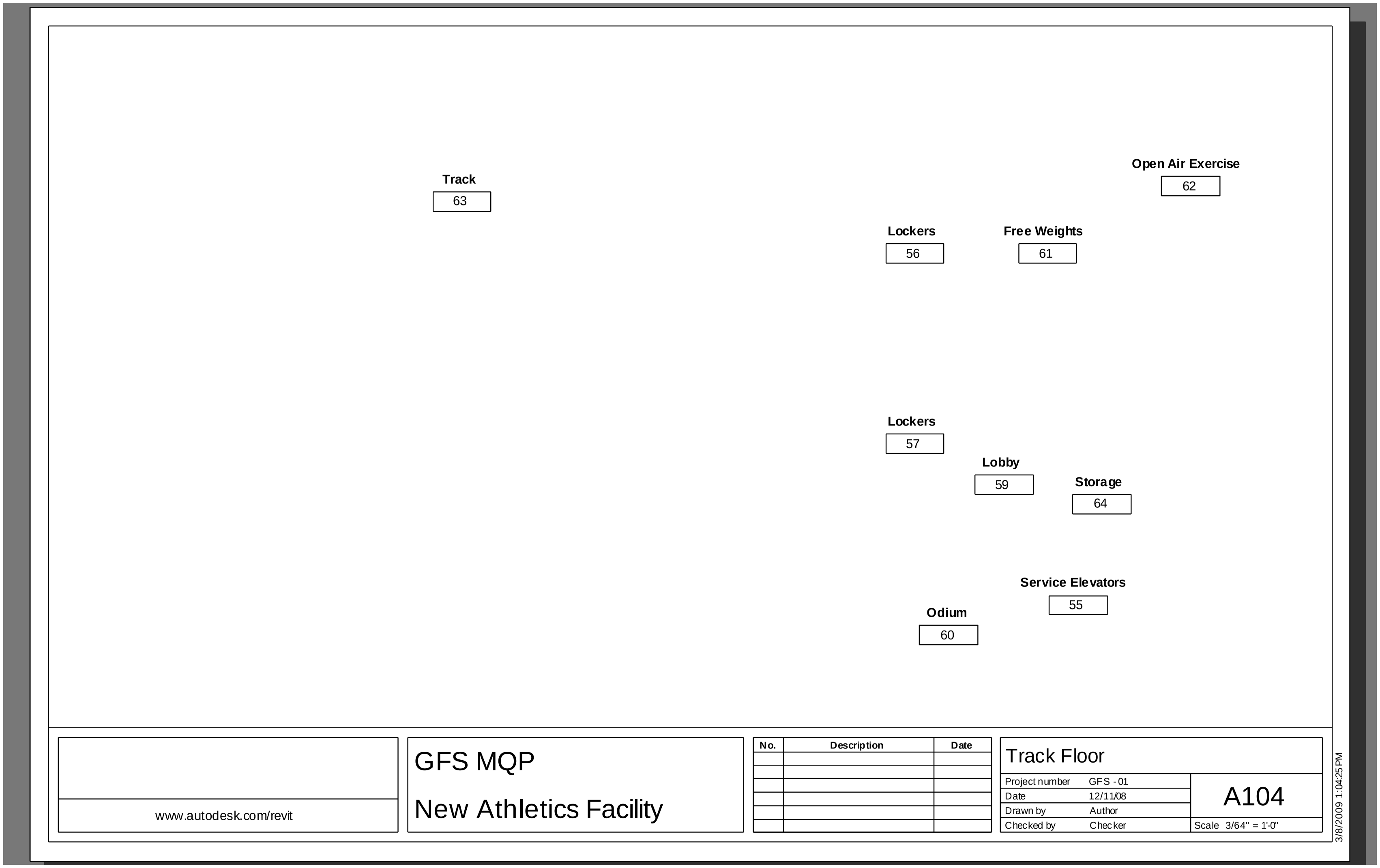
Floor Plans 2/11/09





Break Room
33
Office
34
Office
35
Office
36
Office
20
Corridor
21
Office
37
Office
38
Office
39
Office
40
Office
41
Classroom
27
Corridor
31
Conference
22
Wrestling
26
Storage
32
Rest Room
24
Rest Room
25
Service Elevators
23
Stairwell
29
Spectators
30
Loading Dock
28
10x10 Pits
19
www.autodesk.com/revit
GFS MQP
New Athletics Facility
No.
Description
Date
Office Floor
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
A102
Scale 3/64" = 1'-0"
3/8/2009 1:04:21 PM


3/8/2009 1:04:23 PM
Group Exercise
52
Private Room
47
Fitness Center
48
Service Elevators
45
Lounge
50
Admin
53
Control
46
Rerst Room
54
Rest Room
49
Gymnasium
51
Storage
42
Storage
43
Equipment
44
www.autodesk.com/revit
GFS MQP
New Athletics Facility
No.
Description
Date
Gym Floor
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
A103
Scale 3/64" = 1'-0"


Track
63
Open Air Exercise
62
Lockers
56
Free Weights
61
Lockers
57
Lobby
59
Storage
64
Service Elevators
55
Odium
60
www.autodesk.com/revit
GFS MQP
New Athletics Facility
No.
Description
Date
Track Floor
Project number GFS - 01
Date 12/11/08
Drawn by Author
Checked by Checker
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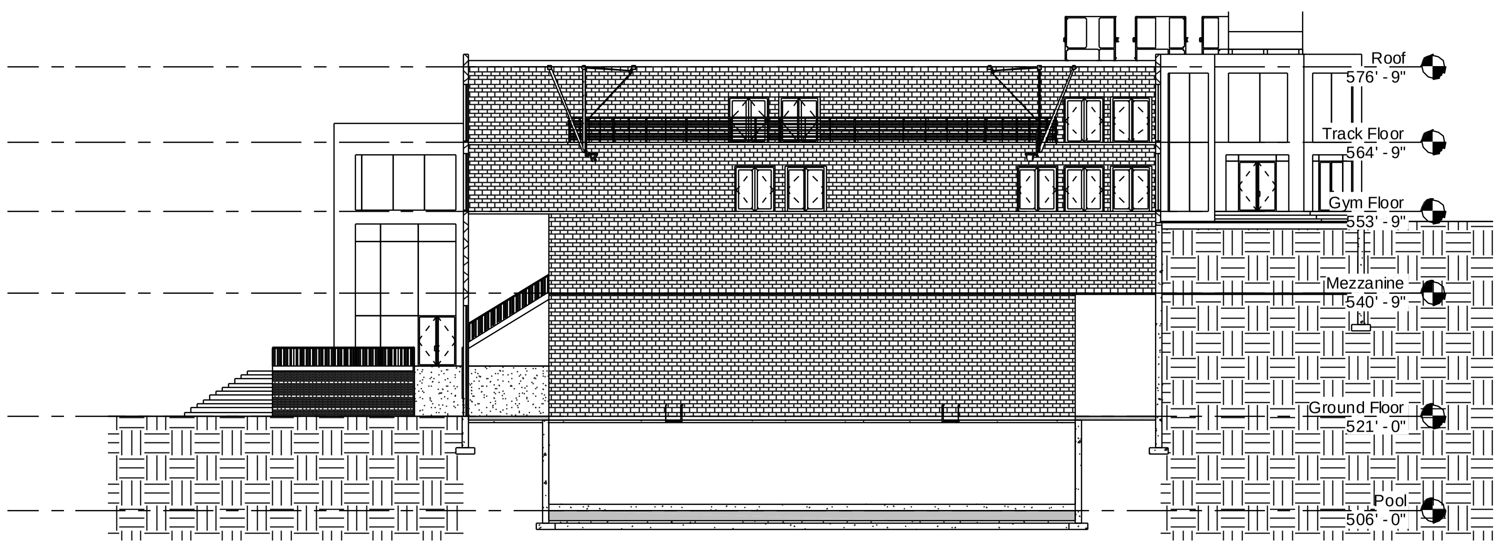

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GFS MQP

New Athletics Facility

No.	Description	Date

Section View

Project number	GFS - 01	A105
Date	12/11/08	
Drawn by	Author	
Checked by	Checker	Scale 1/16" = 1'-0"

3/8/2009 1:04:28 PM

Door Schedule

Height	Width	Level	Count	Type
Ground Floor				
7' - 0"	2' - 6"	Ground Floor	3	30" x 84"
7' - 0"	3' - 0"	Ground Floor	6	
7' - 0"	6' - 0"	Ground Floor	7	
8' - 0"	6' - 0"	Ground Floor	4	Store Front Double Door
Mezzanine				
7' - 0"	3' - 0"	Mezzanine	13	
7' - 0"	6' - 0"	Mezzanine	10	
Gym Floor				
7' - 0"	3' - 0"	Gym Floor	3	36" x 84"
7' - 0"	6' - 0"	Gym Floor	15	
8' - 0"	6' - 0"	Gym Floor	3	Store Front Double Door
Track Floor				
7' - 0"	3' - 0"	Track Floor	1	36" x 84"
7' - 0"	6' - 0"	Track Floor	10	72" x 84"
8' - 0"	6' - 0"	Track Floor	3	Store Front Double Door
Grand total: 78				

Panel Schedule

Area	Height	Width	Type	Count
18 SF	1' - 0"	2' - 0"	Glazed	9
8 SF	3' - 9"	1' - 0"	Glazed	2
138 SF	1' - 0"	6' - 0"		23
68 SF	7' - 6"	1' - 0"	Glazed	9
8 SF	3' - 9"	2' - 0"	Glazed	1
9 SF	8' - 10"	1' - 0"	Glazed	1
9 SF	9' - 0"	1' - 0"	Glazed	1
11 SF	11' - 0"	1' - 0"	Glazed	1
11 SF	2' - 9"	4' - 0"	Glazed	1
144 SF	8' - 0"	2' - 0"	Glazed	9
149 SF	2' - 9"	6' - 0"	Glazed	9
18 SF	9' - 0"	2' - 0"	Glazed	1
225 SF	3' - 9"	5' - 0"	Glazed	12
44 SF	11' - 0"	2' - 0"	Glazed	2
52 SF	9' - 0"	2' - 10 3/4"	Glazed	2
27 SF	8' - 10"	3' - 0"	Glazed	1
27 SF	9' - 0"	3' - 0"	Glazed	1

Panel Schedule

Area	Height	Width	Type	Count
32 SF	8' - 0"	4' - 0"	Glazed	1
338 SF	7' - 6"	5' - 0"	Glazed	9
840 SF	8' - 0"	5' - 0"	Glazed	21
41 SF	9' - 0"	4' - 6"	Glazed	1
42 SF	9' - 0"	4' - 8"	Glazed	1
42 SF	9' - 0"	4' - 8 5/8"	Glazed	1
133 SF	8' - 10"	5' - 0"	Glazed	3
4950 SF	9' - 0"	5' - 0"	Glazed	110
48 SF	12' - 0"	4' - 0"	Glazed	1
912 SF	8' - 0"	6' - 0"	Glazed	19
1024 SF	9' - 9"	5' - 0"	Glazed	21
50 SF	11' - 0"	4' - 6"	Glazed	1
265 SF	8' - 10"	6' - 0"	Glazed	5
880 SF	11' - 0"	5' - 0"	Glazed	16
648 SF	12' - 0"	6' - 0"	Glazed	9
11207 SF				304

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GFS MQP

New Athletics Facility

No.	Description	Date

Quantity Takeoff Examples

Project number	GFS - 01	A111
Date	12/11/08	
Drawn by	Author	
Checked by	Checker	Scale

3/8/2009 1:04:30 PM

Appendix J: Cost Estimate for Group's Model

Revit Take Off 12/16/08

Mass Floor Schedule					
Floor Area SF	Floor Perimeter F	Level	Exterior Surface Area SF	Floor Volume CF	
19547	556' - 9 5/8"	Office Floor	29569	351842.91	
35854	1363' - 9 1/16"	Track Floor	57674	573668.38	
46989	963' - 3 21/32"	Gym Floor	73962	1315701.14	
41907	899' - 9 9/32"	Ground Floor	68990	1156805.09	
144297			230195	3398017.52	Total
$250/SF					Unit Price
36074250					Cost

Revit based Cost Estimate 2/11/09

Trade Description	Area	Cost per S.F.	Total Cost
Masonry	72,255 SF	$8.00	$578,040.00
Forms	26,594 SF	$9.00	$239,346.00
Glazing	11,670 SF	$60.00	$700,200.00
Steel Mesh for Floor Slabs	125,656 SF	$1.00	$125,656.00
Lighting	100,200 SF	$8.50	$851,700.00
Roof	40,758 SF	$17.00	$692,886.00
Thermal for Walls	113,176 SF	$10.00	$1,131,760.00
Finishes	125,656 SF	$28.00	$3,517,739.72
Specialties	125,656 SF	$2.47	$310,370.32
Equipment	125,656 SF	$2.22	$278,956.32
Plumbing	125,656 SF	$7.47	$938,022.04
Heating, Ventilation, A/C	125,656 SF	$36.78	$4,621,627.68
Electrical	125,656 SF	$23.60	$2,965,481.60
Trade Description	**Volume**	**Cost per CY**	**Total Cost**
Concrete	2,611.11 CY	$450.00	$1,174,999.33
Rebar	1,623.09 CY	$45.00	$73,039.05
Gravel	961.33 CY	$22.50	$21,630.00
Cut Soil	17,888.89 CY	$30.00	$536,666.67
Fill Soil	13,416.67 CY	$12.00	$161,000.00
Trade Description	**Weight in Tons**	**Cost per Ton**	**Total Cost**
Steel	316.78	$3,000	$950,353.23
Columns	120.41	$3,000	$361,227.38
Trade Description	**Quantity**	**Cost per Door**	**Total Cost**
General Doors	78	$500	$39,000.00
GRAND TOTAL			$20,269,701.34

Yellow: Based upon team's model total SF using Gilbane's pricing

Unit Price per Square Foot

	Stacked/Mezanine Design with REVIT Square Footage					
				High		Low
CSI Division	**Trade Description**	**Square Foot**	**High Cost**	**Total Cost**	**Low Cost**	**Total Cost**
1.0	General Requirements	144,297	$32.08	$4,629,047.76	$29.72	$4,288,506.84
2.0	Existing Conditions	144,297	$0.04	$5,771.88	$0.03	$4,328.91
	...Building, Grading and Shoring	144,297	$20.73	$2,991,276.81	$7.96	$1,148,604.12
	...Site Improvement & Infrastructure	144,297	$7.28	$1,050,482.16	$6.75	$974,004.75
3.0	Concrete	144,297	$26.49	$3,822,427.53	$19.48	$2,810,905.56
4.0	Masonry	144,297	$15.60	$2,251,033.20	$10.45	$1,507,903.65
5.0	Metals	144,297	$47.51	$6,855,550.47	$39.38	$5,682,704.45
6.0	Wood, Plastics, & Composites	144,297	$3.83	$552,657.51	$3.55	$512,254.35
7.0	Thermal & Moisture Protection	144,297	$29.22	$4,216,358.34	$24.92	$3,595,881.24
8.0	Openings, Windows, CW, etc...	144,297	$20.34	$2,935,000.98	$14.56	$2,100,964.32
9.0	Finishes	144,297	$29.49	$4,255,318.53	$26.50	$3,823,870.50
10.0	Specialties	144,297	$2.56	$369,400.32	$2.38	$343,426.86
11.0	Equipment	144,297	$2.30	$331,883.10	$2.14	$308,795.58
12.0	Furnishings	144,297	$1.18	$170,270.46	$1.09	$157,283.73
13.0	Special Construction	144,297	$19.09	$2,754,629.73	$17.69	$2,552,613.93
	...Fire Suppression	144,297	$4.84	$698,397.48	$4.59	$662,323.23
14.0	Conveying Equipment	144,297	$1.80	$259,734.60	$1.67	$240,975.99
15.0	Plumbing	144,297	$7.75	$1,118,301.75	$7.18	$1,036,052.46
15.0	Heating, Ventilation, A/C	144,297	$38.00	$5,483,286.00	$35.56	$5,131,201.32
16.0	Electrical	144,297	$24.30	$3,506,417.10	$22.87	$3,300,072.39
	SubTotal Contract Cost	144,297	$318.31	$45,931,178.07	$292.75	$42,242,946.75
	Escalation	144,297	2.25%	$1,033,451.51	2.24%	$946,242.01
	Construction Management Costs	144,297	2.00%	$918,623.56	2.00%	$844,858.94
	Total Construction Cost			$47,883,253.14		$44,034,047.69
	Price per Square Foot			$331.84		$305.16
	Difference from Canon Base Design			$3,915,098.14		$65,892.69

Appendix K: Program Area Changes in Conceptual Phase

Preliminary Program

	PROGRAM AREA	ORIGINAL AREA	REVISED UNIT AREA	QUANTITY	TOTAL AREA (NSF)	COMMENTS
1	PUBLIC SPACES					
1.1	Lobby	4,700	4,400	1	4,400	CD adjustment 11/6/08 to offset added 300nsf Unisex Changing Room.
1.2	Hall of Fame/Trophy Display	500	500	1	500	Harrington
1.3	Reception Desk	450	450	1	450	
1.4	Vending	0	100	1	100	Harrington CD adjustment 8/28/08
1.5	Lounge	1,250	0	1	0	WPI adjustment 9/25/08
	Concessions	0	0	1	0	Parking Structure
	Concessions Storage	0	0	1	0	Parking Structure
1.6	Public Restrooms	0	300	2	600	CD adjustment 8/28/08
	Sub-total	6,900			5,450	excludes Harrington
2	ACTIVITY SPACES					
2.1	4-court Gymnasium	29,000	29,000	1	29,000	
2.2	Elevated Jogging Track	8,400	8,400	1	8,400	Above courts within gymnasium
2.3	Gymnasium Storage	0	600	4	2,400	CD adjustment 8/28/08
2.4	Fitness Center	10,000	8,000	1	8,000	WPI adjustment 9/25/08
2.5	Fitness Center Storage	300	300	1	300	
2.6	Free Weights	5,000	3,000	1	3,000	WPI adjustment 9/25/08
2.7	Free Weights Storage	300	300	1	300	
2.8	Group Exercise/Multipurpose	3,600	1,000	3	3,000	WPI adjustment 9/25/08
2.9	Group Exercise Storage	200	400	1	400	CD adjustment 8/28/08
2.10	Meeting Room	1,450	600	2	1,200	WPI adjustment 8/28/08. Provide sinks.
2.11	Meeting Room storage	0	200	2	400	CD adjustment 8/28/08
2.12	Racquetball/Squash Courts	3,700	840	3	2,520	21'x40' WPI adjustment 9/25/08
2.13	Climbing Wall	0	1,200	0	0	
2.14	Natatorium	19,100	17,100	1	17,100	25 yd. x 37.5 m. WPI adjustment 9/25/08
2.15	Natatorium Storage	600	600	1	600	
2.16	Pump Room	600	1,000	1	1,000	CD adjustment 8/28/08
2.17	Natatorium Spectator Seating	2,800	2,800	1	2,800	250 spectators
2.18	Meet Management / Lifeguard	300	120	1	120	WPI adjustment 8/28/08
2.19	Indoor Rowing Tank	0	2,000	1	2,000	(1) 8-person tank WPI adjustment 8/28/08
	Sub-total	85,350			82,540	

	PROGRAM AREA	ORIGINAL AREA	REVISED UNIT AREA	QUANTITY	TOTAL AREA (NSF)	COMMENTS
3	TRAINING & REHABILITATION					
3.1	Office	0	180	2	360	(1) private and (1) shared-use
3.2	Exam Room	0	150	1	150	
3.3	Secure Storage	0	80	1	80	
3.4	Bulk Storage	0	250	1	250	
3.5	Taping / Treatment / Rehabilitation	0	2000	1	2,000	
3.6	Hydrotherapy	0	180	1	180	(2) tanks
3.7	Ice Machine	0	100	1	100	
3.8	Rest room	0	80	1	80	
	Sub-total	4,200			3,200	WPI adjustment 8/28/08
4	ADMINISTRATION/COACHES					
4.1	Reception / Secretarial	300	300	1	300	
4.2	Athletic Director	200	200	1	200	
4.3	Althletic Director Assistants	450	450	1	450	3 @ 150
4.4	Offices	2,900	2,900	1	2,900	18 @ 150, 1 @ 200
4.5	Workroom	1,050	1,050	1	1,050	1@ 600, 1 @ 450
4.6	Video Editing Room	200	200	1	200	
4.7	Storage	150	150	1	150	
4.8	Secure Storage	100	100	1	100	
4.9	Rest Rooms	150	150	1	150	
	Sub-total	5,500			5,500	
5	SUPPORT SPACES					
5.1	Men's General/Pool Locker Room	1,000	1,000	1	1,000	Rec. Center
5.2	Women's General/Pool Locker Room	1,000	1,000	1	1,000	Rec. Center
5.3	Storage & Collection	0	225	1	225	CD adjustment 8/28/08
5.4	Loading	0	400	1	400	CD adjust. 8/28/08. Provide service zone.
5.5	Unisex Change Room	0	300	1	300	CD adjustment 10/09/08
	Sub-total	2,000			2,925	
6	AREA SUMMARY (recreation center only)					
	Public Spaces	6,900			5,450	
	Activity Spaces	85,350			82,540	
	Training Spaces*	5,500			3,200	
	Admin. Spaces*	5,300			5,500	
	Support Spaces	2,000			2,925	
	Total (NSF)	105,050			99,615	WPI adjustment 9/25/08
	Total Gross Square Footage (GSF)				132,488	75% efficiency target

Appendix L: Donation Gifts Opportunities

THE NEW SPORTS AND RECREATION CENTER

AT WPI

Gift Opportunities

With the new Sports and Recreation Center, WPI will usher in a new era of excellence at the university, providing the entire community with a premium sports and recreation center while upgrading significantly the facilities for WPI's varsity athletes—young men and women who everyday offer vivid examples of talent, teamwork, and dedication both on the field and in the gymnasium.

The Sports and Recreation Center offers WPI alumni and friends a variety of naming opportunities. These include:

NAMING OPPORTUNITIES	GIFT AMOUNT
Sports and Recreation Center	$10 million
OUTDOOR SPACES	
Parking Garage	$5 million
Multipurpose Athletic Field	$2.5 million
Softball Field	$2.5 million
PUBLIC SPACES	
Lobby	$1 million
(The lobby includes a reception desk, lounge, hall of fame/trophy display, vending and concessions.)	
ACTIVITY SPACES	
Swimming Pool	$5 million
Four Court Gymnasium	$3 million
Fitness Center	$2.5 million
Suspended Running Track	$1 million
Group Exercise/Multipurpose room	$1 million for entire room
2,400 SF room	$600,000
1,200 SF room	$400,000
Wrestling Practice Room	$1 million
Classroom	$400,000
Donahue Rowing Tank Room	$400,000 (Funded 02/08)
Racquetball Courts (2)	$250,000 each
Squash Courts (2)	$250,000 each

TRAINING AND REHABILITATION

Training and Rehabilitation Suite *(The Training and Rehabilitation Suite includes two offices, exam room, storage area, taping/treatment/rehabilitation room and hydrotherapy.)*	$1.5 million
Training Offices (2)	$100,000 each

COACHES/ADMINISTRATION

Coaches/Administration Office Suite *(The Coaches/Administration Office Suite includes the offices for the Athletic Director, 22 other offices for coaches, a workroom, and storage.)*	$5 million
Film Editing Room	$500,000
Conference Room	$500,000
Athletic Director's Office	$200,000
Coaches Offices (22)	$100,000 each

SUPPORT SPACES

Men's General Locker Room	$500,000
Women's General Locker Room	$500,000
Men's Varsity Locker Room	$500,000
Women's Varsity Locker Room	$500,000
Equipment issue, storage and office	$500,000
Men's Coaches Locker Room	$300,000
Women's Coaches Locker Room	$300,000
Visiting Locker Room (2)	$300,000 each
Officials Locker Room (2)	$100,000 each

If you would like to learn more about these naming opportunities, please contact:

Dexter A. Bailey Jr.
Vice President of Development and Alumni Relations
508-831-6010
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Appendix M: Gilbane Soil Report

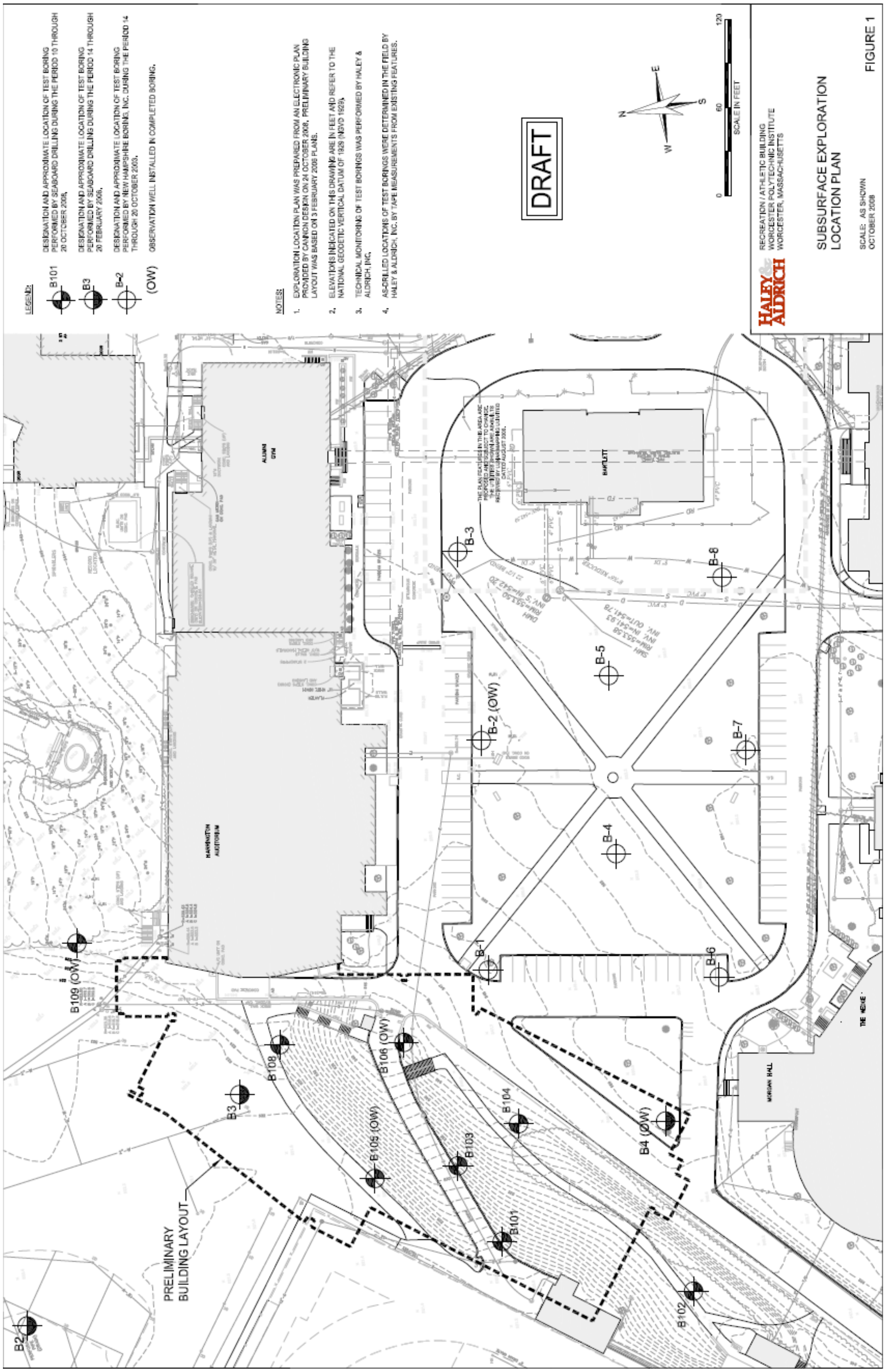

TABLE I
SUMMARY OF SUBSURFACE EXPLORATIONS
RECREATION/ATHLETIC BUILDING
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASSACHUSETTS

DRAFT

Exploration Designation	Estimated Ground Surface El.	Thickness of Stratum Encountered (ft)				Depth to top of Intact Bedrock (ft)	Estimated Top of Intact Bedrock El.
		Fill	Glaciofluvial	Glacial Till	Weathered Rock		
B101	524	2.8	11.7	3.4	NE	17.9	506
B102	537	1.9	NE	32.1	NE	34	503
B103	532	1.6	NE	21.4	NE	23	509
B104	545	2.5	NE	42.3	NE	44.8	500
B105(OW)	521	0.5	NE	7.5	NE	8	513
B106(OW)	543.5	2.6	NE	40.2	NE	42.8	501
B108	526	3.5	NE	21.4	NE	24.9	501
B109(OW)	531	2	NE	27.5	NE	29.5	502
B3	522.5	0.1	NE	18.9	NE	19	504
B4(OW)	550	0.5	NE	52	2.5	55	495
B-1	549	3.5	NE	45.9	NE	49.4	500
B-6	552.5	3.5	NE	44.5	1.5	49.5	503

Notes:
1. NE = Not Encountered within the depth of exploration.
2. Borings B3, B4(OW), B-1, B-6 performed during previous investigations.
3. Elevations indicated are in feet and refer to the National Geodetic Vertical Datum of 1929 (NGVD29).