The Educational Activities Building

PSU Harrisburg Campus

Figure 1 Images courtesy of BCJ

Final Report

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Option: Construction Management

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THE EDUCATIONAL ACTIVITIES BUILDING

The Pennsylvania State University: Penn State Harrisburg, Middletown, PA

Design and Construction Team:

- Owner: Penn State
- Architect: Bohlin Cywinski Jackson
- Construction Manager: Reynolds Construction
- MEP Engineer: IES
- Structural Engineer: Hope Furrer Associates

General Information:

- Location: Harrisburg, PA
- Occupancy: Educational
- Height: 2 stories
- Size: 55,057 GSF
- Building Cost: $19.4 million
- Construction Dates: February 2013-May 2013
- Delivery Method: Design-Bid-Build with a CM-at-Risk

Mechanical:

- One mechanical room located on the 1st floor of the north wing
- Central station air handling unit HVAC system
- Variable air flow distribution system
- Uses chilled water for cooling and hot water for heating

Electrical:

- 1600A, 480V, 3 phase and 4 wire electrical service
- 40kW emergency generator for life safety loads
- Majority of lighting is LED
- Electrical distribution includes various step-down transformers distribution panels

Architecture:

- Contains engineering labs, classrooms, multi-purpose room, faculty research labs and computer labs.
- L-shaped building with a penthouse
- Designed to be LEED certified
- Connected to existing building by a pedestrian walkway connector

Structural:

- Foundation: Spread footings
- Cast in place 5" & 6" Slab-on-Grade
- Structural steel frame
- 2" 20 GA composite steel decking

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Construction Management

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www.engr.psu.edu/ae/thesis/portfolios/2013/mna118/index.htm

Executive Summary

This is the thesis final report, which will provide 4 in depth analysis of the Educational Activities Building project, located at Penn State Harrisburg. From the technical assignment performed in the fall semester, four problems or opportunities were identified to improve the construction process of this project.

Analysis 1: Alternative Roof System (Green Roof) - An opportunity for gaining more potential LEED credits to obtain LEED Silver Certification. An in depth research has been done on different green roof systems an d the current roof system was investigated to ensure the structural stability when the green roof is added. As a result an extensive green roof system was chosen for the Educational Activities Building which would cover 16,000 SQFT of the roof area. The green roof will take 4 days to be installed with a total cost of $181,120. This is a high initial cost for the new roof system; however the return on investment could be seen within the lifespan of the green roof. The biggest benefits are increased real estate value, stormwater management and reducing energy consumptions which results in utility savings.

Analysis 2: MEP Systems Prefabrication/Modularization -Prefabrication/Modularization is a critical industry issue that was considered for the Educational Activities Building project at the 22nd annual PACE Roundtable. MEP systems are the second most building systems that implement prefabrication. The prefabrication scope includes the main ductwork, electrical conduit and plumbing pipes. After a thorough research of this construction method and looking at case studies from previous project it was determined that MEP systems prefabrication will slice the schedule by 41 days. The original MEP systems completion day was 1/9/2014 but after the schedule reduction it was moved to an earlier date 11/13/2013. As for the implementation cost, the total labor savings is $362,329.52 and the general conditions savings is $130,238.14.

Analysis 3: Structural Steel Sequencing- it had been identified that there is a room for improvements in the steel sequence. Because it is on the critical path, many other tasks are dependent on it. To eliminate any potential delays, a new sequence plan is proposed, which will make the process more efficient, save 8 days from the project schedule and $27,328.32.

Analysis 4: Technology Integration for Information Management- The owner of this project "Penn State" is one of the industry leaders when it comes to the use of BIM thanks to the Office of Physical Plant. BIM is heavily used on the Educational Activities Building project but there is a room for more BIM uses such as a project document management and building maintenance scheduling. Additionally, tablets and desktop stations will be used in the field to increase productivity. The cost for the tablets and desktop stations are between $10,000 and $13,000 with a general condition savings of $2,565 per week which results in a $164,160 savings over the entire project schedule.

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BCJ Architecture

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1.0 Project Background

The Educational Activities Building project is located on the PSU Harrisburg Campus. The 55,000SF building is the result of rapid growth in student enrolment at the Capital Campus. It consists of two-story and will host Mechanical, Civil and Electrical Engineering laboratory, classrooms, faculty offices, computer labs and multi-purpose room. The New EAB will be connected to the existing building through a pedestrian walkway connector.

1.1 Client Information

The Pennsylvania State University is one of the leading universities in the nation, with 24 campuses across the state. Penn state Harrisburg is experiencing growth in student population and this project was designed to meet the needs of the new students. The owner has a few expectations regarding the following:

PENNSTATE Harrisburg 1855

Figure 1 Penn State Harrisburg logo. Image Courtesy of psu.edu

- Cost: Keep the cost within the budget to ensure low tuitions for the students.
- Quality: one of the university main goals is to provide state of the art facilities to its students and faculty. The owner demanded the best quality for everything, starting from the project team and ending with the finishing.
- Schedule: The owner wants the building to be up and running by summer 2014 to get it ready for the new academic year.
- Safety: This is a very important part of the construction work within any of the Penn State campuses. Penn State pays much attention to the smallest details of construction safety to ensure the well-being of its students, faculty and the construction workers.

For the mentioned reasons above, Penn State selected the best team to deliver this project. Additionally, Reynolds Construction was chosen due to their familiarity with area and local trades. The owner required the exciting Educational Activities building to be occupied during construction. The new building will be connected to the existing building through a pedestrian walkway connector. As a result, the owner requires the walkway to be finished when the students are on break. The owner has high expectations for the work to be on schedule, and ensure the highest quality possible without exceeding the budget and finally the safety of the students, faculty and construction workers

1.2 Project Delivery System

The project delivery approach is Design-Bid-Build and this approach was chosen because it's common for school project and it has proven to be successful with pervious projects. The owner hired BCJ as a lead architect with a lump sum contract. Reynolds Construction was hired early in the process as a CM at Risk with GMP contract and loosely partnered with BCJ. Contractors were prequalified by the CM and bids were open and evaluated privately with Penn State. The low bid was taken for each package. The chart in figure 2 shows the project delivery method.

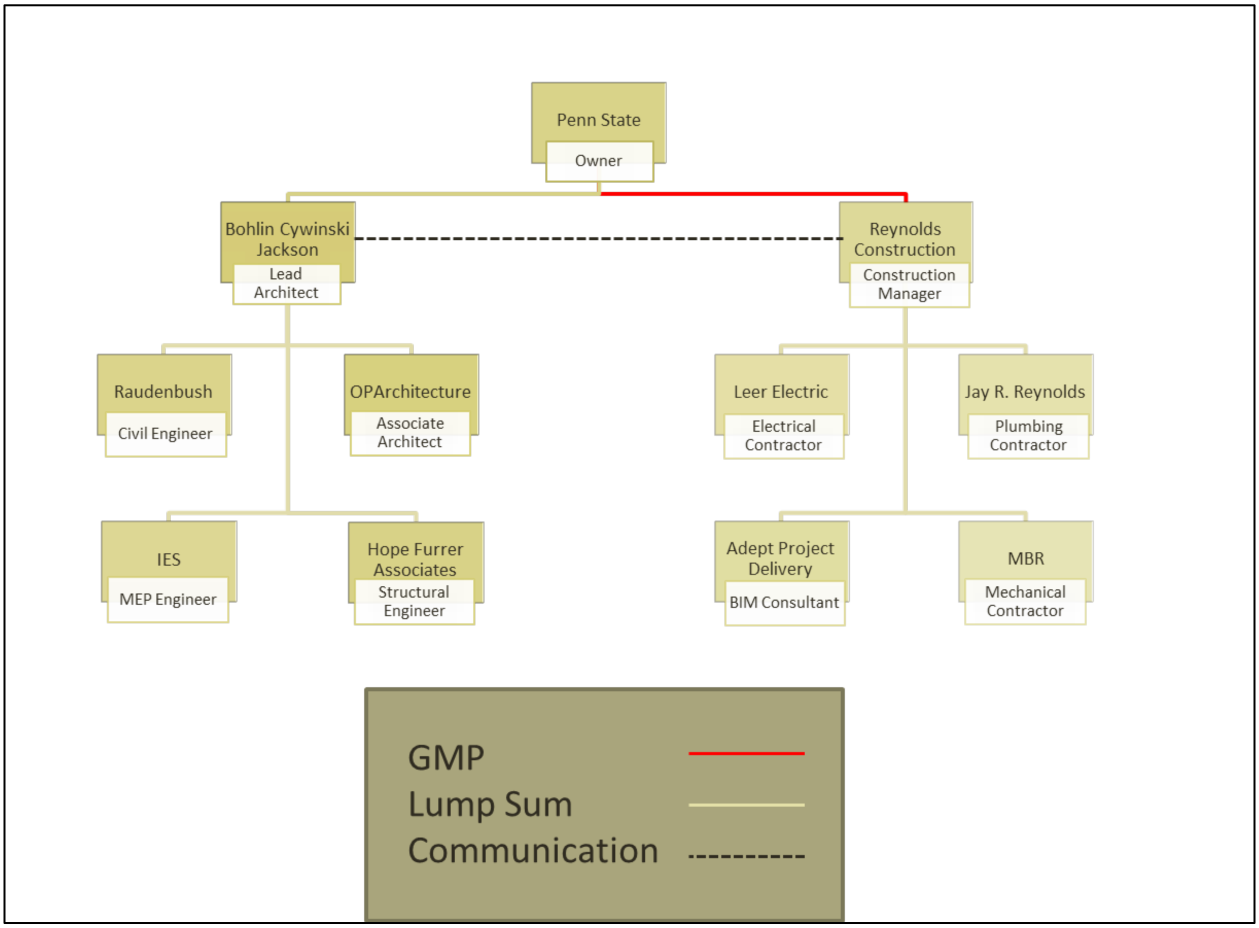

Figure 2 The Educational Activities Building project delivery method.

1.3 Building Systems

Construction

The location of the Educational Activities Building is adjacent to an old existing building and one access road First Street. There is enough space for the construction site as seen in the bird's eye view of the location as shown in figure3. However the existing building will be occupied by students and faculty during construction, which the project team took into consideration. The First Street is used as the main entrance and exit with two gates located on the south and north.

The project team was fully aware and familiar with the climate of this region and they did proper planning to avoid weather delays when creating the construction schedule. The site was empty with the exception of few trees that had to be removed before the beginning the excavation process.

The building is divided into two construction areas: south wing and north wing. That accelerates the construction work and makes it more efficient. The foundation started in the south wing followed by the north wing. With the same coordinates, the slab-on-grade was poured and the steel frame was erected after the curing of the concrete from the ground up. The metal decking with concrete elevated slab was built from top to bottom, starting from the roof and moving down to the second level. As the metal decking and the concrete elevated slab was done for each floor, the MEP rough-in and finishes began. Those activates overlap each other for each floor. Additionally, there was overlap on different activities occurring simultaneously between the south wing and north wing.

Figure 3 Bird's eye view of the project site. Image courtesy of bing.com

<u>Electrical System</u>

The electrical service to the building is 1600A, 480V, 3 phase, 4 wire service and comes from a manhole located on the east side of First Street. It gets to a transformer located outside of the building then it enters through the west side of the first floor of the north wing where the only electrical room is located. The service then proceeds to a switchgear that distributes the power to sub-distribution panels and transformers. The electrical distribution includes various step-down transformers, distribution panels and branch panels located throughout the building to supply power to the different equipment. There is 80KW diesel emergency generator located outside the building next to the transformer and it is used to provide life safety loads and other miscellaneous loads in the event of a power outage. Figure 4 will help identify the locations of the different components of the electrical system.

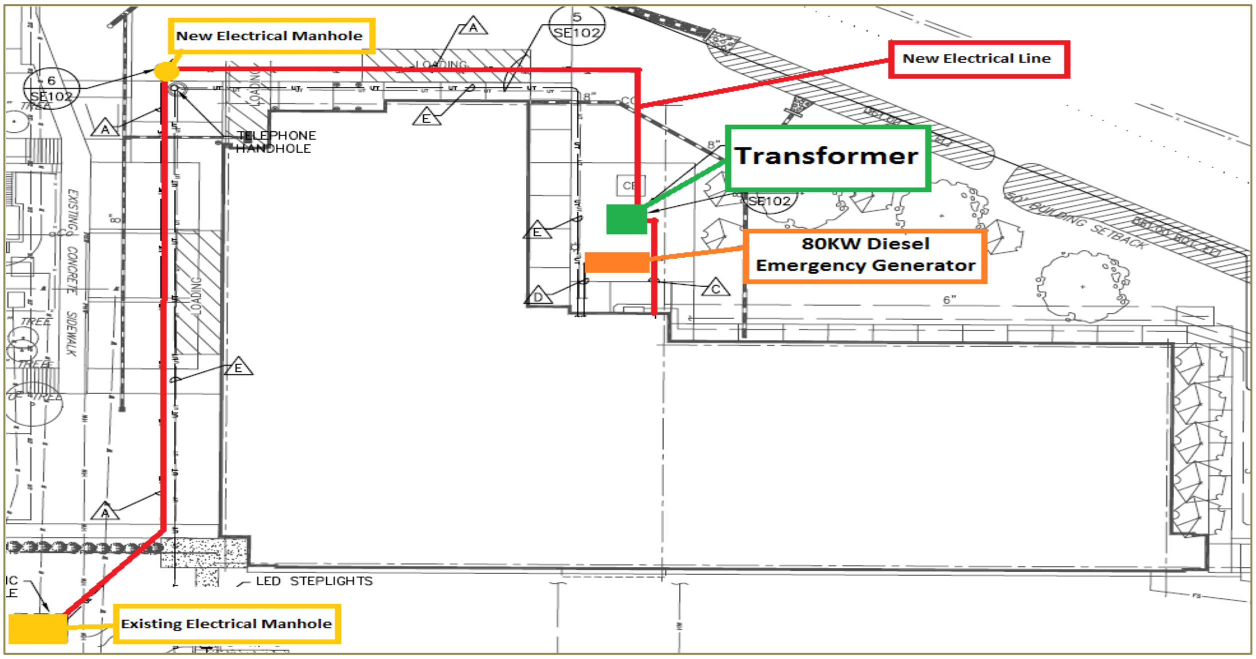

Figure 4 The electrical system plan. Image courtesy of BCJ

Lighting System

The building majority lighting system is LED lighting including recessed 1'x4' for the classrooms and labs and 3" wide linear LED fixtures and LED downlights for the corridors. The fluorescent fixtures are utilized for the lab wing corridors. The lighting control system is based on a localized Creston GLPAC units placed on the ceiling of each region. The regions consist of either 4 or 8 zone units. Although, the laborites typically have 3 zones with an occupancy sensor and photocell to provide daylight harvesting.

Mechanical System

The mechanical system is a central station air handling unit which utilizes chilled water for cooling and hot water for heating. The mechanical room is located on the first floor of the north wing right next to the electrical room. The system consists of a 200 ton cooled chiller to produce chilled water located on the roof. A screw compressor is used to control the capacity from 100% to 10% of the load. This is beneficial to supply the correct amount of chilled water and temperature needed for the most demanding zone in the building. The system has 4 air handling unites and equipped with total energy recovery wheels to exchange sensible and latent energy between the exhaust air and the incoming outside air. All four units are located inside the penthouse.

Structural System

The foundation consists of 8" CMU foundation walls and cast in place concrete footings ranging in size from 3'x3' to 12'x39'. The slab-on-grade is made out of 3500 psi normal weight concrete with a thickness of either 5" or 6". The reinforcement steel for the slab-on-grade utilizes 6x6-W2.9xW2.9 welded wire mesh. The composite metal decks are covered with a 3.25" layer of 3500psi lightweight concrete and 6x6-W1.4xW1.4 welded wire mesh. The structural system is made of steel framing. The beams and girders are mostly wide flange beams ranging from W8x15 to W30x90 with a few HSS and C beams. Beams run from south to north, while girders run from east to west. Likewise, columns are generally wide flange beams ranging from W8x21 to W10x100 and few HSS. Certain columns extend throughout the building height and some extend for one or two floors. The columns are spaced with a typical pattern scheme.

Fire Protection

The building utilizes an active wet pipe fire protection system. Sprinkler heads are distributed throughout the building with a maximum coverage of 225 square foot. Additionally, portable fire extinguishers are provided in different areas of the building. The fire resistance rating for the stairways, stairways doors and elevator shafts is one hour.

Transportation

The building has two sets of staircases one located in the 2 levels part of the north wing and one on the east side of the south wing. This eases traveling by the occupants between the building levels. There is one elevator placed in a centralized location between the two wings.

Telecommunications

The Educational Activities Building contains rooms with projectors, screens and a computer to control the system. The computer labs in this building will contain desktops, printers and other equipment.

Building Façade:

The building exterior is made of Aluminum Curtain Wall system. The walls are covered with brick veneer on the outside and 1" insulated glazing unit on the inside. The curtain wall is connected to the ground with 4" CMUs with ½" exterior gypsum sheathing. In addition, glazed aluminum channels are used around the openings in vertical sections of the building.

A summary of the building systems is provided in table 1 in the following page.

Table 1 Building systems summary.

Building System	Description
Demolition	• Make an opening on the east side wall of the existing building to place a double door.
Structural Steel Frame	• Three types of bracing: 1. Single Diagonal Bracing 2. Eccentric Diagonal Bracing 3. Vertical K-Bracing • Mobile crane is used for the steel erection.
Cast-In-Place Concrete	• Used for the footings, foundation walls, slab-on-grade and suspended slabs. • Engineered formwork system of plywood and metal. • Reshoring is used till proper curing of the concrete.
Mechanical System	• One mechanical room located in the first floor of the north wing. • Mechanical unites placed on the roof and penthouse. • HVAC System: Central station air handling unit. • Variable air flow distribution system.
Electrical System	• 1600A, 480V, 3 phase and 4 wire electrical service. • 40kW emergency generator. • Various step-down transformers. • Majority of the lighting system consists of LED lighting.
Curtain wall	• Glazed aluminum curtain wall

Sustainability Features

- Mechanical system sustainability features:
  - The HVAC system is central station air handling unit, which utilizes chilled water for cooling and hot water for heating.
  - Variable volume supply and return fans using variable frequency drives on the motors.

- Energy recovery wheels which recover sensible and latent energy from relief and exhaust air.

❖ Electrical system sustainability features:
- Electrical distribution includes various step-down transformers.
- Majority of the lighting in the building are LED lighting with lighting control based on localized sensors.

1.4 Project Schedule

The construction work on the Educational Activities Building project has duration of 16 months. The planning and design began on January 12th, 2012 and the substantial completion is set for May 30th, 2014. The schedule is a major driver for the project because the owner expecting the building to be ready for the student to start the academic year. Table 2 shows a breakdown of the different major phases of the project and their durations.

Table 2 Project Schedule Overview.

Schedule Summary	
Phase	**Duration**
Design	January 12th, 2012 - June 11th, 2012
Notice to Proceed (Construction)	February 4th, 2013
Substructure	March 6th, 2013 – July 11th, 2013
Superstructure	May 1st, 2013 – July 17th, 2013
MEP Rough-In	July 12th, 2013 – January 16th, 2014
Building Enclosure	August 2nd, 2013 – January 9th, 2014
Interior Finishes	September 20th, 2013 – May 22nd, 2014
Testing and Commissioning	December 26th, 2013 – May 22nd, 2014
Substantial Completion	May 30th, 2014

The site work started on February 4th, 2013 followed by the foundations. Right after the foundations were placed the erection of the steel started, so as the slab-on-grade. The steel erection sequence moved from south to north. Based on figure 5, the 3 floors were erected upward for phase 1, 2 & 3. Then the two floors for Phase 4 & 5 followed by the one floor phases 6, 7 and 8. The metal decking will work from the penthouse and working its

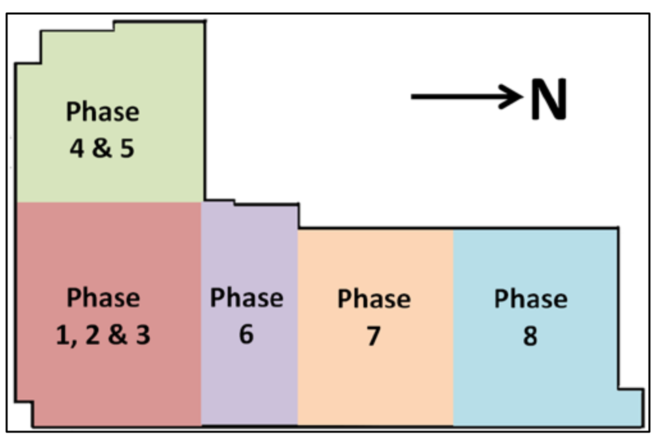

Figure 5Structural steel erection sequences.

way to the ground floor.

The MEP rough-in started 5 days before the end of the superstructure phase and will last for a little over 6 months. The sequence starts from the penthouse then moves to Level two ending with the ground floor. The MEP rough-in starts with the HVAC rough-in then Fire Alarm rough-in, Plumbing rough-in, Electrical rough in and finally Sprinkler rough-in.

The next phase was the building enclosure, which started in the beginning of August and will last for 5 months. It overlaps the MEP rough-in phase and started at the North wing and moving to the South wing. Just as the MEP rough-in phase, the interior finishes started at the penthouse and is working its way to the first floor.

The testing and commissioning will start on December 26th of this year and will last till the last week of the construction schedule. The substantial completion is set for May 30th, 2014 however the owner will move in the first floor on May 8th to work on the furniture and equipment.

See Appendix A for the Original Detailed Project Schedule

1.5 Project Cost

The Educational Activities Building project is a structural steel frame building with concrete slab over metal decking built on top of concrete footings. The detailed structural systems estimate was performed by doing quantity take off for each structural component. Including footings, slab-on-grade, structural steel frame, metal decks and slab on metal decks. The steel reinforcement, formworks and placing were considered for the concrete work. RS Means Costworks 2013 was used to match these elements with their prices. The cost of material, labor and equipment were taken into accounted when this estimate was performed. The estimated structural system total cost is $2,132,632.61 which results in $41.48 per square foot. Table 3 categorizes the structural system cost into two CSI division, concrete ($566,705.41) and structural steel ($1,565,927.2). The cost concrete was 15% shy of the Reynolds estimated cost while the cost of structural steel was 8% less than Reynolds estimated cost. That's might be due to using different cost data or some associated costs. The total project cost is $19.4 million which makes the percent of structural system cost 10.99%.

Table 3 Estimate breakdown based on structural element

CSI Division	Structural Element	Estimated Cost ($)	Cost ($) per SF	Actual Cost ($)
5	concrete	566,705.41	11.02	666,674
3	Structural Steel	1,565,927.2	30.46	1,704,433
	Total	2,132,632.61	41.48	2,371,107

Notes:

- There are 14 different types of concrete footings used for the building foundations. The total concrete volume and reinforcement rebar weight were calculated. The concrete used for the footings is 4500psi normal weight concrete.
- Slab-on-grade is 3500psi normal weight concrete with two different thicknesses, 5 and 6 inches. Both types of slabs utilize 6x6-W2.9xW2.9 welded wire reinforcement.
- Most of the steel structural is wide flange beams and columns with various sizes and few channels and hollow structural sections beams.
- The second level and penthouse have 2" 20 gauge galvanized metal deck while the roof has a 1 ½" 20 gauge galvanized metal deck. All metal decks are covered with a 3.25" layer of light weight concrete with 6x6-W1.4xW1.4 welded wire reinforcement.

Assumptions:

- Concrete is placed by using pumped.
- The cost of few steel beams was not found due to their size so the next bigger beam cost was used to represent their price.
- No profits or overhead were included in the estimate.
- The concrete formworks are used 4 times.
- When calculating the reinforcement for the footings, a 1" edge space was assumed.

As for the assembly estimate the total was about $3,079,058 and that's about a million dollar shy from the actual estimate. The biggest part of the actual estimate is the HVAC system at $1,931,375, followed by the Electrical system at $1,622,283 then Plumbing at $524,837.

***See Appendix B for the Detailed Project Estimate ***

1.6 General Conditions Estimate

The general conditions cost of the Educational Activities Building project is estimated to be $1,016,492.35 for the entire construction schedule of 16 months. This results in $63,530.77 spending on general conditions for each month. Table 4 breakdowns the main components of the general conditions cost, the item cost percentage of the GC cost and comparison with the actual cost. The overall GC cost is 5.2% of the total project cost. The estimate is over the actual cost by approximately $130,000. That's due to the use of multiple cost data sources and different duration for several field personal the performance Bond was estimated to be 1.4% of the overall project cost of $19.4 million.

Table 4 General conditions cost breakdown.

Item	Estimated Cost ($)	Percentage (%)	Actual Cost ($)
Field personal	659,600	64.9	511,450
Temporary Utilities	31,045.6	3	256,400
Field Offices and Sheds	49,460.38	4.9	90,510
Cleaning Up	4,786.368	0.5	28,500
Performance Bond	271,600	26.7	NA
Total	1,016,492.35	41.48	886,860

The field personal includes a project manager, field engineer and superintendent. It was assumed that they will all spend 16 months on the construction site. The temporary power costs were based on 12 hours per day use and the cost of that is about $450 a week. The field offices cost includes two 20’x8’ office trailers, two storage boxes (20’x8’ & 40’x8’) and air conditioning for the hot summer months. Additionally, it takes into account the cost of 6’ high fence and office equipment such as printers and other office’s supply.

The pie chart below in figure 6, provides a visual representation for the percentage of each major item of the general conditions cost. The biggest cost is field personal of $659,600 followed by the performance bond of $271,600.

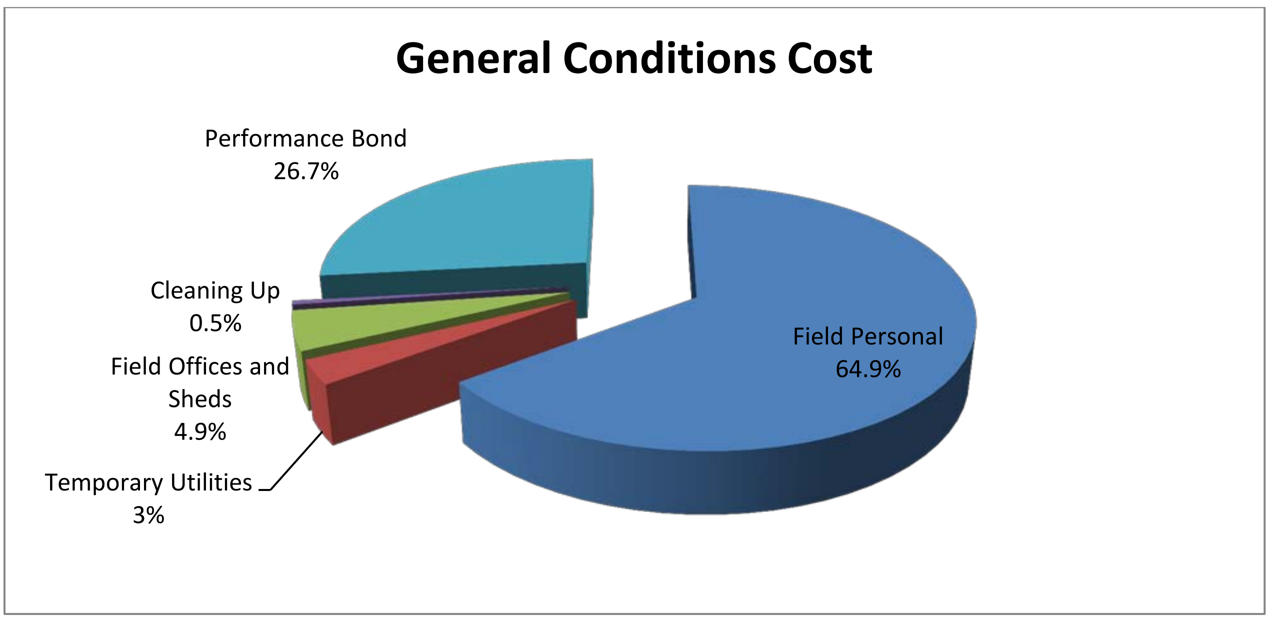

Figure 6 General Conditions cost estimate pie chart.

See Appendix C for the General Conditions Estimate

1.7 Site Layout Planning

Excavation

The pedestrian and traffic flow were taken into consideration when creating the excavation site plan. The existing one story building will be occupied by students and faculty while the new building is being constructed. There's a 6' high fence surrounding the construction site. Two office trailers will be used on this project and they are located south of the project, across from the old building. The temporary power will be taken from an existing power line near the trailers. An existing parking lot is located right next to the trailers and it will be utilized for temporary parking. As mentioned in technical assignment 1 there will be 3 gates, one is located on the south west side and will be mainly used by workers. The second gate is located on the south east and will be used as the main entrance for trucks and deliveries, while the north east gate will serve as the main exit; this is ideal due to the location of these two gates on First Street. Two ramps will be used on the construction site one is located on the west side of the south wing and the other tamp is located on north of the north wing.

Superstructure

Same as excavation all trucks and deliveries must enter through the south east gate and leave the site through the north east gate. The steel erection will start from the south wing and ending at the north wing. A mobile crane with a swing radius of 60' will be utilized for the erection process. The steel laydown area is located within the crane limit for easy access. When erecting the south wing, the crane crew has to be extra cautious as the existing nearby building will be occupied.

Building Enclosure

For the building enclosure the same mobile crane will be used to construct the west exterior walls while scaffolding will surround the south, east and north walls to ensure an efficient and fast construction of the building exterior. The materials laydown area will be located in the same place where the steel laydown area had been. This is a very important phase because multiple trades will be on site doing work so there must coordinate with each other to avoid causing any delays.

See Appendix D for the Site Plans

1.8 Building Information Modeling Use Evaluation

Penn State University pays a lot of attention to BIM and requires BIM implementation on all projects located on its premises. The Educational Activities Building being one of these projects, BIM was used from the beginning and it plays a huge role in this particular project.

After a thorough analyzing of the Penn State BIM manual, the BIM use list and Level 1 Process map have been created to at least meet the university requirements (Appendix F). This project should utilize BIM for the following:

- Record Modeling
- 3D Coordination (Design)
- 3D Coordination (Construction)
- 4D Modeling
- Engineering Analysis
- Design Authoring

Each one of these uses was carefully chosen to deliver the project efficiently. The record modeling includes information relating to structural and MEP systems in addition to other systems. This use helps with future renovation plans or even regular maintenance of the different building systems. Additionally, it provides the owner with an accurate model of the project. The 3D Coordination is a very important element of BIM due to its benefits. It's basically clash detection for any of the building different systems. It uses a 3D model to coordinate between the different subcontractors. By doing so it eliminate any schedule delays due to conflicts between subcontractors, increases productivity and decreases construction cost and time.

The 4D model is a 3D model combined with the construction schedule. The main purpose of the 4D modeling is to provide the different project teams with a better understanding of the phases of the project and its sequencing. This also leads to increase productivity and decrease waste on site. The engineering analysis is a very efficient tool to provide analysis and solutions which improves the overall quality of this project.

This implementation requires transparency and cooperation from each party including but not limited to the architect, CM, owner, subcontractors, etc. This is beneficial for everyone and it could save them a lot of time and money. There should be weekly coordination meetings between the project teams to review the project progress and plan for any potential challenges. Each party is responsible to submit their own reports on the construction work to ensure that everyone is on time and falling behind.

Table 5 shows the BIM uses for each phase of the project. Based on this the BIM uses analysis (Appendix F) was then developed to decide the uses to implement on this project.

Table 5 BIM uses

	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING MAINTENANCE SCHEDULING
	SITE ANALYSIS		DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN	X	BUILDING SYSTEM ANALYSIS
		X	3D COORDINATION	X	3D COORDINATION		ASSET MANAGEMENT
		X	STRUCTURAL ANALYSIS		DIGITAL FABRICATION		SPACE MANAGEMENT / TRACKING
		X	LIGHTING ANALYSIS		3D CONTROL AND PLANNING		DISASTER PLANNING
			ENERGY ANALYSIS	X	RECORD MODELING	X	RECORD MODELING
		X	MECHANICAL ANALYSIS				
			OTHER ENG. ANALYSIS				
			SUSTAINABLITY (LEED) EVALUATION				
			CODE VALIDATION				
X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)
	COST ESTIMATION		COST ESTIMATION		COST ESTIMATION		COST ESTIMATION
	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

The actual BIM uses implementation on this project is quite similar with the suggested uses with the key players being BCJ (Architect), Reynolds (CM) and Penn State (Owner). In my opinion the project team did a great job on implementing BIM uses that will be most beneficial for this specific project. They also are very efficient when it comes to weekly meetings and coordination. The models were transferred from design to construction through cooperation of the project team. The BIM is also used for turnover to the owner for the following uses:

- Record Model: to compare the design to the installed conditions.
- As-Built Model: to document the installed conditions during construction.

See Appendix E BIM Evaluation

2.0 Analysis 1: Alternative Roof System (Green Roof)

2.1 Problem/Opportunity Identification

There were several sustainable ideas considered for the Educational Activities Building project to obtain the minimum credits required for the LEED Basic Certification. From the Technical Reports, it was observed that there more potential credits to achieve LEED Silver Certification. However, the main focus here is to improve the building systems while staying under the budget. It would be interesting to see how this could affect the building performance in the long run.

Figure 7 an aerial view of Educational Activities Building. Image courtesy of BCJ

2.2 Background Research

One of the main areas that will be researched is alternative roof systems that could potentially add value to the project. Green roof system stood out for its increasing popularity even with Penn State projects such as the Millennium Science Complex. Although, green roof systems have a higher initial cost, it will reduce the mechanical load which will decrease the utility cost in the long run. The main goal here is not only to obtain more LEED credits but to make the project more sustainable and efficient. The HUB addition project is utilizing a green roof and it will be used as a case study. Additionally, the city of Chicago developed green roof requirements, which will be looked at as a part of this analysis. A value engineering analysis will be performed on the changing the current roof system to the green roof system. Other alternative roof systems will also be considered for the project.

2.3 Potential Solutions

While using a green roof system might increase the cost, it will have the following positive impacts:

- Reduced mechanical loads

- Improved storm water management
- Increase roof life span which will decrease the cost of replacing it every several years
- Improved aesthetics
- Potential LEED credits

2.4 Methodology

To perform this analysis the following steps will be taken:

- Investigate the current roof system
- In depth research of different green roof systems available
- Evaluate the cost and schedule impact of the alternative roof system
- Redesign the roof structure in case if the green roof system was selected (Structural Breadth)
- Perform value engineering analysis and constructability review
- Determined if the best roof system alternative should be implemented on the project

2.5 Expected Outcome

The implementation if the green roof system will increase the overall sustainable performance of the project. Despite the initial high cost of the green roof system, the owner could be pursued by presenting the long run benefits of the new system such as the long life cycle and reduced mechanical loads. Additionally, there will be a chance to earn more LEED credits to achieve a higher LEED Certification.

2.6 Resources and Tools

The following resources will be used to help with this analysis:

- The project structural engineer
- The Architectural Engineering Department at Penn State
- Office of the Physical Plant at Penn State
- Green roof systems manufacturers
- Online journals on green roof systems
- Project schedule and documents

2.7 Current Roof System Investigation

Roofing

The roofing consists of several layers as shown in figure 10. The top layer is a single-ply roof membrane as in figure 8, with varying thickness and a minimum of ½ inch, in addition to a combination of adhesives and sealant used as a weatherproofing system. The next layer is made of ½ inch gypsum bored followed by a rigid insulation. The insulation is Thermoplastic Polyolefin (TPO)

Figure 8 Single-ply roof membrane, image courtesy of www.pazroofing.com

roofing with a minimum thickness of 4 inches as a base and another layer of insulation on top of it with a slope of ¼ inches per foot. TPO roofing systems as shown in figure 9, are known for their high heat reflectiveness and energy efficiency; it is made of a combination of polypropylene (plastic) and ethylene propylene (rubber). Next, the air-barrier is placed between the rigid insulation and the structural part of the roof. Additionally, it is installed with base flashing to ensure the continuity of air barrier with the roofing membrane. Per the project specifications, the roofing system should have an initial solar reflectance index of no less than 0.7 and an emissivity of no less than 0.75.

Figure 9 TPO roofing installing process, image courtesy www.summitroofing.info

Roof

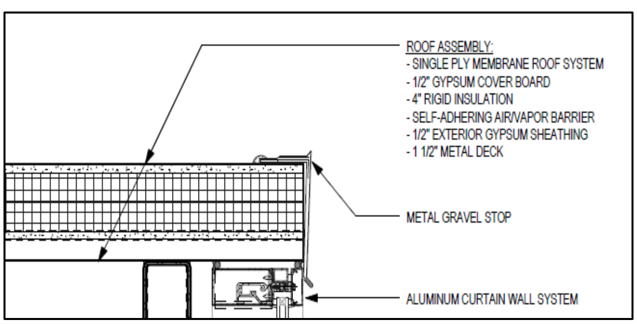

Figure 10 the components of the roof system. Image courtesy of BCJ

The structural component of the roof is made of a metal decking continuous over 3 spans minimum and concrete. The roof is a 1 ½ inches type B 20 gauge galvanized metal roof deck and it is welded to the structural supporting members with a minimum strength of 300 plf. The galvanized metal deck is covered with a 3.25 inches layer of light weight concrete with 6x6-W1.4Xw1.4welded wire reinforcement.

2.8 Green Roof Systems Research

Green roof systems are known for their many benefits and have been used in Europe for the past 30 or 40 years. They can be used on several types of buildings, from residential to warehouse. It can collect rain water, reduce the heat island effect, provide a habitat for wildlife and add aesthetic to the exterior of a building. Additionally, green roof system help decreasing the heating/cooling loads, increase the life span of the roof and increase the property value and that will benefit the owner and the occupants. Generally speaking, green roofs only add 17 (Dry) to 30 (Wet) lb/sf to the roof's load which will require a simple modification of the structural system of the roof.

Extensive

This type of roof system is characterized of its vegetation, ranging from shrubbery to small grasses, bergs and flowering herbaceous plants, which need little maintenance and no permeate irrigation system, figure 11. The growing medium depth for an extensive green roof system is typically 6 inches or less. These systems are ideal for efficient storm water management with low maintenance needs. Extensive greenrooms are very cost efficient. These roofs are ideal for integrated PV/Solar systems like the Sun-Root system.

Figure 11 an example of Extensive Green Roof system. Image courtesy www.greenrooftechnology.com

Semi-Intensive

Figure 12 an example of Semi-Intensive Green Roof system. Image courtesy of www.greenrooftechnology.com

A semi-intensive green roof system is characterized by small herbaceous plants, ground covers, grasses and small shrubs, requiring moderate maintenance and occasional irrigation, figure 12. A typical growing medium depth for a semi-intensive green roof is 6 to 12 inches. This system is able to retain more storm water than an extensive system and provides the potential to host a richer ecology. Though higher in maintenance, this green roof system also provides the potential for a formal garden effect.

Intensive

An intensive green roof system is characterized by its variety of vegetation ranging from herbaceous plants to small trees with professional maintenance and advanced green roof irrigation systems, figure 13. A typical growing medium depth of an intensive green roof is 6 inches or more. Intensive green roofs offer a great potential for design. This system supports everything from small home gardens to full scale public parks. Plant selection and design greatly affects the maintenance required for the upkeep of these roofs. Rooftop farms, urban roof farms or vegetable farms on roofs are clearly intensive green roofs and require higher nutrient applications and focused maintenance. Table 6 summarizes the description of each type of the green roof systems.

Figure 13 an example of Intensive Green Roof system. Image courtesy of www.calfinder.com

Table 6 Comparison between the different types of green roof systems.

Criteria	Extensive Green Roofs	Semi-Intensive Green Roofs	Intensive Green Roofs
Depth	3 - 5 inches	6- 7 inches	8 - 24+ inches
Weight max.	15- 25 lbs/ft²	25- 40 lbs/ft²	35 - 80+ lbs/ft²
Plants	Mosses, Sedums, Succulents, Herbs and few Grasses	Selected Perennials, Sedums, ornamental Grasses, Herbs and little Shrubs	Perennials, Lawn, Putting green, Shrubs and Trees, rooftop farming
Irrigation	no, not recommended	partially, as-needed	yes, automatic/flood
Maintenance	low	medium	high
Use	Living machine	Diversity, habitat	Garden, Park
Costs	low	medium	high

2.9 Green Roof System Components

As mentioned above, there are several varieties of green roofs but they all contain the same components. The lower layer consists of the building roof decking, vapor control layer, insulation, waterproof membrane and protection mat like most typical roofs. Next is the drainage layer topped with filter layer to prevent the soil particles from clogging the drainage. The most upper layer consists of the plants and vegetation mix in growing medium. Figure 14 shows a detailed sectional view of a typical green roof system.

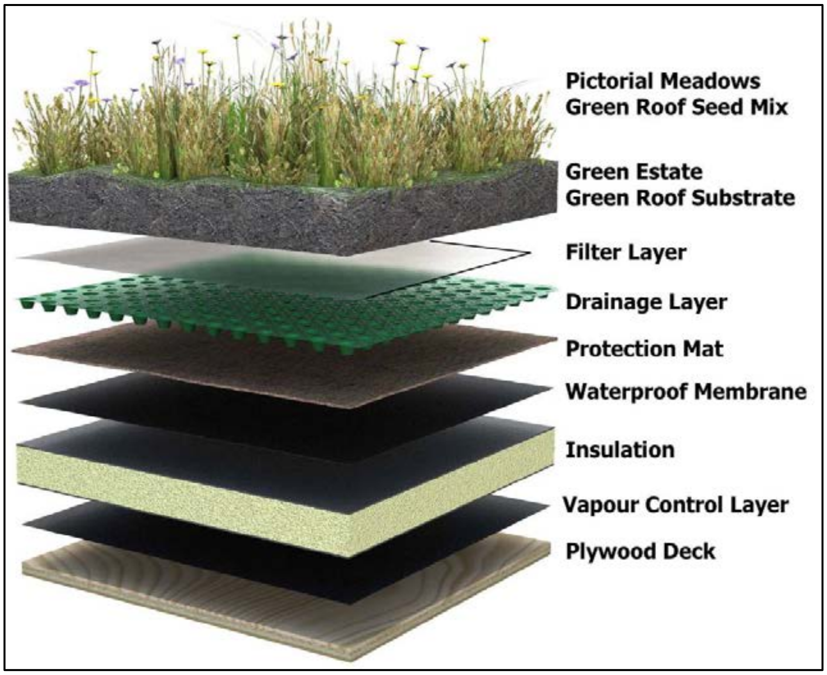

Figure 14 sectional view of a typical green roof system components. Image courtesy of www.impressivemagazine.com

2.10 Chicago Case Study

The city of Chicago is a great example of an urban area that took initiative to explore and implement green roof under the Mayor Richard M. Daley's lead. The City of Chicago Department of Environment put a team of architects, engineers and ecologist to work together on designing a green roof system for the City Hall to set an example for this relatively new roof system. Upon completion, the team started monitoring and studying the green roof system. One of the biggest results was a surfa19ce temperature reduction of 70 degrees and an air temperature reduction of 15 degrees, figure 15.

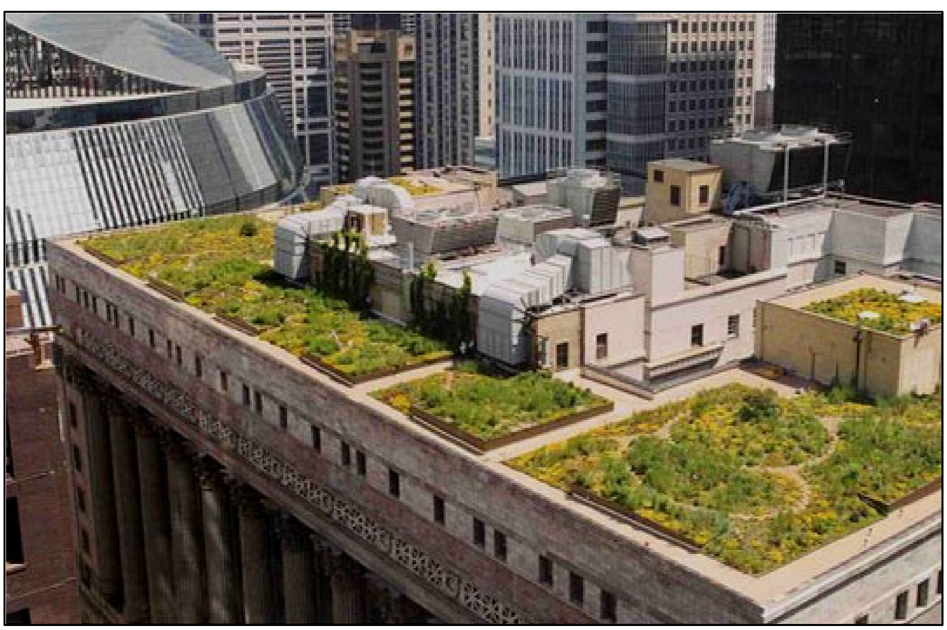

Figure 15 the green roof system of the Chicago City Hall. Image Courtesy of www.asla.org

2.11 Roof System Loads

Table 7 Roof loads schedule.

Loading (PSF)	Level 2 Roof and Penthouse Level Roof	Penthouse Level Roof with Future Solar Array	Multipurpose RM Roof	Roof over Penthouse Mechanical Room	Connector Roof	South Canopy Roof
Concrete Slab	40	40	40	-	-	-
Metal Deck	2	2	2	2	2	2
Additional ¾" Concrete	8	8	8	-	-	-
M/E/C/L	8	8	83	16	8	8
Membrane	4	4	4	4	4	4
Insulation	5	5	5	5	-	5
Future Solar Array	-	10	-	-	-	-
Permanent Equipment	-	-	-	-	-	-
Total Dead Load	67	77	100	27	15	19
Live Load	40	40	150	40	20	40
Total Load	107	117	250	67	35	59

2.12 Proposed Green Roof Design

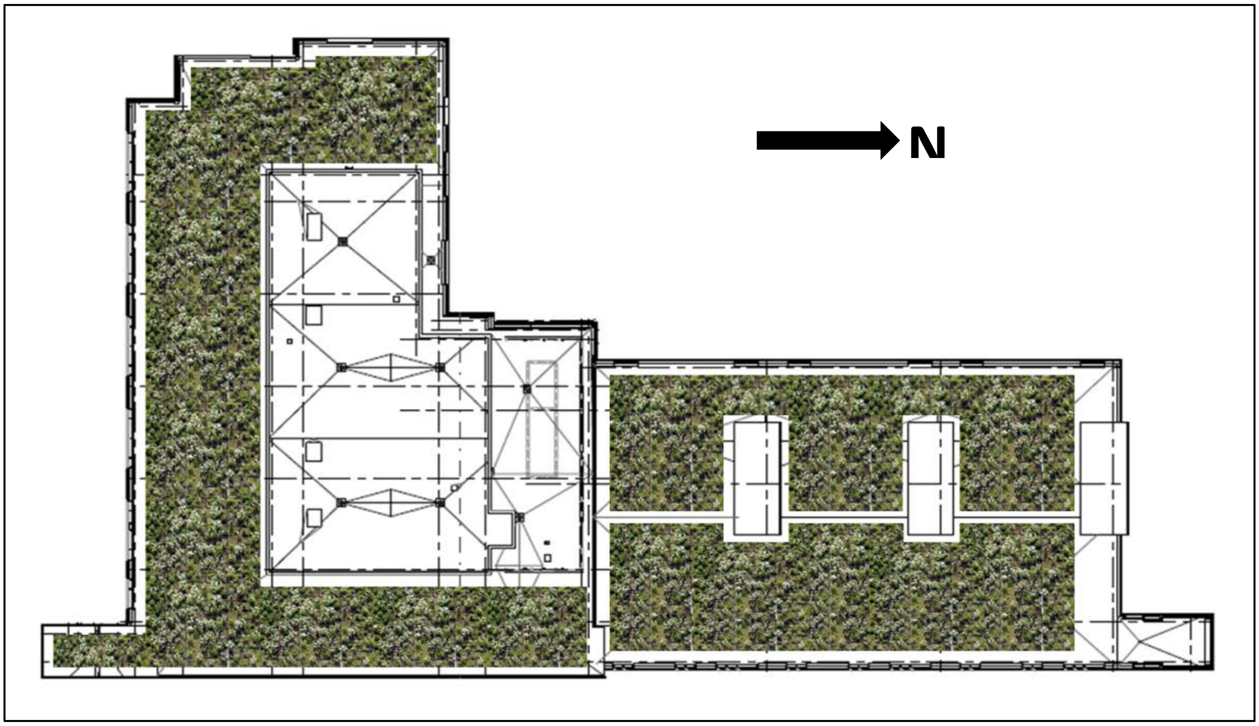

Figure 16 proposed Green Roof System.

The proposed green roof system design for the Educational Activities Building is presented in figure 16. It covers about 16,000 SQFT which is about 55% of the total roof area for exception of the penthouse and 3' wide walkways on the sides for maintenance purposes. From the research done on green roof systems, the extensive green roof system will be considered for this project due to its light weight and low cost.

2.13 Constructability Review

The roof of the Educational Activities Building will be built as designed, and then the green roof system will be delivered to the construction site in the form of pre-grown trays, figure 17. Labor power then will be used to place the trays on the roof. The installation productivity rate is 4000 SQFT per day with 4 laborers. From the proposed green roof design area, it will take 4 days to complete the green roof. According to the RSMeans value, the total cost of the green roof system including labor and material is $17,440, table 8.

Figure 17 an example of a Green Roof System tray. Image courtesy of www.greenroofs.com

The initial cost of this solution is high, but the green roof system advantages will make it up in the first 20 years which is well within the its life span of 40 to 50 years. Other savings come from the ability of green roof systems to help with reducing the building's mechanical load which results in utility cost savings. Additionally, it protects the roof components and extends their life spans which minimizes maintenance needs and cost.

Table 8 The productivity rate and detailed cost of green roof. RSMeans Value.

Description	Unit	Quantity	Daily Output (SF)	Material Cost ($)	Labor Cost ($) per day	Total Material Cost ($)	Total Labor Cost ($)	Total Cost ($)
Green Roof System 4" Deep	S.F.	16,000	4,000	10.5	0.82	168,000	13,120	181,120

The below graphs is a cost analysis regarding the return on investment from implementing the green roof system. It was made by GSA where they list increased real estate value, community benefits, stormwater management followed by energy savings as the highest reasons to use green roof systems. The graph shows that the real estate value increases by $33 per square foot while improved storm water management saves about $10 per square foot.

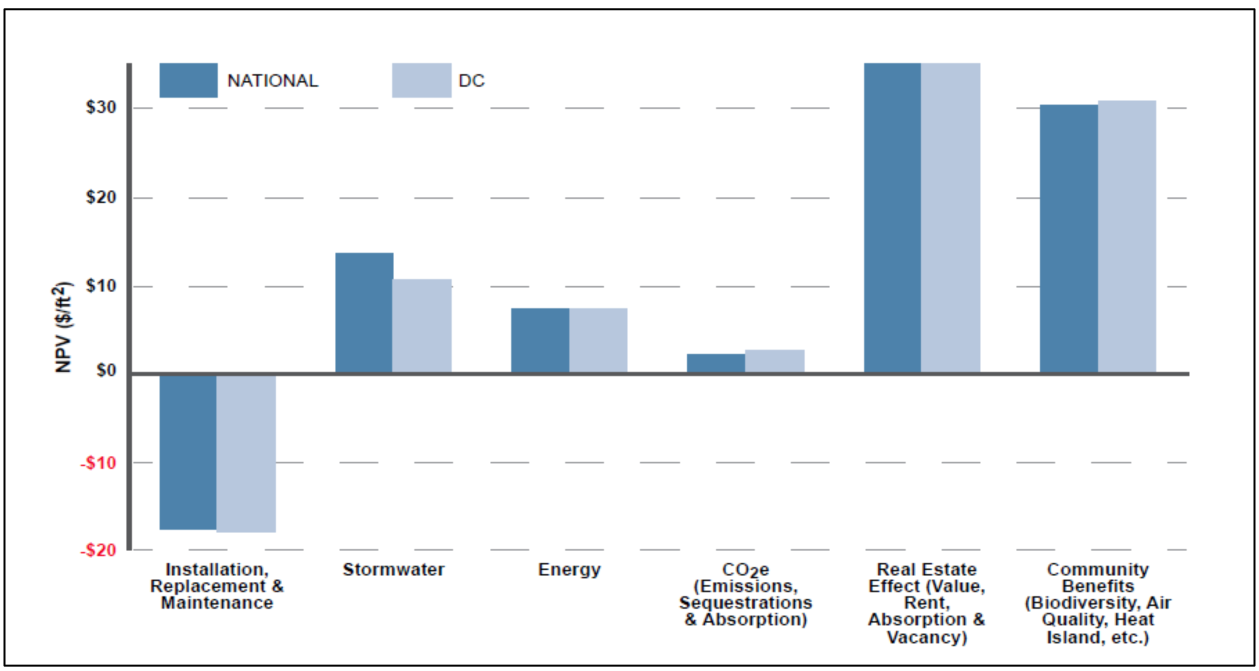

Figure 18 Cost-Benefit analysis green roof systems. Image courtesy of gsa.gov

2.14 Summary

As mentioned earlier green roof systems have been used in Europe for the past 30 or 40 years. However, it became popular in the USA due to a cultural shift in the construction industry toward green and lean buildings. The proposed green roof system for the Educational Activities Building project will cover 16,000 SQFT of the roof area. It will take 4 days to be installed and with an initial cost of $181,120. Although, the cost of implementing this solution is high but the money savings from less energy consumption and increased property value will pay back within the green roof lifespan.

See Appendix G Structural Breadth

3.0 Analysis 2: MEP Modularization

3.1 Problem/Opportunity Identification

Through analyzing the Educational Activities Building project schedule from the Technical Report 2, it has been observed that the MEP System activities overlap each other as shown in table 9. This causes congestion on the construction site due to having multiple crews working at the same time. As a result, the potential for accidents and reduction in productivity is increased. Additionally, having a crew for each component of the MEP systems increases the labor cost. In the 22nd annual PACE Roundtable, one of the critical industry issues Multi-trade Modularization was the main topic discussed in the breakout sessions. If this could be implemented on the project, it will eliminate the problems from the MEP systems such as cost and site congestion.

Table 9 MEP system construction schedule

Task	Start Date	Finish Date	Duration (Days)
Mechanical Rough-In	7/17/2013	11/21/2013	92
Electrical Rough-In	9/4/2013	12/9/2013	69
Plumbing Rough-In	9/4/2013	11/28/2013	62
Mechanical Distribution	8/14/2013	12/13/2013	88
Electrical Distribution	9/27/2013	12/18/2013	59
Plumbing Distribution	9/4/2013	1/1/2014	86
Mechanical Finishes	9/13/2013	12/26/2013	75
Electrical Finishes	9/27/2013	12/24/2013	63
Plumbing Finishes	10/11/2013	1/9/2014	65

3.2 Background Research

Multi-trade modularization is a growing trend and being employed in many projects. In order for multi-trade modularization of the MEP System, figure 19 to be applied on the Educational Activities Building project several things will be considered. An

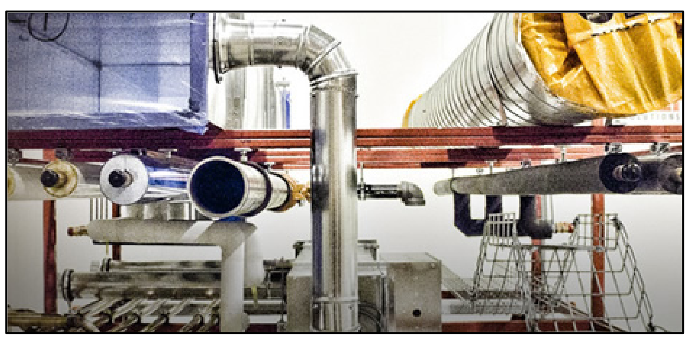

Figure 19 A sample of MEP Modularization. Image courtesy of www.modulusmep.com

analysis of the building different zones will be performed to decide what sections of the building can utilize it the best. Additionally, an evaluation of the multi-trade modularization of the MEP System impact on the cost and schedule will be done. In depth research of the region modularization shops will be done to find the cost, time and quality of their products. Finally, other building systems will be considered to see the feasibility of utilizing modularization. The main goal is to improve the constructability and accelerate the overall project schedule.

3.3 Potential Solutions

Implementing the multi-trade modularization of the MEP System will have several positive impacts on the project:

- Improve the quality of the final product by manufacturing it in a control environment, figure 21.
- Accelerate the project schedule by decreasing the MEP System activities to the minimum such as installation and inspections, figure 20.
- Lower the cost by eliminating the need for multiple crews for each trade.
- Safety onsite is improved by lowering the site congestion.

3.4 Methodology

To perform this analysis the following steps will be taken:

- Research the uses of multi-trade modularization in the construction industry.
- Analyze if this solution is best implemented for the MEP System of the entire project or just a specific section of the building.
- Review pervious projects that have utilized this solution.
- Research modularization shops in the region
- Determine constructability issues and the impact on the schedule
- Estimate the cost of implementing this solution
- Determined if this solution should be implemented on the project

Figure 20 The installation process of the MEP system modular. Image courtesy of www.globaloff-site.com

Figure 21 A modularization shop where the components are built in a control environment. Image courtesy of www.mepsolutions.com

3.5 Expected Outcome

This analysis will compile a lot of information regarding the utilization of multi-trade modularization on construction projects. Upon the completion of this research, a deeper understanding of issues related to modularization will be obtained. The evaluation of the cost, schedule and quality will prove the benefits of implementing this solution on the Educational Activities Building.

3.6 Resources and Tools

The following resources will be used to help with this analysis:

- The project manager Mr. Adam Dent
- The 22nd Pace Roundtable discussion sessions
- Office of the Physical Plant at Penn State
- Modularization shops in the region
- Online journals on multi-trade modularization
- Project schedule and documents

3.7 Multi-Trade Modularization Research

The construction industry is one of the largest industries and big changes don't happen quickly or easily. However, many of the construction industry members are aware of the advantages of modularization and prefabrication, and they are applying these concepts to their projects. These advantages are briefly described as follows:

- Schedule Acceleration:
    - Unlike traditional construction, in prefabrication the building system components can be constructed in a warehouse while the building is being construction onsite, figure 22.
    - Prefabrication reduces the schedule which translates into earlier project completion.

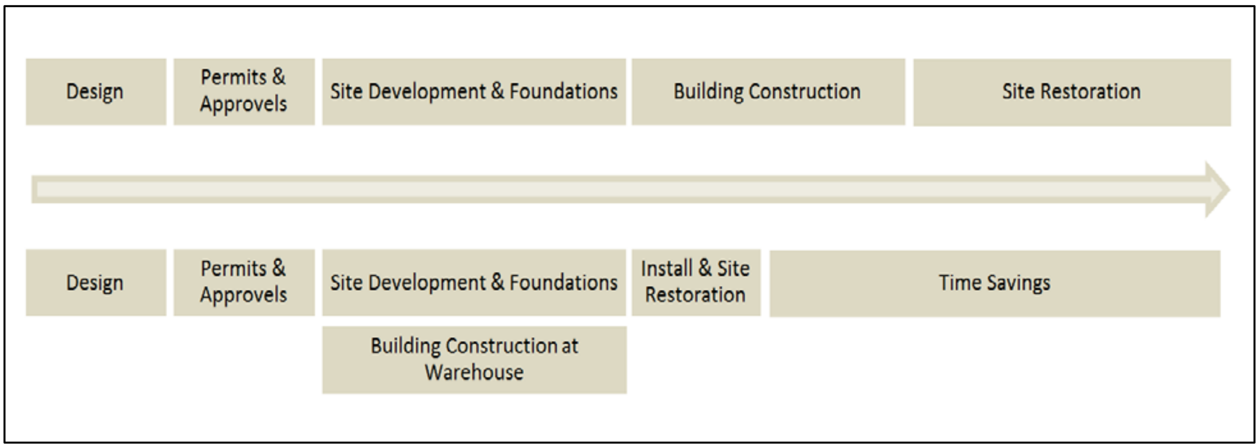

Figure 22 Traditional Construction VS. Modular Construction.

- Enhanced Level of Safety:
    - Since the process is performed in a controlled environment and at low height, any risks related to overhead work is eliminated.
    - The prefabrication shops are kept clean and organized which reduces tripping hazards.
- Waste Reduction:
    - Waste is reduced on site because the components are prefabricated to the exact dimensions.
    - Prefabrication leads to fewer mistakes which usually require using more materials.
- Improved Quality:
    - Labors are working in a controlled environment with access to every part of the MEP components.

- Cost Savings:
  - By reducing the schedule, the cost related to general conditions is decreased.
  - Installation of MEP modular units doesn't require skilled labor and minimize the man power needed on site which saves cost on labor wages.

McGraw Hill Construction on prefabrication performed a research on prefabrication and modularization within the construction industry. The study discussed the history, benefits, uses and impact of these construction methods. Additionally they gave out surveys to the industry members such as contractors, architects and engineers to collect data straight from people who have firsthand experience with these construction approaches. The study lists improve productivity and competitive advantage as the biggest two drivers for prefabrication and modularization followed by generating greater return on investment and owner/client demand. As for the schedule, 35% of the industry members reported a 4 weeks or more decrease in the construction schedule. Additionally, higher education sector ranks second only to healthcare sector in using prefabrication and modularization, but it is the industry's largest sector by value at $43 billion in 2011. It estimated that 42% of higher education projects have implemented prefabrication and modularization. As mentioned above, the study indicated this method of construction can cut down the schedule and reduce the project budget. According to the surveys, 65% of industry members claim that prefabrication decreases the project cost; amongst the 65%, about two thirds reported a decrease by 1%-20%. Moreover, MEP systems prefabrication is ranked second for the most prefabricated building systems. The following page contains graphs summarizing some of the important results that were conducted from the study.

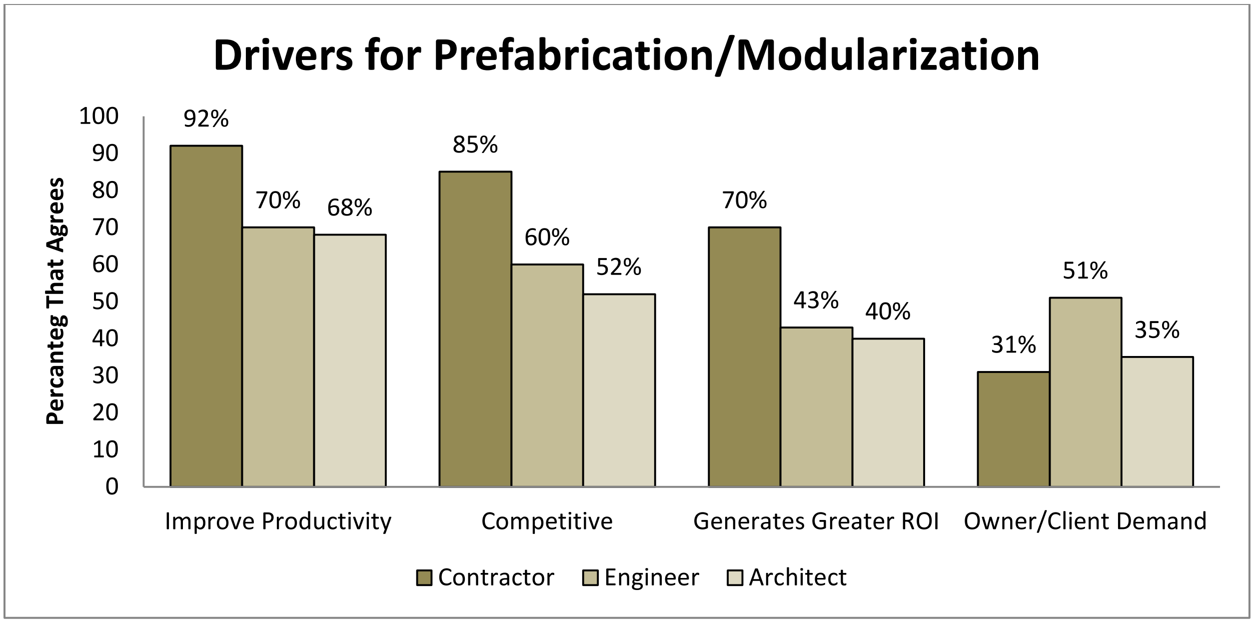

Figure 7 Drivers for prefabrication/modularization based on key players.

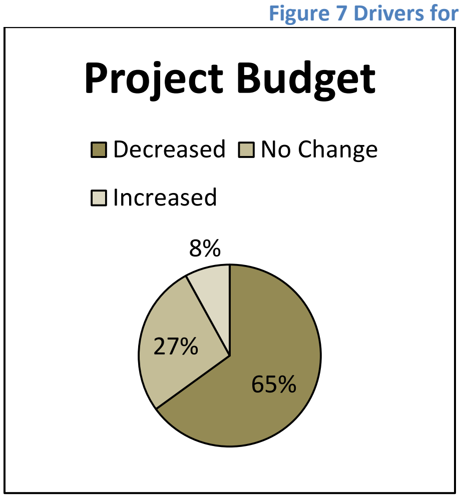

Figure 24 A pie chart shows the impact of prefabrication/modularization on the project cost.

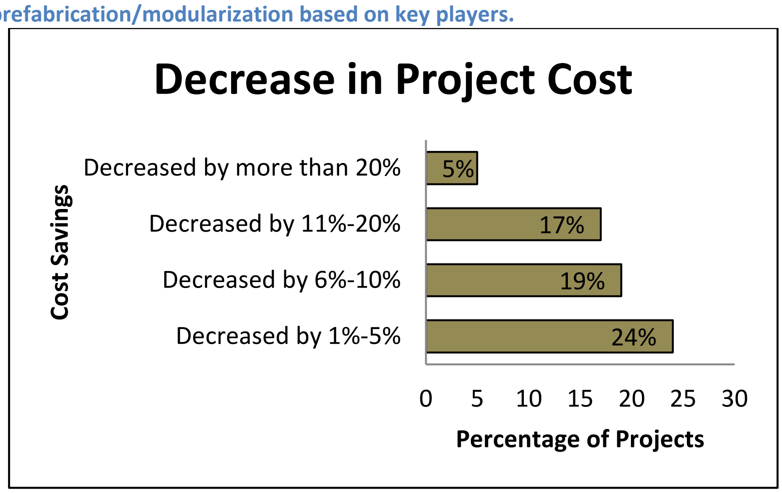

Figure 25 The percentage of decrease in a project cost due to prefabrication/modularization.

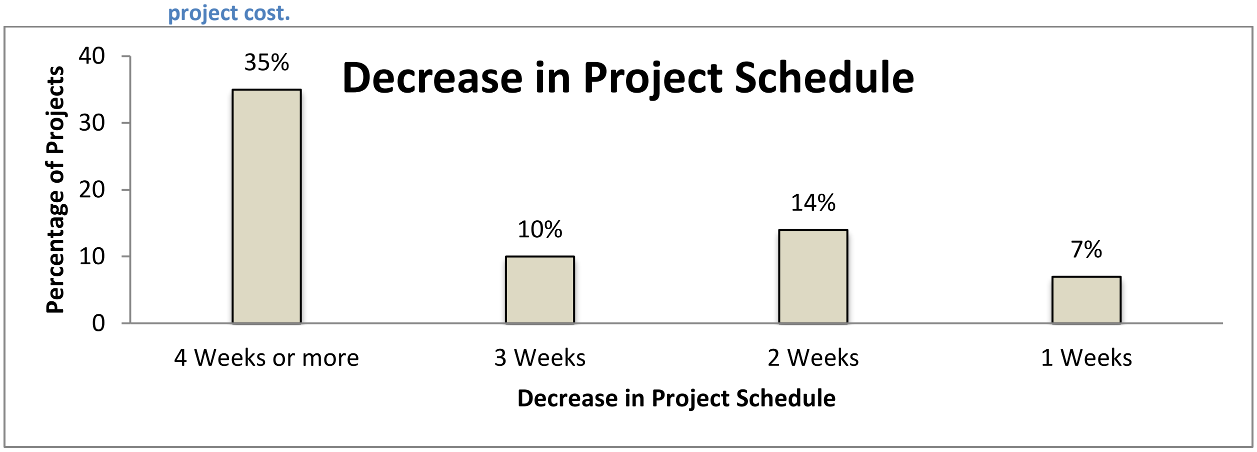

Figure 26 The impact of prefabrication/modularization on the project schedule.

According to a survey made by FMI Corporation in 2013, 81% of electrical and mechanical contractor own their private prefabrication/modularization shops. This happened as a result of many factors, such as the need to lower prices, the lack of skilled labor and the use of BIM which made it easier to coordinate the design of the different systems between the trades. However, the main motive for mechanical and electrical contractors to use prefabrication/modularization is to increase productivity which will reduce the project overall schedule. Additionally, in the education construction sector the growth of modularization is faster than other markets.

Fortunately, the Educational Activities Building is heavily relying on the use of BIM which will allow the use of multi-trade modularization on this project. Multi-trade Modularization requires more planning and coordination between the different trades and BIM offers an effective way of communication early on the in the process. The Pennsylvania State University who's the owner of this project has previous experiences with modularization and that would make it easier to convince the owner to apply this method on the project. During a discussion with the project manager Mr. Adam Dent, he said it might be possible to implement modularization on the Educational Activities.

3.8 Case Studies

Case Study 1

The Miami Valley Hospital Southwest Addition is 484,000 square feet, 12 story high project with a cost of $135 million, figure 27. Skanska USA Building Inc. in a joint venture with Shook Construction provided the management services during the pre-construction and construction phases of the project. During the design development, project team leaders decide to gather the mechanical, electrical, plumbing and drywall trades in a prefabrication shop to assemble five levels of integrated MEP racks, bed head walls and bathroom pods. The project was delayed for 14 months because the team found a sandy seam of soil that was neglected during the bores testing and that lead to pulling out 10 footings and redesigning the foundations. However, multi-trade prefabrication helped to reduce the schedule by 8 to 10 weeks.

Figure 27 the Miami Valley Hospital Addition. Image courtesy of Benjamin Benschneider

The scope of prefabrication consisted of 178 identical patient rooms, figure 28 (bed head walls and bathroom pods) and 120 overhead corridor integrated MEP racks, figure 29 assembled by 18 workers in the prefabrication shop with zero injuries. According to the project executive for the field operations in Skanska Mr. Marty Corrado, the productivity of workers at the shop was 3 times higher compared to those on the construction site, while maintaining a 20% less labor costs. The worker were able to install 33 bathroom in an 8 hour work day to install 33 bathroom pods and 1.5 weeks to rough-in 30,000 S.F. pf patient floor. It was estimated that 35% to 40% of the project was built off-site while the structure was being erected on site. Five out of the 12 floor are dedicated for patient rooms, where each floor has three wings; each includes a 15 ft. wide corridor with 11 “same handed: rooms to ease the prefabrication

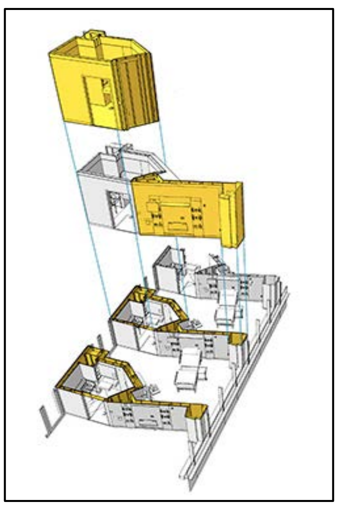

Figure 28 Headwall and bathroom pod modular, Image courtesy www.nbbj.com

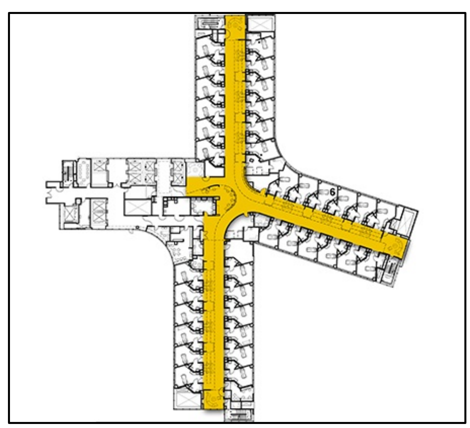

Figure 29 Corridor integrated MEP racks for the 3 wings, Image courtesy www.nbbj.com

process throughout repetition. For each corridor, there are two 8 ft. wide and 20 ft. long corridor integrated MEP racks that are placed side by side along the length of the corridor. This design reduced the chaos above the ceiling to help the maintenance staff with finding and fixing any problems in the future.

On the construction site, installation process starts once the concrete deck was put in place, the corridor drywalls and integrated MEP racks ceiling clips were laid out with the addition of fireproofing. The integrated MEP racks were delivered on Saturdays only because the crane would be in use during the week for ongoing steel erection. The crane is used to place the integrated MEP racks on the floor, which took a day for each level and a week to place them in their final position. Two weeks later, the bathroom pods and headwall units were delivered to the same floor and the crew spent the entire following week distributing and placing the pods and headwall units to their final positions. The process is the same for every other floor out of the 5 patient room floors.

In conclusion, this project witnessed the most ambitious implementation of multi-trade prefabrication in the US, which helped to cut more than 2 months from the schedule and save 1% to 2% off the cost. The project team learned few valuable lessons from this project regarding prefabrication:

- The development of prefabrication should begin from the start to eliminate the need of any major design changes. Mr. Corrado stated that if the prefabrication decision had been made from day one, the schedule could have been reduced by 4 to 6 months.
- Plan the prefabrication components production so they can be delivered to the construction site in time to avoid the need of any additional warehouses.
- Collaboration between the different trades is an important factor for a successful multi-trade prefabrication. “We all had to buy into this process to make it work” says Mr. Fishking, a principle architect at NBBJ.
- BIM is an important key to carry out multi-trade prefabrication; the 3D design helps with modeling the prefabrication parts.

3.9 MEP Systems Prefabrication/Modularization Scope

When determining the scope of the MEP systems prefabrication for the Educational Activities Building, lessons from the in depth research were taken into consideration. As discussed earlier, some of the most crucial issues are the construction site accessibility, the number of levels, the building exterior and the interior layout of the building. The following table summarizes the mechanical system components that will be prefabricated and, figures 30-33 show the planned prefabrication for the mechanical systems components.

<u>Mechanical System</u>

Table 10 the quantity and dimension of the mechanical system components that are considered for prefabrication.

Duct Size	Length of each part (ft)	Quantity	Notes
6”x4”	3	1	
8”x4”	2	1	
8”x6”	3,4,2,3,3	5	
10”x6”	2,3	2	
10”x10”	4,2,2,2,2,2	6	
10”x12”	3	1	
12”x10”	3,6,25	3	Split the 25’ into two 12.5’s
12”x12”	1,1,8	3	
14”x10”	5	1	
14”x12”	8,7,2	3	
16”x10”	12	1	Split the 12’ into two 6’s
16”x12”	3,4,4,2,7,7,6,4,2,4,6,2	12	
16”x14”	5,3,5,2,7,3,6	7	
16”x18”	6,2	2	
18”x8”	3,8,8	3	
18”x10”	2	1	
18”x12”	5, 2,4	3	
18”x14”	11,3,6,2,2,2,2,2,4,6,5,6,6	13	Split the 11’ into two 5.5’s
18”x16”	6,2,5,4,10,9,10,10,9,9,2,2,10,9,10	15	Split the 10’ into two 5’s And 9’ into two 4.5’s
18”x18”	3	1	
20”x7”	2,1,2,1,1,1	6	
20”x10”	1	1	
20”x12”	2	1	
20”x14”	7,5	2	
20”x16”	5	1	
20”x18”	2,4,1	3	
20”x20”	7,3,6	3	

22"x14"	6,1	2	
24"x8"	2,3	2	
24"x14"	8	1	
24"x16"	8	1	
24"x20"	13,1,3,20,2,5,2,2	8	Split the 13' into two 6.5's
26"x14"	7	1	
26"x20"	4	1	
30"x18"	4	1	
30"x20"	5	1	
30"x34"	4,4,1	3	
32"x24"	2	1	
32"x32"	3,3	2	
34"x12"	2	1	
34"x14"	3	1	
34"x20"	5	1	
34"x24"	4	1	
34"x28"	5	1	
34"x30"	5	1	
34"x46"	13,5	2	Split the 13' into two 6.5's
36"x18"	3	1	
40"x16"	5	1	
42"x20"	7	1	
44"x20"	7,4	1	
44"x20"	9	1	Split the 9' into two 4.5's
44"x26"	7,6	2	
44"x32"	2,4	2	
48"x16"	11,4,4,4	4	Split the 1' into two 5.5's
48"x22"	1,9,2,4,7,6	6	Split the 9' into two 4.5's
50"x20"	2	1	
50"x28"	6	1	
50"x30"	14,2,4	3	Split the 14' into two 7's
54"x20"	2	1	
54"x24"	6	1	
54"x30"	2	1	
60"x22"	9,4,4,5,11	5	Split the 11' into two 5.5's And 9' into two 4.5's
64"x18"	6	1	
66"x30"	4,6,1,1	4	
84"x24"	6	1	
Total		171	184 (171+13extra pieces)

Assumptions

- All components will be 7" long or less, for the exception of the 12"x10" piece.
- Only main ductwork branches will be considered for prefabrication.

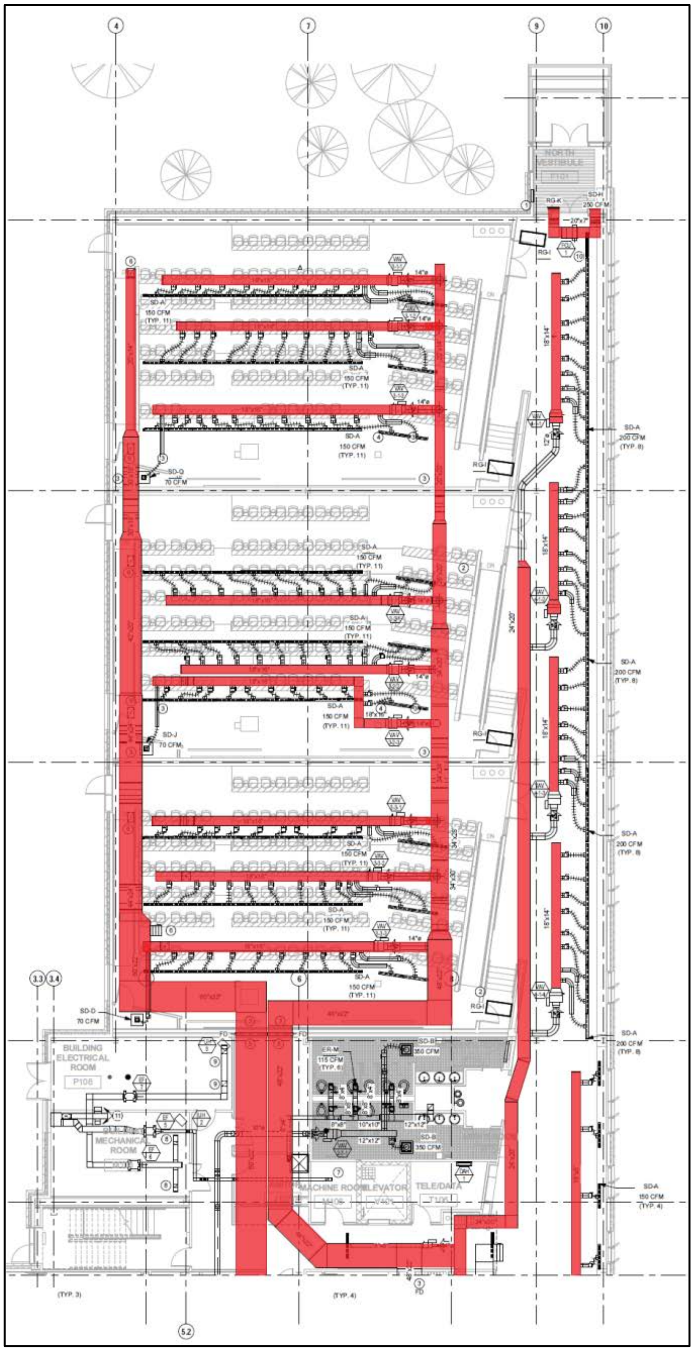

Figure 30 the proposed ductwork of the north wing that will be considered for prefabrication are highlighted in red. The sizes vary from 18"x4" to 60"x22" and will be fabricated to the appropriate lengths to minimize the delivery trips and the number of units. Image courtesy of BCJ

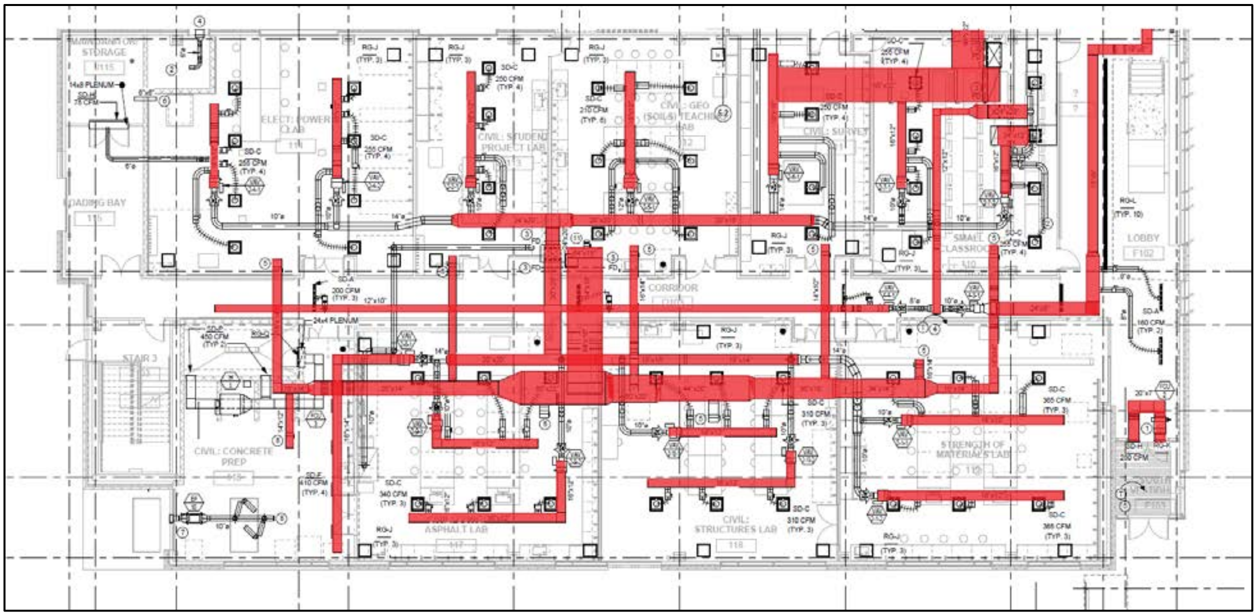

Figure 31 the proposed ductwork of the first level in the south wing that will be considered for prefabrication are highlighted in red. The sizes range between 12”x10” and 64”x18” and will be fabricated to the appropriate lengths to minimize the delivery trips and the number of units. Image courtesy of BCJ

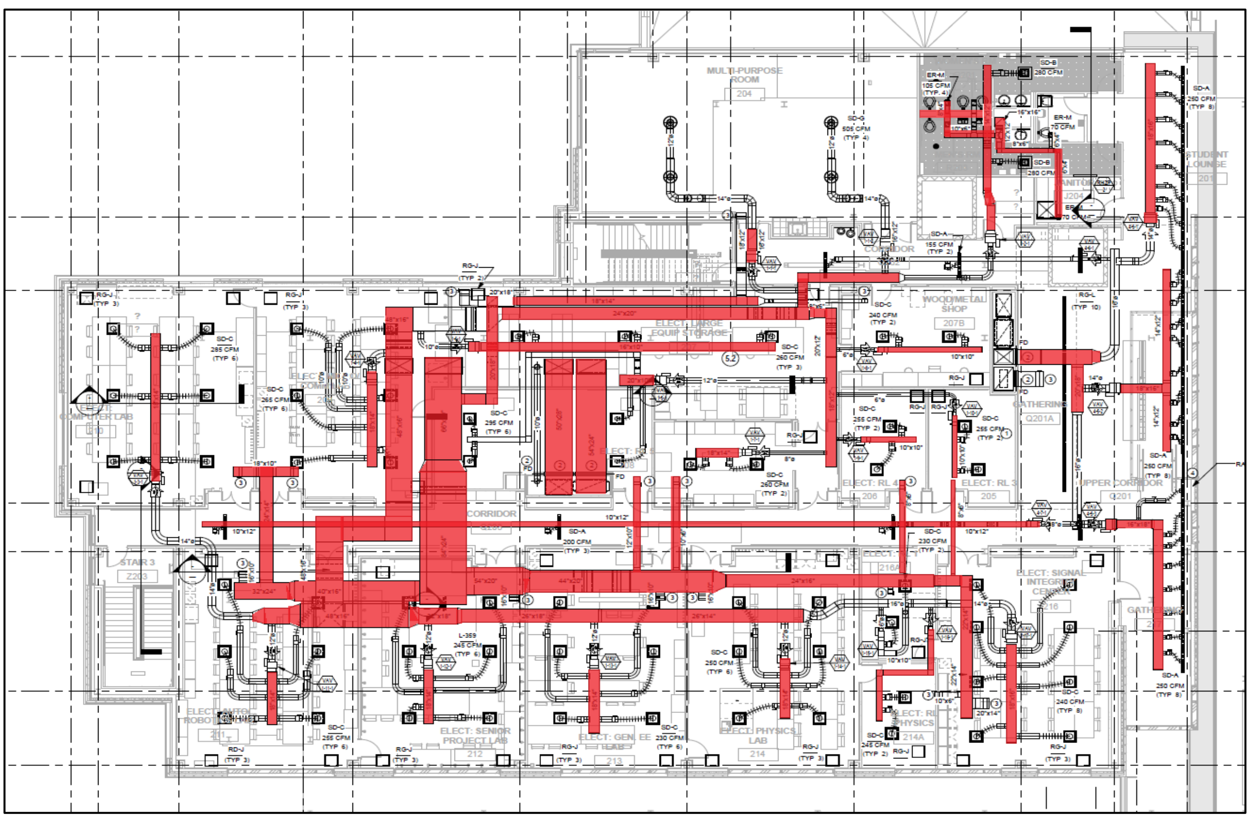

Figure 32 the proposed ductwork of the second level of the south wing that will be considered for prefabrication are highlighted in red. The sizes vary from 6”x4” to 84”x24” and will be fabricated to the appropriate lengths to minimize the delivery trips and the number of units. Image courtesy of BCJ

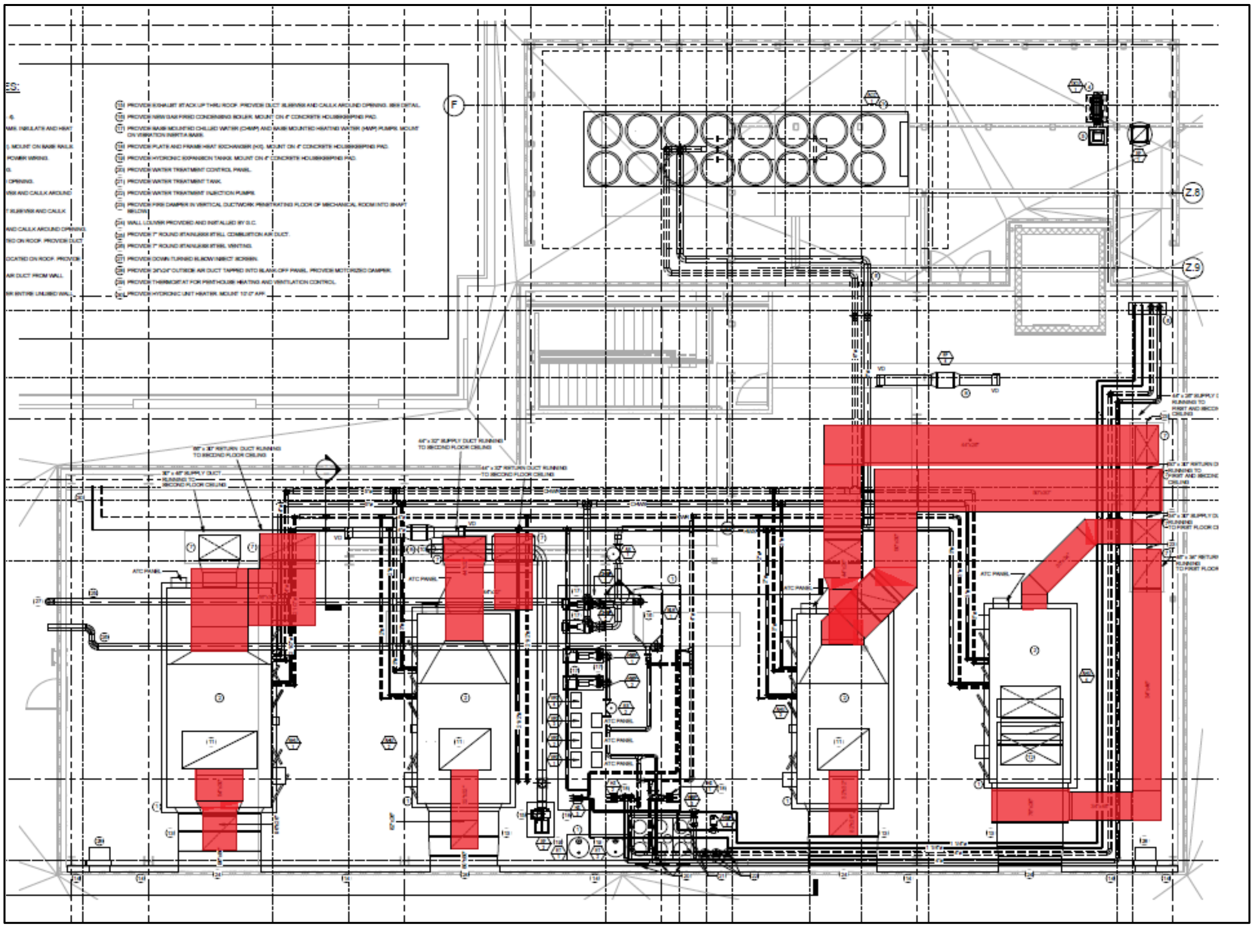

Figure 33 the proposed ductwork of the penthouse that will be considered for prefabrication are highlighted in red. The sizes vary from 32"x32" to 66"x30" and will be fabricated to the appropriate lengths to minimize the delivery trips and the number of units. Image courtesy of BCJ

Electrical System

Only the following conduit in table 11 will be considered for prefabrication.

Table 11 the quantity and dimension of the electrical system components that are considered for prefabrication.

Description	Unit	Quantity	Notes
Copper tubing, type L, 1/2" diameter	L.F.	989	-
Copper tubing, type L, 3/4" diameter	L.F.	450	-
Copper tubing, type L, 1" diameter	L.F.	550	-
Copper tubing, type L, 1-1/4" diameter	L.F.	128	-
Copper tubing, type L, 1-1/2" diameter	L.F.	133	-
Copper tubing, type L, 2" diameter	L.F.	77	-
Copper tubing, , type L, 2-1/2" diameter	L.F.	150	-
Pipe cast iron, 3" diameter	L.F.	155	-
Pipe cast iron, 4" diameter	L.F.	280	-
Total		2,912	-

<u>Plumbing System</u>

The following plumbing system components are considered for prefabrication.

- Domestic water supply pipes:
  - Copper pipe type L , ½” 1,033LF
  - Copper pipe type L , ¾” 430LF
  - Copper pipe type L , 1” 600LF
  - Copper pipe type L ,1 ¼” 116LF
  - Copper pipe type L , 1 ½” 140LF
  - Copper pipe type L , 2” 80LF
  - Copper pipe type L , 2 ½” 155LF
- Sanitary waste pipes:
  - Cast iron pipe, 1 ½” 330LF
  - Cast iron pipe, 2” 412LF
  - Cast iron pipe, 3” 200LF
  - Cast iron pipe, 4” 474LF
- Storm water pipes:
  - Cast iron pipe, 4” 160LF
  - Cast iron pipe, 6” 612LF
- Natural gas pipes:
  - Black steel pipe, 2” 420LF

3.10 Prefabrication Shops

Jay R. Reynolds, INC. is the plumbing contractor for the Educational Activities Building project. They are very familiar with the region and have worked with Penn State on several projects in the past such as the Bryce Jordan Center. They offer prefabrication services and own a warehouse with qualified workers who ensure that the schedule and owner demands will be met. Their workshop is located in Willow Street, PA about 45 minutes away from the construction site, as shown in figure 34.

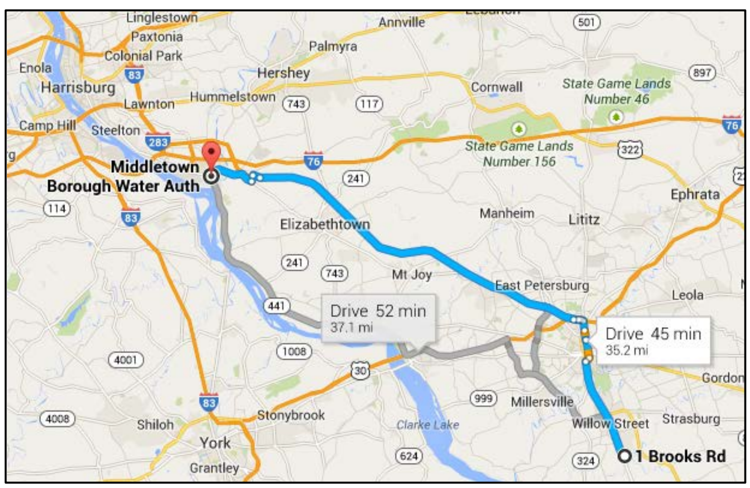

Figure 34 a map of the location of the prefabrication shop and the construction map. Image courtesy of google maps

3.11 Constructability Review

According to the McGraw Hill Construction study, the job site conditions have a direct effect on the decision making of the use of prefabrication/modularization. Some of these conditions include job site accessibility, number of stories, type of building exterior and layout of building interior, figure 35. According to the survey respondents, 58% agreed that job site accessibility is the biggest factor due to the numerous trips required to deliver the prefabricated systems. A detailed planning of the construction site location and accessibility is critical to ensure an easy delivery process. Number of stories comes next at 53% of respondents agreeing that it has a huge impact on prefabrication and moralization because of lifting concerns which requires greater logistic planning.

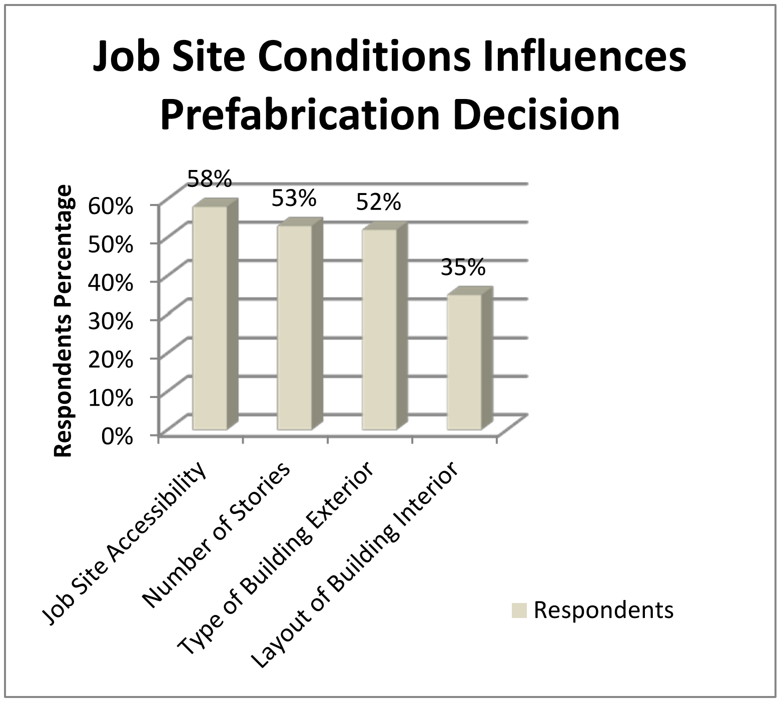

Figure 35 the percentage of respondents reported these job site conditions as the biggest influences on the prefabrication/modularization decision.

The Educational Activities Building has an ideal site as mentioned earlier. The site has two accesses. One is located on the North East corner on First Street and the second access is located on the South West corner, which is reachable from First Street through a parking lot, figure 36 shows site accesses circled in yellow. The building is divided into two main areas; the north wing consists of one level and the south wing consists of two levels and a mechanical penthouse. This will increases the feasibility of applying prefabrication because of the low height and the use of mobile

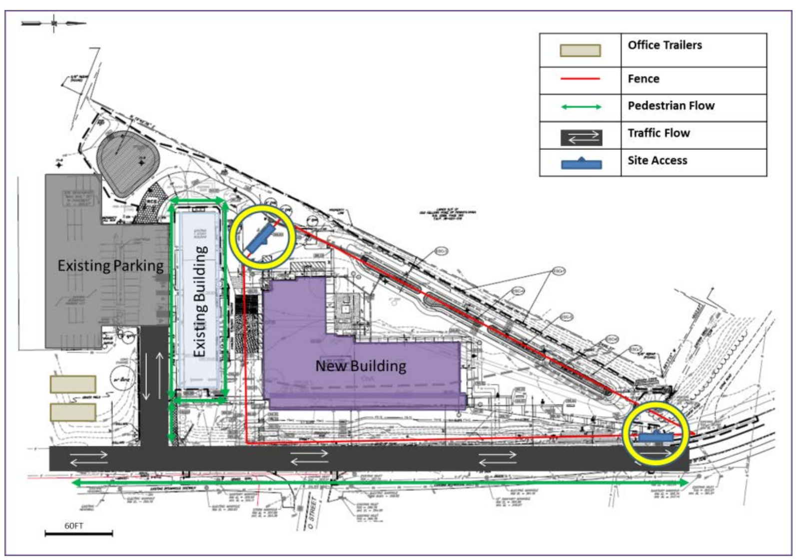

Figure 36 The construction site accesses circled in yellow.

crane. As for the building exterior, which is usually built prior to the interior components, leaving openings is an ideal way for hoisting the MEP systems into the building. These openings could be sealed with temporary plastic sheets for weather protections and will be permanently closed when the MEP systems are put in place.

3.12 Schedule and Cost Savings

The Miami Valley Hospital Southwest Addition case study will be the base of the calculation for the schedule reduction. As mentioned, the productivity rate at the prefabrication workshop was triple the productivity rate on site. However, the prefabrication productivity rate is assumed to be double the site productivity for the Educational Activities Building project. This was productivity rate was assumed as an average which yields in cutting the duration by half with an addition of 5 days just in case of any extra work that needs to be done, as shown in table 12. These schedule reductions means that each contractor will have the potential to finish work in a smaller interval and the overall schedule reduction is 41 days. The new MEP system construction schedule is shown in table 13.

Table 12 Schedule reduction due to prefabrication.

Contractor	Original Installation Duration (Days)	Prefabrication Installation Duration (Days)	Duration Reduction (Days)
Mechanical	117	64	53
Electrical	80	45	35
Plumbing	92	51	41
Total	127	86	41

Table 13 new MEP systems construction schedule.

Task	Start Date	Finish Date	Duration (Days)
Mechanical System	7/17/2013	10/14/2013	64
Electrical System	9/4/2013	11/5/2013	45
Plumbing System	9/4/2013	11/13/2013	51

The total schedule reduction along with labor cost will be used to determine the total cost savings due to prefabrication. From the technical assignments and information received from the project team, the labor hourly rate and the number of workers for each contractor was established. By using this information, prefabrication prices and assuming an 8 hour work day, the total cost for both on site and prefabrication labor cost are shown in table 14.

Table 14 Hourly and daily labor wages for each contractor.

Contractor	# of Laborers	Hourly Wages ($/Hour)		Daily Wages ($/Day)	
		Onsite	Prefabrication shop	Onsite	Prefabrication shop
Mechanical	4	63.55	33.47	2,033.6	1,071.04
Electrical	3	66.04	35.5	1,584.96	852
Plumbing	3	67.34	36.11	1,616.16	866.64
Total				5,234.72	2,789.68

The tables below show the total labor and general conditions cost savings due to prefabrication.

Table 15 Total labor cost savings by using prefabrication.

Contractor	Onsite Labor Cost ($)	Prefabrication Labor Cost ($)	Total Labor Cost Savings ($)
Mechanical	237,931.2	68,546.56	169,384.64
Electrical	126,796.8	38,340	88,456.80
Plumbing	148,686.72	44,198.64	104,488.08
Total	513,414.72	151,085.20	362,329.52

Table 16 General conditions cost savings.

General Conditions	Original Duration (Days)	Duration Reduction (Days)	Cost per Day ($/Day)	Total General Conditions Cost Savings ($)
	127	41	3,176.54	130,238.14

3.13 Summary

The MEP prefabrication is ideal for the Educational Activities Building project due its benefit and the fact that BIM is used heavily in this project, which simplifies the implementation of this solution. As a result the, the schedule is reduced by 41 days because the MEP systems will be completed on the 11/13/2013 instead of 1/9/2014 due to prefabrication. Additionally, the project team will be able to save $362,329.52 on labor wages and $130,238.14 on general conditions cost. Looking at these benefits, schedule reduction and cost savings, this solution is recommended for the Educational Activities Building project.

See Appendix G Mechanical Breadth

4.0 Analysis 3: Structural Steel Sequencing

4.1 Problem/Opportunity Identification

The structural steel sequencing plan on the Educational Activities Building project is good but there is more room for improvement, shown in figure 37. From the Technical Report 3, it was established that the structural steel activities is on the critical path which means there are huge risks that connected to it. Most construction activities post the structural steel erection can't start till the final completion of it. So any delays in the structural steel activities will lead to delay the overall project schedule.

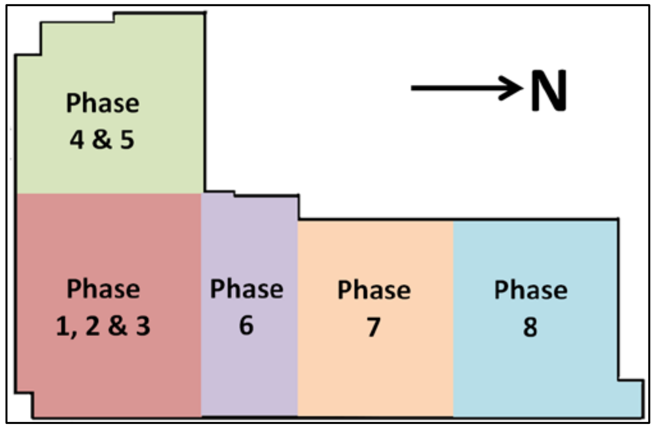

Figure 37 The current structural steel sequence used on the EAB project

4.2 Background Research

A thorough research on methods to improve the structural steel sequence will be performed. The construction site will be studied to find the optimal locations for storage areas, cranes and other items. Multiple structural steel sequencing plans will be created and evaluated to select the best alternative for the current sequence plan. Additionally, any activities dependent on the completion of the structural steel erection will be studied to create solutions for any potential delays. As a result, it will be possible to start some of these activities before the completion of the steel frame. The main goal is to ease constructability and sequencing the steel frame erection to avoid any delays. There is a great opportunity to perform value engineering analysis in this area.

4.3 Potential Solutions

The potential solutions are either to re-sequence the structural steel erection activities or find alternative ways to start some of the activities that have finish –to-start relationship with it. This will allow other trades to start working earlier and avoid any delays and added cost to the project.

4.4 Methodology

To perform this analysis the following steps will be taken:

- Analyze the current structural steel sequence and the site plan
- Investigate projects that employed an efficient sequencing plans
- Develop alternative sequencing plans
- Create a rating system to compare and evaluate the alternative sequencing plans
- Choose the optimal alternative sequencing plan
- Perform a cost estimate and schedule reduction
- Determined if the best alternative should be implemented on the project

4.5 Expected Outcome

The expected outcome of this analysis is to find the ideal structural steel sequencing for the Educational Activities Building project. If an improved sequencing plan to be chosen, it will result in schedule reduction and better constructability by using a more efficient erection process.

4.6 Resources and Tools

The following resources will be used to help with this analysis:

- The project team: the steel fabricator and Mr. Adam Dent
- The Architectural Engineering Department at Penn State
- Office of the Physical Plant at Penn State
- Structural steel subcontractor
- Online journals on structural steel sequencing
- Project schedule and documents

4.7 Current Structural Steel Sequence

As previously mentioned in the second technical assignment, the structural steel sequence has a room for improvements. The building is divided into 5 areas with one area consisting of 2 levels and a penthouse, one with 2 levels and the last 3 areas with one level each. The structural steel sequence started on south east corner which includes phase 1, 2 and 3 while the first crane stage is located within the building perimeter in the center of the south wing. After the first 3 phases were completed, the work on phase 4 and 5 began while maintain the crane in the same location. When the south wing was completed, the work on phase 6 started and the crane was moved to its second location, outside of the building perimeter on the southwest of the north wing. Phase 7 came next and the crane was moved to its third location on the west of the north wing. Finally the crane was moved to the last stage 4 northwest of the north wing, and the work started on phase 8 as shown in figure 38. The biggest risk with this sequence is that tasks which will be performed by other trades on the north wing can't start till the final completion of the superstructure.

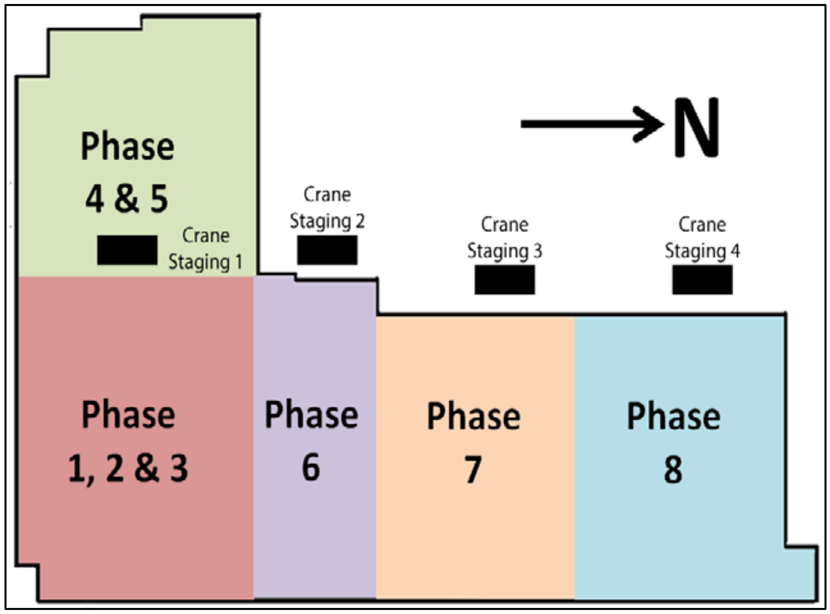

Figure 38 Structural steel sequence and crane staging.

As for the site plan, the project has two entrances; one is located on the southwest of the building with a temporary construction access from First Street through an existing parking lot into the project site. The other entrance is located on the northeast of the construction site with a direct access from First Street as shown in figure 39. for the laydown area the topsoil was removed and stabilized with 6" of AASHTO No. 57 course aggregate on a layer of PADot Class 1 geotextile, which will be removed upon completion and replaced with topsoil and permanent seed mix.

The structural steel erection is one of the most important tasks on the critical path, due to the dependencies of other tasks on the completion of the structural frame. There are several parties that has to be involved in the planning such as the general contractor, steel contractor, steel erector, steel supplier and structural engineer.

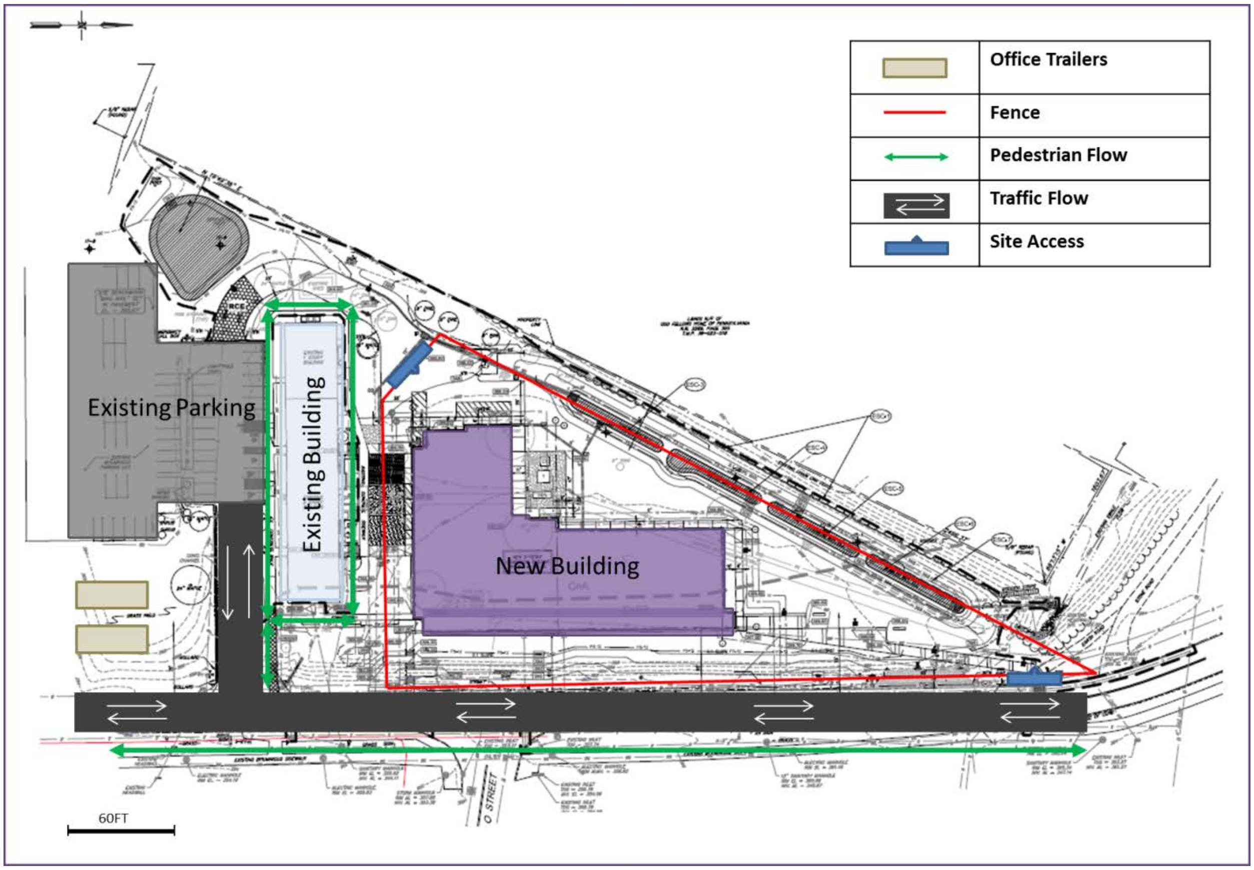

Figure 39 The Educational Activities Building site plan.

When planning the structural steel sequence the following factors must be considered:

- The building and site size and shape:
  - The building is L shaped with a footprint area of 28,755 square feet. The construction site is shaped as a right triangle with an area approximately 94,050 square feet.
  - The relationship between the size of the building and the size of the construction site has an important effect on the steel erection planning; spaces required for deliveries, construction materials storage and equipment locations.
- Adjacent existing buildings and roads:
  - The project is adjacent to an existing building to the south and First Street on the east.
  - The sidewalk near the building on First Street will be closed during construction by a 6ft high fence, pedestrian will be able to use the sidewalk across the street from the project.
- The soil conditions: table 17 describes the type of soil in the construction iste.

Table 17 Soil conditions description.

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
CnA	Chavies fine sandy loam, 0 to 3 percent slopes	0.5	48.4%
CnB2	Chavies fine sandy loam, 3 to 8 percent slopes, moderately eroded	0.5	51.6%
Totals for Area of Interest		1.0	100.0

- Underground utilities location:
- Size and type of the required equipment:
    - Crane size and location; the goal is to minimize the number of crane locations.
    - Tools include but not limited to; crane, welding equipment, hand tools, etc.
- The material delivery, storage and staging:
    - Laydown are size and location; the goal is to place it as close as possible to the structure and within the crane reach. The location could be moved as the erection progresses; it could start within the building footprint and moved to outside the building perimeter toward the end.
    - The storage area would be located within the construction site fence for security reasons.
    - The steel will be delivered in 3 loads. The first 1/3 of the steel members will be delivered first and while it is being erected the second 1/3 will be delivered and stored on site and so on. This is done to eliminate any delays in the schedule due to late deliveries.
    - The delivery will be come from First Street into the existing parking lot to enter the construction site through the southwest gate.
    - As soon as the steel is delivered to the site, a crew will rearrange the steel into the order that it will be erected.

.

4.8 Crane Selection

A mobile crane will be used to place the structural steel members in their positions. However, instead of placing the crane in four different locations it will be in one for the entire project. The crane that will be used is a rough terrain crane with a 50 ton capacity, 110' boom and 32' jib. This choice was determined by examining the heaviest and furthest loads the crane would have to carry. The beam of each critical beam is calculated then using the distance from the final position of the steel piece and to the crane is used to check the crane ability to do the lift safely as shown in tables 18 & 19. The critical beams are shown in figures 40 & 41. The roof of the south wing has the same structural member configuration.

Table 18 the critical beams of the north wing types, dimension and passing test.

Beam #	Beam Size	Beam Length (ft)	Beam Weight (lb)	Distance from Crane	Safety Check
Beam 1	W8x24	11	264	90	Passes
Beam 2	W8x24	20	480	90	Passes
Beam 3	W8x24	20	480	90	Passes
Beam 4	W8x24	20	480	90	Passes
Beam 5	W24x55	11	605	85	Passes
Beam 6	W24x162	37.5	6,075	80	Passes
Beam 7	W24x162	44.5	5,103	75	Passes
Beam 8	W24x76	44..5	3,382	60	Passes
Beam 9	W24x131	44.5	5,829.5	65	Passes
Beam 10	W24x131	44.5	5,829	75	Passes
Beam 11	W24x84	44.5	3,783	80	Passes
Beam 12	W24x117	44.5	5,206	85	Passes
Beam 13	W24x146	44.5	6,497	30	Passes
Beam 14	W24x146	44.5	6,497	40	Passes
Beam 15	W24x117	44.5	5,206	60	Passes
Beam 16	W24x162	45.75	7,411	30	Passes
Beam 17	W24x162	45.75	7,411	40	Passes
Beam 18	W24x103	45.75	4,712	50	Passes
Beam 19	W24x162	45.75	7,411	60	Passes
Beam 20	W24x131	38.5	5,043	70	Passes

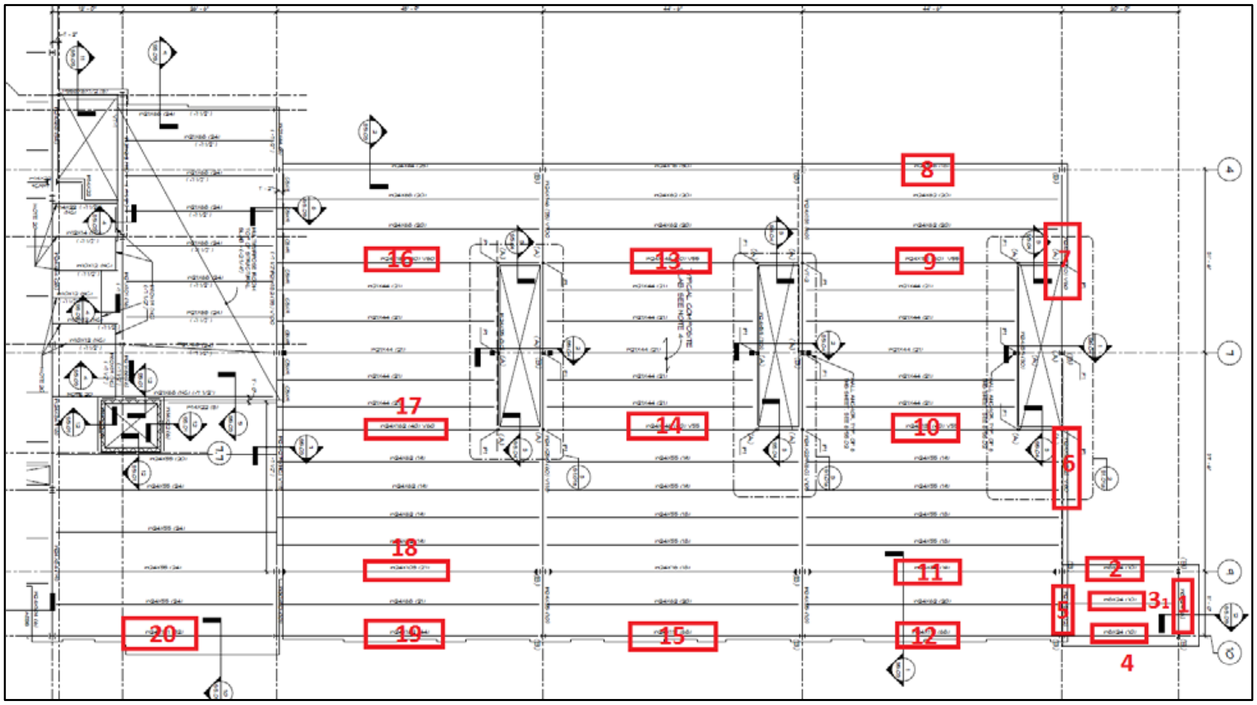

Figure 40 the critical beams of the north wing that are tested to ensure that it won't exceed the crane limit. Image courtesy of BCJ

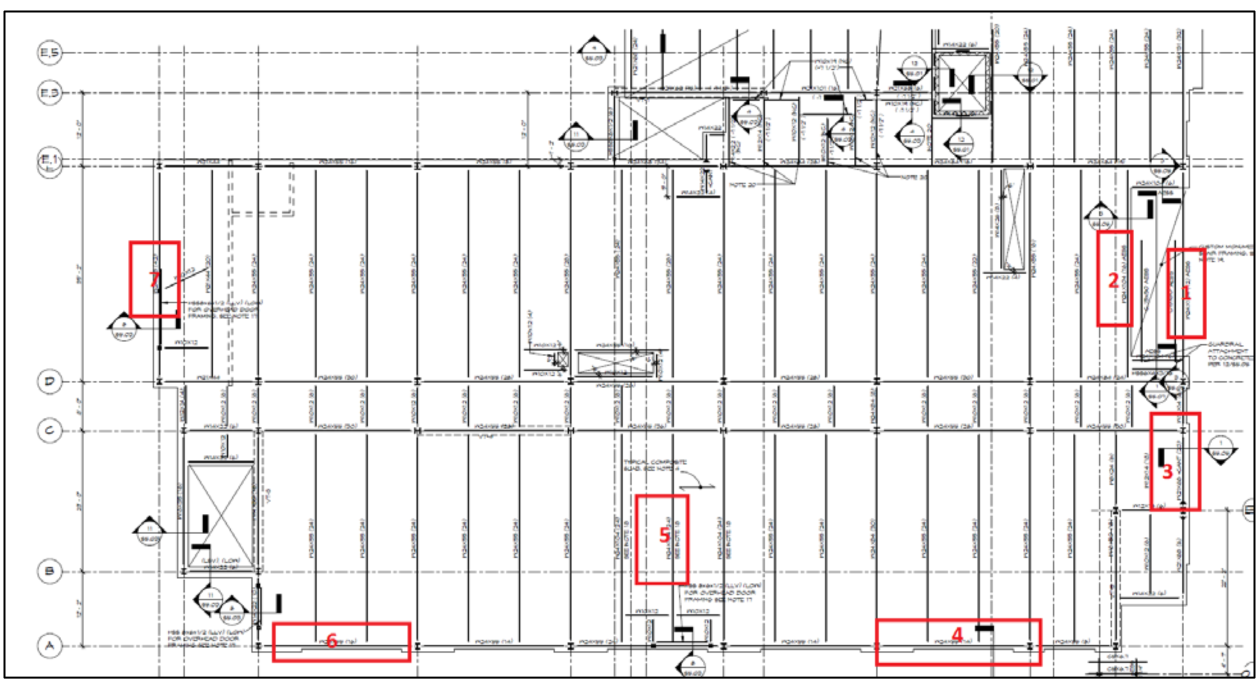

Figure 41 the critical beams of the second level of the south wing that are tested to ensure that it won't exceed the crane limit. Image courtesy of BCJ

Table 19 the critical beams of the second level of the south wing types, dimension and passing test.

Beam #	Beam Size	Beam Length (ft)	Beam Weight (lb)	Distance from Crane	Safety Check
Beam 1	W24x104	35.17	3,657	75	Passes
Beam 2	W24x104	35.17	3,657	70	Passes
Beam 3	W21x68	22.17	1,507	85	Passes
Beam 4	W24x55	25	1,375lb	90	Passes
Beam 5	W24x104	35.17	3,657	75	Passes
Beam 6	W24x55	26'	1,730	85	Passes
Beam 7	W24x68	35.17	2,391	75	Passes

(Feet)	35	40	50	*60	70	80	90	100	110
10	100,000 (63.5)	80,400 (66.5)	74,400 (71.5)	44,600 (75.5)					
12	88,050 (60)	79,050 (63.5)	70,900 (69)	44,600 (74)	@35,600 (75.5)				
15	74,500 (54)	67,450 (59)	63,350 (65.5)	44,600 (71)	35,600 (74)	@33,000 (75.5)			
20	54,700 (43)	53,850 (50.5)	50,900 (59)	44,600 (66)	35,600 (70)	33,000 (72.5)	25,500 (75)	@23,300 (75.5)	
25	41,450 (29)	41,150 (40.5)	40,700 (52.5)	40,350 (60.5)	35,550 (65.5)	33,000 (69)	25,500 (71.5)	23,300 (74)	@18,500 (75.5)
30		32,450 (28)	32,050 (45)	31,750 (55)	30,550 (61)	28,950 (65)	25,500 (68)	23,300 (71)	18,500 (73)
35			25,950 (36.5)	25,650 (48.5)	26,500 (56.5)	24,900 (61)	23,000 (64.5)	21,200 (68)	18,500 (70.5)
40			21,400 (25)	21,150 (41.5)	22,000 (51.5)	21,750 (57)	20,000 (61)	18,450 (65)	18,000 (67.5)
45				17,600 (33.5)	18,500 (46)	19,100 (53)	17,600 (57.5)	16,300 (61.5)	15,750 (65)
50				14,600 (23)	15,250 (39.5)	15,700 (48)	15,650 (53.5)	14,400 (58)	13,950 (62)
55					12,650 (32.5)	13,100 (43)	13,550 (49.5)	12,850 (54.5)	12,450 (59)
60					10,500 (23)	11,000 (37.5)	11,450 (45)	11,550 (51)	11,150 (55.5)
65						9,350 (31)	9,780 (40.5)	10,200 (47)	10,050 (52.5)
70						7,870 (22)	8,370 (35)	8,780 (43)	9,090 (49)
75							7,180 (28.5)	7,590 (38.5)	7,980 (45)
80							6,120 (20)	6,560 (33)	6,950 (41)
85								5,680 (27)	6,060 (37)
90								4,910 (19)	5,280 (32)
95									4,600 (26)
100									3,990 (18.5)
Minimum boom angle (deg.) for indicated length									0

Figure 42 the allowable crane limit for each case circled in red. Image courtesy of www.bigge.com

See Appendix F for Crane Specification

4.9 The Proposed Structural steel Sequence

As a result it is feasible to use this type of crane for the structural steel erection tasks. The crane will be located right outside the building parameter, north of the south wing and west of the north wing. This location is ideal because the crane radius covers the entire project floor area and the project team would not have to change the location of the crane several times. The steel laydown area will be located to the west of the building, within reach from the crane to ensure an efficient and faster steel erection. Additionally, the sequence will start from the north wing to the south wing. That's because the north wing consists of 1 level and once it's done other trades can start their tasks. Figure 43 shows the proposed site plan during the erection of structural steel.

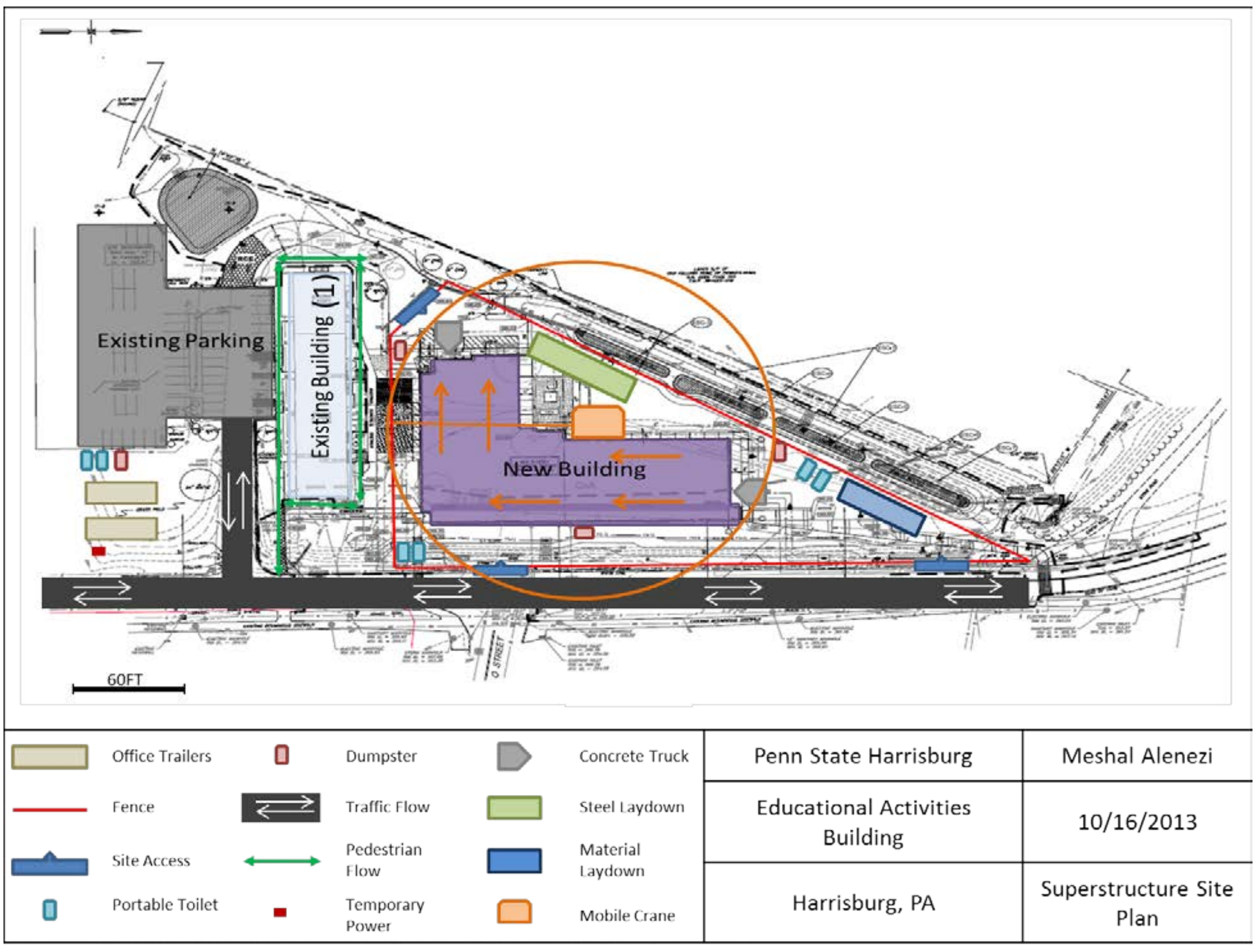

Figure 43 the proposed structural steel sequence, including the crane radius and the steel laydown area.

4.10 Comparison

Tablet 20 compares the original structural steel sequence with the proposed structural steel sequence based on different criteria.

Table 20 the original structural sequence vs. the proposed structural sequence.

Criteria	Original Steel Sequence	Proposed Steel Sequence
Crane Size	30 Ton, 90' Boom, 43' Jib	50 Ton, 110' Boom, 32' Jib
# of Crane Locations	4	1
Duration (Days)	26	18
Steel Deliveries Phases	4	3
Steel Laydown	Within 30' from the crane	Within 30' from the crane
Sequence Direction	From the South Wing to the North Wing	From the North Wing to the South Wing

4.11 Schedule Impact and Cost Savings

Due to the fact that the crane would be located in same, it will create a continuous and uncomplicated structural steel erection. As seen in the previous section, the proposed structural sequence plan will save 8 days from the steel erection schedule. The cost savings resulted from that is shown in table 21.

Table 21 shows the total cost savings due to the proposed sequencing of the structural steel.

	Daily Cost ($/Day)	Schedule Reduction (Days)	Total Savings ($)
Structural Labor	239.5	8	1,916
Crane Operator	119.4	8	955.2
Crane	270	8	2,160
General Conditions	3,176.54	8	25,412.32
Total			30527.52

4.12 Summary

After an in depth research, several sequencing plans were made but only the most efficient plan was compared to the original sequencing plan. The main proposed change is to use a bigger crane so there will be no need to move it to different locations. The new plan starts the structural steel sequence from the north wing to the south wing, the opposite of the original plan. The reason for that is the north wing consists of one level so as soon as the structural frame is constructed work from other trades can start. As a result the structural duration of the project schedule was reduced by 8 days. The cost savings came from structural labor saving of $1,916, crane savings of $3,115.2 and general conditions saving of $ 25,412.32, which brings the total savings to $30,527.52.

5.0 Analysis 4: Technology Integration for Information Management

5.1 Problem/Opportunity Identification

Information management for the work force was one of the main topics discussed during the breakout session at the 22nd annual PACE Roundtable. As mentioned in the technical report 3, there is a cultural shift toward the use of technology in the construction industry. Using the old fashioned way of handling documents and communication is not sufficient enough to meet the industry needs nowadays. Project teams spend a good amount of their time going through printed documents and communicating with each other. If the technology tools available in the industry can be implemented on this project, it can increase the efficiency of the project team and the workforce.

5.2 Background Research

From the technical report 3 section on the PACE Roundtable, it has been noticed that an increasing percentage of the industry is utilizing technology tools on their projects. Technology can save much of the time wasted on finding or sharing information between the project participants. There is a good chance for integrating more technology into the project due to the heavy use of BIM. For instance, tablets in figure 44 could be used on the construction site as a tool for easy access to the project documents.

Figure 44 Using tablets to view BIM files. Image courtesy of www.obamapacman.com

5.3 Potential Solutions

The solution consists of different components that will help to solve the presented issues. The first task is to create a system for managing and sharing information between the different project teams. Then technology tools such as tablets will be integrated into the construction site so the workforce can view what activities needed to be performed on each day. Additionally these tablets can be used to provide the workers with the right amount of information they need to know instead of confusing them with too much information. The main goal is to increase the efficiency of the construction process of the Educational Activities Building.

5.4 Methodology

To perform this analysis the following steps will be taken:

- Research the technology tools uses in the construction industry
- Interview the project manager (See Appendix B)
- Review pervious projects that have utilized this solution
- Determine the feasibility of implementing this solution
- Estimate the cost of implementing this solution
- Determined if this solution should be implemented on the project

5.5 Expected Outcome

The expected outcome of this analysis is a document covering the use of technology in the construction industry and the qualitative impact on this specific project. If the advantages of applying this solution on the Educational Activities Building project outweigh the disadvantages, it will be recommended to the owner. It is believed that using technology tools can enhance information management of the project.

5.6 Resources and Tools

The following resources will be used to help with this analysis:

- The project manager Mr. Adam Dent
- The Architectural Engineering Department at Penn State: Professor Robert Leicht
- Office of the Physical Plant at Penn State: Mr. Eric Nulton
- Industry members: Mascaro Constriction
- Online journals on technology used in the construction industry
- Project documents

5.7 Preliminary Analysis

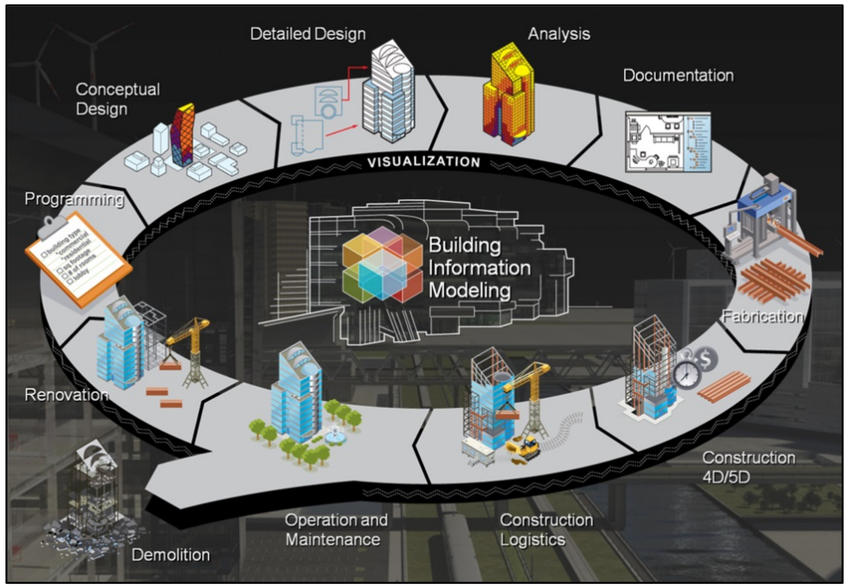

Figure 45 A diagram shows several uses of BIM. Image courtesy of buildipedia.com

Technology has been used within the construction industry for several years, and it went through different phases. However, the construction industry lags behind when it comes to utilizing the most advanced technology tools. This analysis focuses on the use of mobile technology and software available that are utilized to improve the construction process and the overall quality of the project. Many companies are aware of the importance to adapt to the cultural shift toward using modern technology. For that specific reason and many others, this analysis is important to consider for the Educational Activities building project.

BIM Uses

The report investigates the use of BIM on this project and determines what other potential features of BIM could be utilized for it. One of BIM best and most used features is to detect any potential clashes between the different building systems, which could save a lot of money and time. The following BIM features were chosen by the project team to meet the minimum the requirements of the Office of Physical Plant. They are grouped based on the features used for each phase of the project:

- **During planning**
  - Energy Analysis
  - Existing Conditions Modeling
- **During Design**
  - Design Intent Model Development
  - Design Reviews
  - 3D Design Coordination
  - Energy Analysis

   - Model Commissioning
- **During Construction**
   - Means & Methods Model Development
   - Constructability Reviews
   - 3D Construction Coordination
   - Model Commissioning Verification
- **Prior to Project Turnover**
   - Record Model
   - As-Built Model

Additionally, there are several BIM uses that could be considered to improve the overall construction process or operation of the building. BIM could be used as a tool for document management where the project team can share information and documents between each other. Architects, engineers or contractors can update the construction progress or request information through BIM. Another feature to be considered is "Building Maintenance Scheduling", BIM can be used to plan maintenance activities, track maintenance record and increase the maintenance productivity for the project systems over its operational life. This will help to improve the performance of the facility, avoid emergency repairs and reduce the overall cost of maintenance. Furthermore, there is a potential for the project team to implement "Space Management and Tracking" use of BIM. The team has to develop a precise record model and as-built model to be integrated into PSU's facility management system. The Educational Activities Building contains class rooms and laboratories which makes this specific BIM use a great help to manage the space in case of any changes in the building functionality.

Background Information on Mobile Technology Tools used in the Construction Industry

Mobile technology is another important element to be investigated for the Educational Activities Building project. It can be used during all phases of the construction process; planning, designing and constructing. Tablets are a good example for mobile technology tools due to their light weight, small size and high functionality. Tablets could be used for viewing documents such as drawings, specifications, construction

Figure 46 Using tablets to viewing project documents on site. Image courtesy of constructarabia.com

schedule especially in the field without the need to carry any heavy paper documents figure 46, which saves the cost of printing them. Moreover, they are a great medium for communication and sharing information/progress between the project team. In the past few years, many construction companies launched their own applications on different tablets to be utilized by their teams. It is estimated that each project manager, BIM manager and superintendents saves on average 1 to 2 hours per day by using tablets. Another Important tool is Google Glass, which is relatively a new concept but it could have a huge positive impact on the construction industry. One of Google Glass greatest advantages is the fact that it allows the person who is wearing them to have both of his hands available to perform any other tasks.

Mobile technology helps to manage the project efficiently while minimizing the cost resulted from miscommunication between the project team. In addition, these technology tools and trends are suitable for nay project type or size. Tablets are great example due to the wide range of applications available on them and the ability to use remote data storage to share information or documents such as blueprints. The applications could be secured and only authorized professionals can have access to the contents. Most tablets come with high definition cameras which allows for taking pictures of any issues on site and immediately send it to the responsible party for a quick solution or even using live webcam to get an instant professional opinion. These cameras could be used to keep track of the construction progress as well.

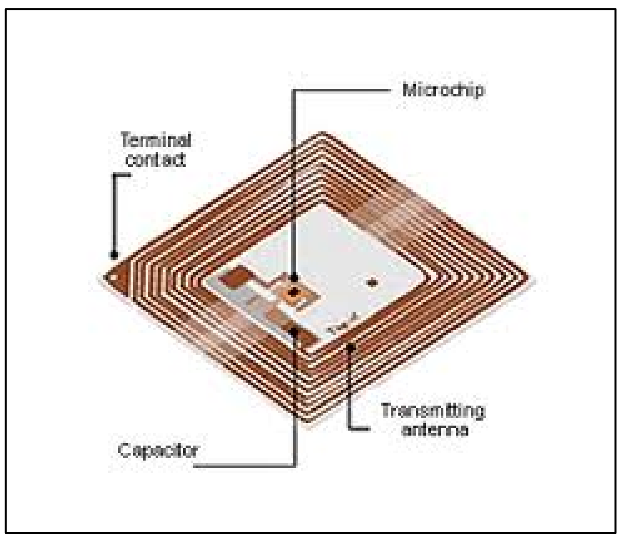

Figure 47 a simple diagram shows the components of the RFID tag. Image courtesy of skyrfid.com

Another great feature that is available in the construction industry is Global Positioning System "GPS" which can be used to track heavy machinery. Additionally, when combining RFID tags with construction materials, any waste, loss or theft could be reduced or eliminated. RFID tags are small labels that can be attached to any object so its exact location can be tracked using a small tool that can receive the RFID tags signals, figure47. According to a survey done by www.gpsinsight.com, 50% of the construction industry use GPS to certain extend which is more than the government (44%) and other industries. 86% of the respondents said the use of GPS is "either somewhat or very beneficial to the business". That includes four out of the five areas that were covered in the survey; productivity, fuel usage, vehicle routing, and customer service for the exception of vehicle maintenance.

5.8 Project Manager Interview on Technology Integration for Information Management

1. **What issues have you or other members of the project team encountered when communicating with each other?**

Not many at all. Most everyone is technologically-capable and were used to using web-meeting software and web-based/ftp sites for file distribution.

2. **How is technology utilized in the Educational Activities Building project?**

We are using BIM for coordination & modeling, clash-detection and asset management. Each classroom is outfitted w/the current standard of classroom A/V equipment. Drawings and submittals are produced and processed/approved electronically. O&M manuals will be in a searchable electronic format.

3. **Have you used any technology tools such as tablets in previous projects? And how comfortable are you with technology?**

We have been using tablets for a few years. Tablets enable us to easily transport an entire set of drawings/documents into the field for inspections. The Labor & Industry building inspector also utilizes a tablet for his inspections and prefers drawings electronically in lieu of hardcopy.

4. **How are project documents and drawings being used? Are electronic versions being used more that printed versions?**

Hardcopies are still being used in the trailers and field – mostly for ease of keeping as-built and less-expensive and more-convenient to distribute among workers. Electronic files are used as well between the design team members and owner as well as the construction manager.

5. **How do you predict the future of the construction industry in regard to using technology?**

Technology is improving the process – both in quality and speed. Proper use of technology will also reduce change orders and cost of construction. It will also allow the end-user easy access to documentation (submittals, O&Ms, drawings, etc.) for a lifetime. The amount of paperwork related to building projects and space to store it will be greatly reduced over time.

5.9 Case Studies

Case study 1: Roger's O'Brian Con

Building Design + Construction "BD+C" magazine asked several companies from their BIM list to share their vision of BIM 2.0. The answers included better mobility solutions, integrating BIM with virtual reality technologies and influence on the use Of Global Positioning System "GPS" within the construction industry. Google Glass is a piece of technology that has the potential to bring the office to the field. These glasses are limited and in the prototype stage, also they cost about $1500 a piece but once it is commercially available it will cost about $250. Todd Wynne, the operation technology specialist from Rogers-O'Brien Construction is the expert when it comes to technology uses within the construction industry. He stated that "90% of technology available today has been attributed to the office, not the field" these technologies include but not limited to BIM, material tracking and laser scanning. Additionally, tablets and linked PDF documents can be used as a convenient method of information exchange and communication between the office and the field. Wynne believes that Google glass can eliminate inefficiencies within the construction industry. He expects the future of construction to be a world where tasks are performed adequately with technology that is attached to our bodies; hand free. Wynne has used Google Glass on field figure 48 for quality control, in-wall inspections, taking photos and holding meetings through live webcam to solve issues in the field.

Figure 48 Todd Wynne using Google Glass on a construction site. Image courtesy www.bdcnetwork.com

Figure 49 Todd Wynne using live webcam to communicate with the project architect. Image courtesy of www.bdcnetwork.com

For instance, one day Wynne along with a project engineer were overseeing the construction site when they came across a subcontractor who had a question regarding the flashing on the roof. Fortunately, Wynne was wearing his Google glass and he called the architect using live webcam to walk him through the problem figure 49. As a result, the subcontractor was able to get his answers within minutes and the project engineer issued a confirming RFI instead of standard

RFI which shortened the process by two weeks. Figure 50 gives a closer look of Google Glass.

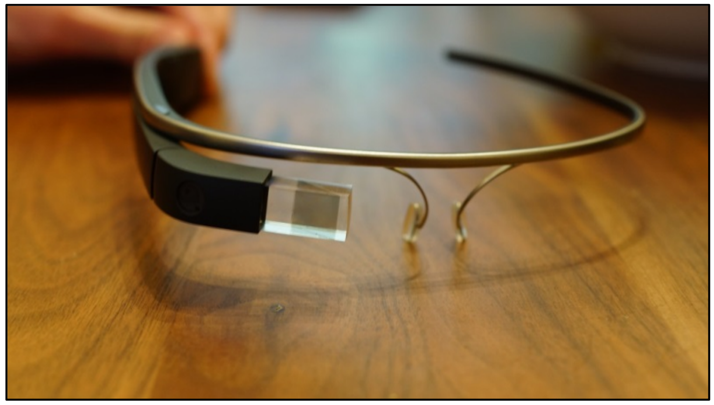

Figure 50 Google Glass. Image courtesy of www.google.com/glass

Case study 2: FieldLens

According to the CEO of FieldLens, Doug Chambers, FielLens is the Facebook of the construction industry. Its main purpose is to make communication between the project team as accessible and effortless as possible. The project team can use it to issue jobsite tasks, track field progress and organize project document in one place. FieldLens was created by a team of experts who worked in the construction industry for years and are familiar with jobsites problems that face the project team on a daily basis. Their main goal is to eliminate the cost related to miscommunication that can lead to expensive solutions for incorrectly installed work, or printed paper document which is estimated to be approximately $40 billion annually. Every member of the project team can use it, including the owner, general contractor, designers, subcontractors, engineers, etc. For each project profile, the team can customize the newsfeed and organize information to control who has access for specific information. The website is very secure and user friendly, no training is required and can be used with minimum technology practice. The cost is $180 a year or $20 a month per user. The website is accessible on desktops, lab tops, tablets or even smartphones which makes even easier to view documents without using any complex tools, figure 51.

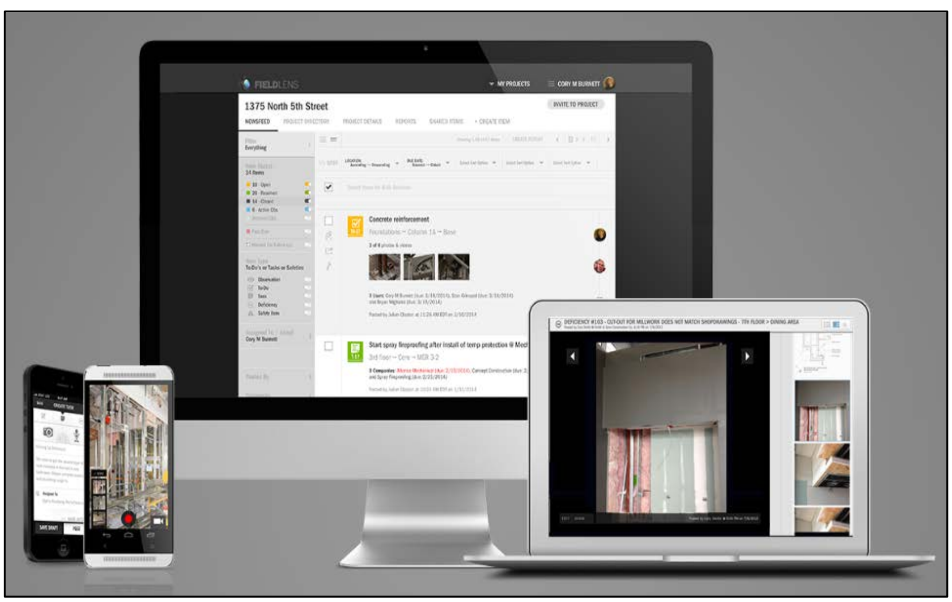

Figure 51 Fieldlens can be viewed using lab tops, desktops, tablets or even smart phones. Image courtesy of Fieldlens.com

Case study 3: Dael Thermal

In 2013 the Canadian mechanical contractor Dael Thermal realized the amount of money wasted on paper documents and miscommunication between the project team. To solve this problem, they provided all field technicians with tablets equipped with mobile service management applications. As a result, Dael Thermal was able to remove the cost associated with paperwork, improve the productivity of the project team, minimizing service call delays and improving on-site repair capabilities. Additionally, they were able to process requisitions, get customer permissions and obtain contracts through mobile channels.

The project team can manage the tasks and submit or update information while on the construction site to reduce the risk of miscommunication. The combination of tablets and mobile service management applications gave Dael Thermal's employees the opportunity to perform their tasks under a single intuitive, logical and user friendly interface.

Case Study 4: DAVIS Construction Motion Tablet PCs

DAVIS Construction is a well-known general contractor who provides construction and design services. The company requires high levels of consistency and accuracy for their projects; as a result the job site inspections were going through issues related to that. To resolve these issues after the failure of using traditional methods, DAVIS decided to consult with Motion Computing, which led the company to utilize Motion Tablet PCs. These tablets have the capability to coordinate DAVIS's safety and quality assurance procedures such as scheduling inspections and creating deficiency reports. By implementing this technology, the productivity was noticeably increased and DAVIS was able to maintain its high safety standards. Additionally, the electronic software makes it easier for inspectors to work together due to its standardized format.

The tablets were used for the first time at the CityVista project, where DAVIS superintendents had the ability to access plans, 3D models, specifications and share photos while working on the construction site. Everything was organized in one database by one person, assistant superintendent Jeff Finley and that saved a great deal of time. According to the senior superintendent on the same project Josh Roe, they had to schedule 3 walkthroughs and 3 verifications with a minimum of 5 units a day which was performed by 4 people and that was made possible by the use of these tablets. On top of all these benefits mentioned above, is the reliability and security of these tablets and its software which made DAVIS decide to utilize these tablets on more projects in the future. Table 22 shows the different types of tablets offered by Motion Computing to DAVIS and combined with a brief description of each tablets, manufacturer's suggested retail price and their benefits.

Table 22 Comparison between the different types of tablets offered by Motion Computing.

Tablet Type	R12	F5te	CL910
Tablet Image			
	Images courtesy of Motion Computing		
Description	For people who are on the move, from the office to the vehicle to the field.	Perfect for field workers with advanced remote management capabilities.	Lightweight and durable, designed for challenging conditions.
MSRP $	$2,299-$ $4,049	$2,300-$4,800	$1,300-$2,000
Benefits	Reliable on site data, eliminates communication delays and reduces paper waste and man hours.		

5.10 Cost of Implementation

To estimate the cost of Technology Integration for Information Management, several companies have been contacted to request quotation for prices. However, first the project team was analyzed to determine the users of any technology integration considered for the Educational Activities Building project. The following table lists the members of the project team, table 23.

Table 23 Project team members.

ORGANIZATION	ROLE	NAME
Penn State	Project Manager	Adam Dent
Penn State	BIM Manager	Colleen Kasprzak
BCJ	Project Manager	Natalie Gentile
BCJ	Project Architect	Michele Mercer
BCJ	BIM Coordinator	T.Jay Beatty
OPA	Project Architect	Kyle Hollick
Hope Furrer Associates	Project Manager	Stephanie Slocum
Hope Furrer Associates	BIM Coordinator	Michael Hamer
IES	Principal/ Project Manager	Jeffery Balan
IES	Mechanical Engineer	John Azemar
IES	Electrical Engineer	Michael Ferry
IES	Mechanical Designer	Joe Rogers
Raudenbush	Project Manager	Doug Gamber
Raudenbush	Project Engineer	Catherine Hoover
Reynolds Construction	BIM Manager	Walter Tack
Reynolds Construction	Project Executive	Jeff Merritt
Reynolds Construction	Project Manager	Brian Shaffer
Reynolds Construction	On-Site Construction Manager	John Dudash

Based on table 24, the quantity of the needed tools and memberships has been determined. The tablets and Google Glass are only considered for the general contractor Reynolds Construction team and the Penn State Team due to their daily presence in the construction site. In addition, two desk top stations are suggested to be available on site for everyone to review their daily tasks and update a list of completed work. As for the FieldLens membership, it will be considered for every member of the Penn State, BCJ, Hope Furrer Associates, IES, Raudenbush and Reynolds Constructions teams to ensure easy access to the project information for everyone.

Table 24 the direct cost associated with implementing the proposed technology tools.

Item	Quantity	Cost $/Unit	Total Cost $
Generic Tablets	6	400-600	2400-3,600
Google Glass	4	250	1,000
FieldLens Membership	18	20 (per month for 16 months)	5,760
Desktops	2	250-1500	500-3,000
Desktop Stations	2	65	130
Utility Cost			104
Total			10,614-14,314

The utility cost was estimated based on the average annual electricity consumption, the next assumptions were made

- Each tablet is charged once daily
- Each desktop is used for 9 hours everyday
- All devices will be used for approximately 1.5 years which is the duration of the project

5.11 Proposed Technology Integration Strategy

The proposed technology integration strategy was determined by considering the results of the in-depth research of technology application within the construction industry. FieldLens would be implemented due to its user friendly interface and ability to provide a platform for communication between the project teams. In addition, BIM "Document Management" feature will be considered which will not require much work due to the heavy use of BIM on the Educational Activities Building project. Also, the "Building Maintenance Scheduling" feature will be implemented on this project.

The two desktop stations will be placed in two different locations of the project; one located right outside of the office trailers and one is located in the South West of the building, figure 52. The desktop stations will be made of a computer cabinet ($65 each) with a lock to protect it from the weather elements and theft.

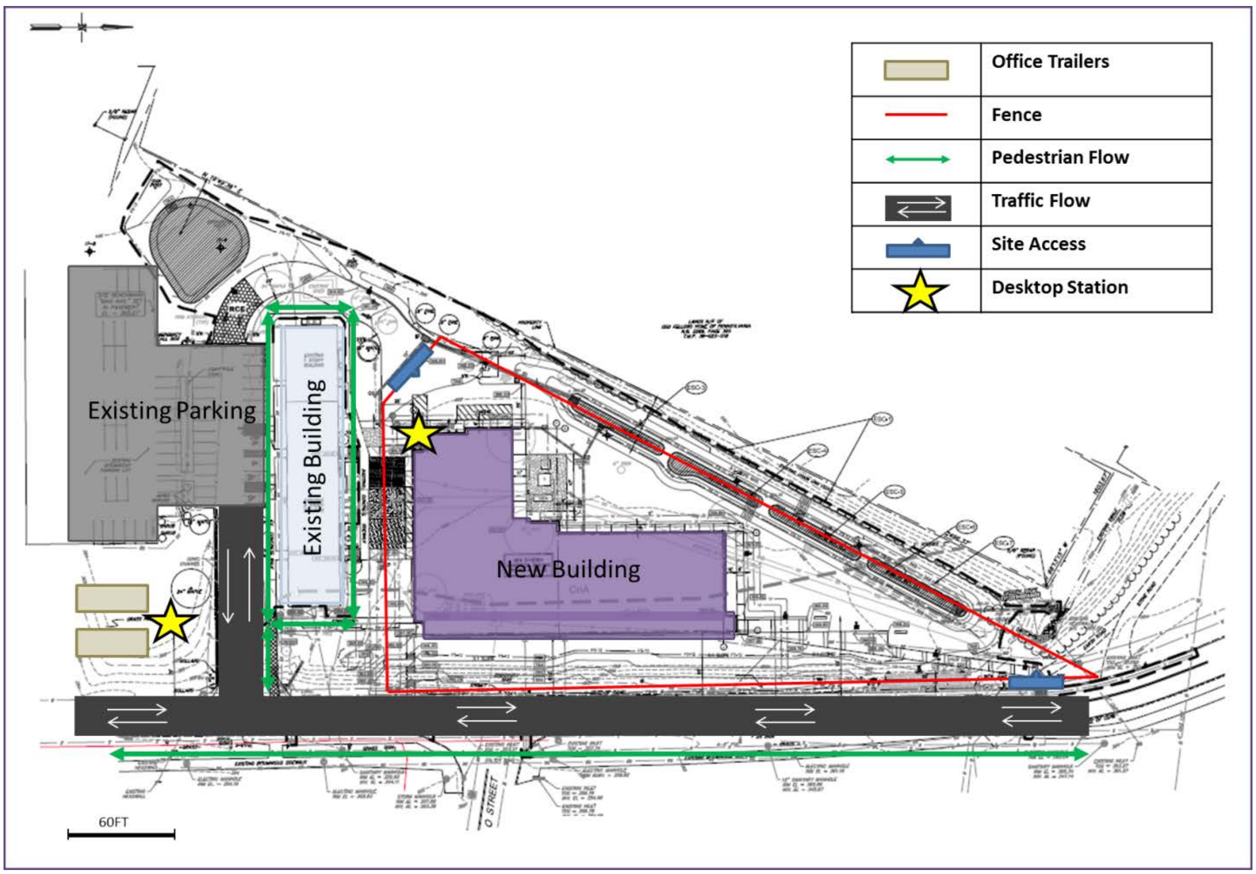

Figure 52 The site plan showing the location of the desktop stations.

As for Google glasses, they will not be considered for the project due to its limited quantity and high price. Additionally, they are still in the prototype stage and there is more room for improvements.

Savings were calculated by using the data found through the in-depth research and case studies as well as general conditions information from technical assignment 2. Table 25 shows the total savings by implementing these technologies.

Table 25 Cost savings.

Item	Quantity (Hours per week)	Cost ($) /Unit (Hour)	Total Cost Savings ($) Per Week
Penn state Project Manager	5	95	475
Penn state BIM Manager	5	65	325
Reynolds Construction BIM Manager	5	65	325
Reynolds Construction Project Executive	5	103	515
Reynolds Construction Project Manager	5	95	475
Reynolds Construction On-Site Construction Manager	5	90	450
Total			2,565

The initial cost for implementing these solutions and eliminating Google Glass is $9,614 to $13,314. However based on the time savings reported above, the cost saving is estimated to be around $2,565 per week. These savings reduces the budget by $164,160 over the entire project duration. The return on investment is projected to start on the fifth week of the construction.

5.12 Summary

Technology has become a big part of our daily life no matter what field we work in. The construction industry is a little behind compared to other industries when it comes to technology. However, nowadays there is a greater shift toward improving the construction process through the use of technology. The Educational Activities Building project utilizes many BIM uses, but has observed that more uses could be used such as building maintenance scheduling. Additionally, tablets will be used to reach a better level of efficient project management and communication. The use of technology on this project will save $2,565 of the general conditions cost each week or $164,160 during the entire project duration.

Resources

Project documents

Technical assignment 1, 2 & 3

Analysis 1

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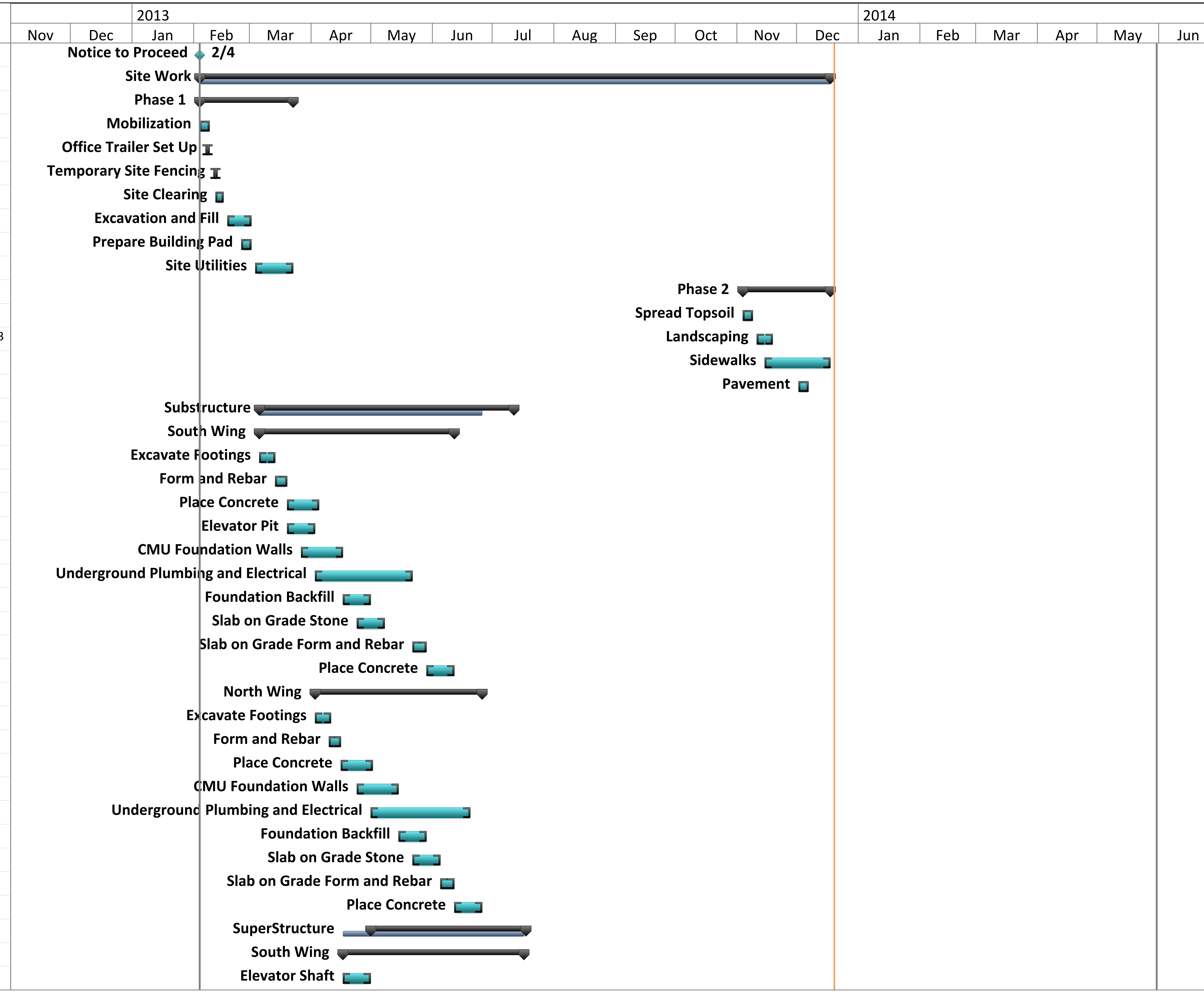
APPENDIX A- Original Detailed Project Schedule

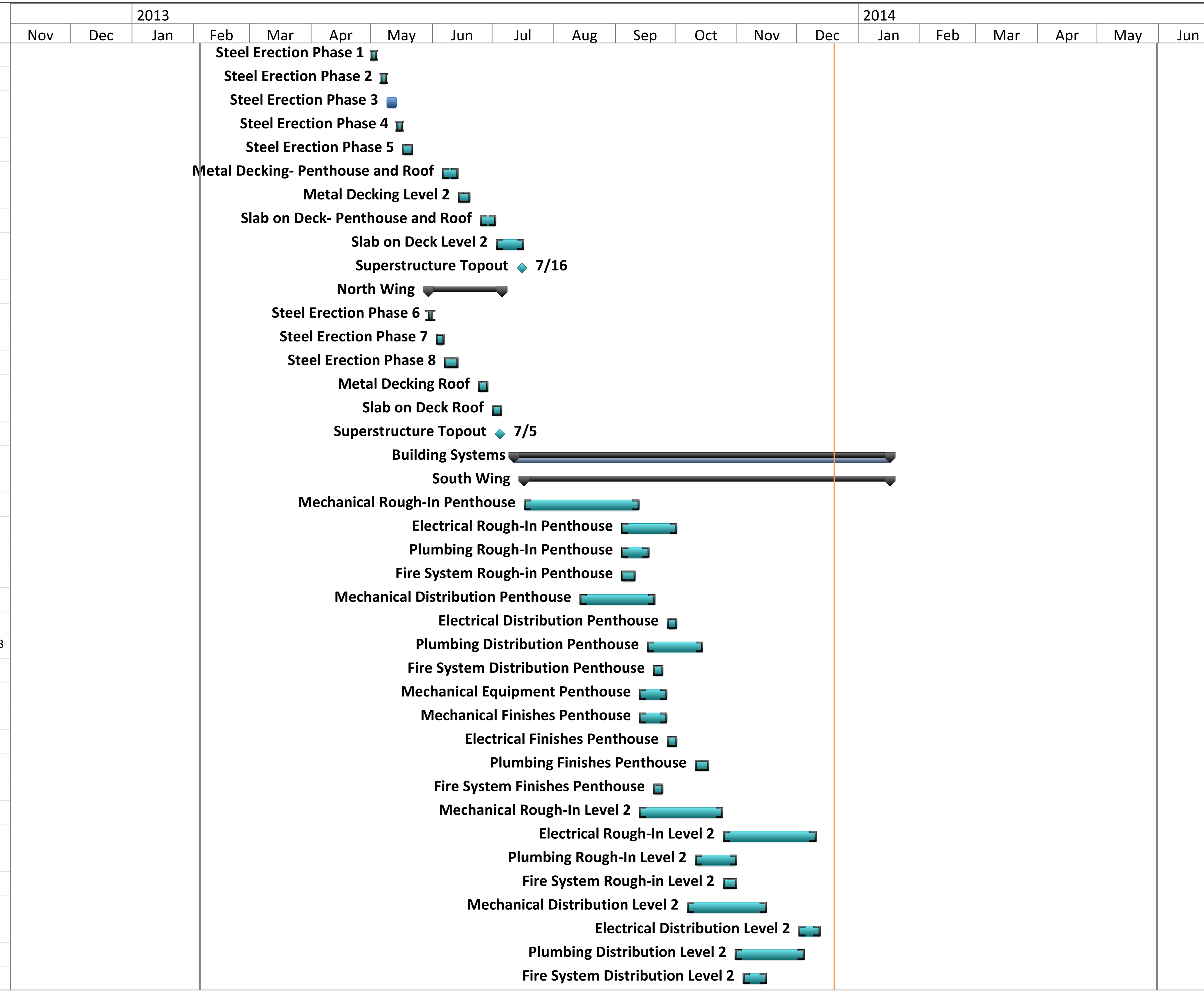
ID	Task Name	Duration	Start	Finish
1	Notice to Proceed	0 days	Mon 2/4/13	Mon 2/4/13
2	**Site Work**	**227 days**	**Mon 2/4/13**	**Tue 12/17/13**
3	**Phase 1**	**35 days**	**Mon 2/4/13**	**Fri 3/22/13**
4	Mobilization	5 days	Mon 2/4/13	Fri 2/8/13
5	Office Trailer Set Up	2 days	Thu 2/7/13	Fri 2/8/13
6	Temporary Site Fencing	2 days	Mon 2/11/13	Tue 2/12/13
7	Site Clearing	4 days	Tue 2/12/13	Fri 2/15/13
8	Excavation and Fill	10 days	Mon 2/18/13	Fri 3/1/13
9	Prepare Building Pad	5 days	Mon 2/25/13	Fri 3/1/13
10	Site Utilities	15 days	Mon 3/4/13	Fri 3/22/13
11	**Phase 2**	**32 days**	**Mon 11/4/13**	**Tue 12/17/13**
12	Spread Topsoil	5 days	Mon 11/4/13	Fri 11/8/13
13	Landscaping	6 days	Mon 11/11/13	Mon 11/18/13
14	Sidewalks	23 days	Fri 11/15/13	Tue 12/17/13
15	Pavement	5 days	Mon 12/2/13	Fri 12/6/13
16	**Substructure**	**92 days**	**Wed 3/6/13**	**Thu 7/11/13**
17	**South Wing**	**70 days**	**Wed 3/6/13**	**Tue 6/11/13**
18	Excavate Footings	6 days	Wed 3/6/13	Wed 3/13/13
19	Form and Rebar	4 days	Thu 3/14/13	Tue 3/19/13
20	Place Concrete	12 days	Wed 3/20/13	Thu 4/4/13
21	Elevator Pit	10 days	Wed 3/20/13	Tue 4/2/13
22	CMU Foundation Walls	15 days	Wed 3/27/13	Tue 4/16/13
23	Underground Plumbing and Electrical	35 days	Wed 4/3/13	Tue 5/21/13
24	Foundation Backfill	10 days	Wed 4/17/13	Tue 4/30/13
25	Slab on Grade Stone	10 days	Wed 4/24/13	Tue 5/7/13
26	Slab on Grade Form and Rebar	5 days	Wed 5/22/13	Tue 5/28/13
27	Place Concrete	10 days	Wed 5/29/13	Tue 6/11/13
28	**North Wing**	**60 days**	**Wed 4/3/13**	**Tue 6/25/13**
29	Excavate Footings	6 days	Wed 4/3/13	Wed 4/10/13
30	Form and Rebar	4 days	Wed 4/10/13	Mon 4/15/13
31	Place Concrete	12 days	Tue 4/16/13	Wed 5/1/13
32	CMU Foundation Walls	15 days	Wed 4/24/13	Tue 5/14/13
33	Underground Plumbing and Electrical	36 days	Wed 5/1/13	Wed 6/19/13
34	Foundation Backfill	10 days	Wed 5/15/13	Tue 5/28/13
35	Slab on Grade Stone	10 days	Wed 5/22/13	Tue 6/4/13
36	Slab on Grade Form and Rebar	5 days	Wed 6/5/13	Tue 6/11/13
37	Place Concrete	10 days	Wed 6/12/13	Tue 6/25/13
38	**SuperStructure**	**56 days**	**Wed 5/1/13**	**Wed 7/17/13**
39	**South Wing**	**65 days**	**Wed 4/17/13**	**Tue 7/16/13**
40	Elevator Shaft	10 days	Wed 4/17/13	Tue 4/30/13



Project: EAB.mpp
Date: Fri 12/20/13

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

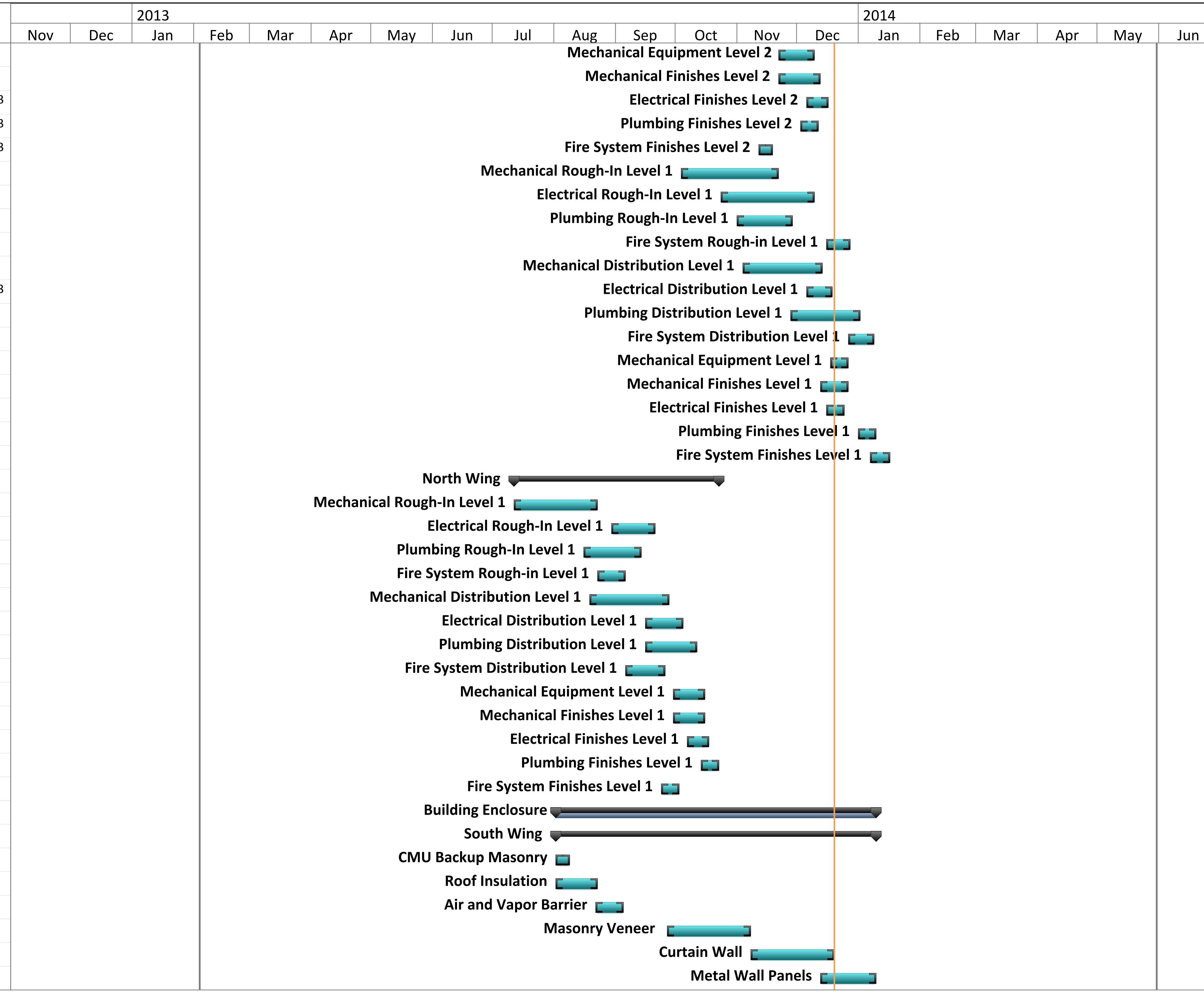
ID	Task Name	Duration	Start	Finish
41	Steel Erection Phase 1	3 days	Wed 5/1/13	Fri 5/3/13
42	Steel Erection Phase 2	3 days	Mon 5/6/13	Wed 5/8/13
43	Steel Erection Phase 3	3 days	Thu 5/9/13	Mon 5/13/13
44	Steel Erection Phase 4	3 days	Tue 5/14/13	Thu 5/16/13
45	Steel Erection Phase 5	3 days	Fri 5/17/13	Tue 5/21/13
46	Metal Decking- Penthouse and Roof	6 days	Thu 6/6/13	Thu 6/13/13
47	Metal Decking Level 2	4 days	Fri 6/14/13	Wed 6/19/13
48	Slab on Deck- Penthouse and Roof	6 days	Tue 6/25/13	Tue 7/2/13
49	Slab on Deck Level 2	10 days	Wed 7/3/13	Tue 7/16/13
50	Superstructure Topout	0 days	Tue 7/16/13	Tue 7/16/13
51	**North Wing**	**27 days**	**Thu 5/30/13**	**Fri 7/5/13**
52	Steel Erection Phase 6	2 days	Thu 5/30/13	Fri 5/31/13
53	Steel Erection Phase 7	4 days	Mon 6/3/13	Thu 6/6/13
54	Steel Erection Phase 8	5 days	Fri 6/7/13	Thu 6/13/13
55	Metal Decking Roof	5 days	Mon 6/24/13	Fri 6/28/13
56	Slab on Deck Roof	5 days	Mon 7/1/13	Fri 7/5/13
57	Superstructure Topout	0 days	Fri 7/5/13	Fri 7/5/13
58	**Building Systems**	**135 days**	**Fri 7/12/13**	**Thu 1/16/14**
59	**South Wing**	**132 days**	**Wed 7/17/13**	**Thu 1/16/14**
60	Mechanical Rough-In Penthouse	42 days	Wed 7/17/13	Thu 9/12/13
61	Electrical Rough-In Penthouse	20 days	Wed 9/4/13	Tue 10/1/13
62	Plumbing Rough-In Penthouse	10 days	Wed 9/4/13	Tue 9/17/13
63	Fire System Rough-in Penthouse	5 days	Wed 9/4/13	Tue 9/10/13
64	Mechanical Distribution Penthouse	28 days	Wed 8/14/13	Fri 9/20/13
65	Electrical Distribution Penthouse	3 days	Fri 9/27/13	Tue 10/1/13
66	Plumbing Distribution Penthouse	20 days	Tue 9/17/13	Mon 10/14/13
67	Fire System Distribution Penthouse	3 days	Fri 9/20/13	Tue 9/24/13
68	Mechanical Equipment Penthouse	10 days	Fri 9/13/13	Thu 9/26/13
69	Mechanical Finishes Penthouse	10 days	Fri 9/13/13	Thu 9/26/13
70	Electrical Finishes Penthouse	3 days	Fri 9/27/13	Tue 10/1/13
71	Plumbing Finishes Penthouse	5 days	Fri 10/11/13	Thu 10/17/13
72	Fire System Finishes Penthouse	3 days	Fri 9/20/13	Tue 9/24/13
73	Mechanical Rough-In Level 2	30 days	Fri 9/13/13	Thu 10/24/13
74	Electrical Rough-In Level 2	33 days	Fri 10/25/13	Tue 12/10/13
75	Plumbing Rough-In Level 2	15 days	Fri 10/11/13	Thu 10/31/13
76	Fire System Rough-in Level 2	5 days	Fri 10/25/13	Thu 10/31/13
77	Mechanical Distribution Level 2	30 days	Mon 10/7/13	Fri 11/15/13
78	Electrical Distribution Level 2	9 days	Mon 12/2/13	Thu 12/12/13
79	Plumbing Distribution Level 2	25 days	Thu 10/31/13	Wed 12/4/13
80	Fire System Distribution Level 2	10 days	Mon 11/4/13	Fri 11/15/13



Project: EAB.mpp
Date: Fri 12/20/13

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

ID	Task Name	Duration	Start	Finish
81	Mechanical Equipment Level 2	12 days	Fri 11/22/13	Mon 12/9/13
82	Mechanical Finishes Level 2	15 days	Fri 11/22/13	Thu 12/12/13
83	Electrical Finishes Level 2	7 days	Fri 12/6/13	Mon 12/16/13
84	Plumbing Finishes Level 2	7 days	Tue 12/3/13	Wed 12/11/13
85	Fire System Finishes Level 2	5 days	Tue 11/12/13	Mon 11/18/13
86	Mechanical Rough-In Level 1	35 days	Fri 10/4/13	Thu 11/21/13
87	Electrical Rough-In Level 1	33 days	Thu 10/24/13	Mon 12/9/13
88	Plumbing Rough-In Level 1	20 days	Fri 11/1/13	Thu 11/28/13
89	Fire System Rough-in Level 1	10 days	Mon 12/16/13	Fri 12/27/13
90	Mechanical Distribution Level 1	30 days	Mon 11/4/13	Fri 12/13/13
91	Electrical Distribution Level 1	9 days	Fri 12/6/13	Wed 12/18/13
92	Plumbing Distribution Level 1	25 days	Thu 11/28/13	Wed 1/1/14
93	Fire System Distribution Level 1	9 days	Fri 12/27/13	Wed 1/8/14
94	Mechanical Equipment Level 1	7 days	Wed 12/18/13	Thu 12/26/13
95	Mechanical Finishes Level 1	10 days	Fri 12/13/13	Thu 12/26/13
96	Electrical Finishes Level 1	7 days	Mon 12/16/13	Tue 12/24/13
97	Plumbing Finishes Level 1	7 days	Wed 1/1/14	Thu 1/9/14
98	Fire System Finishes Level 1	8 days	Tue 1/7/14	Thu 1/16/14
99	**North Wing**	**73 days**	**Fri 7/12/13**	**Tue 10/22/13**
100	Mechanical Rough-In Level 1	30 days	Fri 7/12/13	Thu 8/22/13
101	Electrical Rough-In Level 1	16 days	Fri 8/30/13	Fri 9/20/13
102	Plumbing Rough-In Level 1	21 days	Fri 8/16/13	Fri 9/13/13
103	Fire System Rough-in Level 1	10 days	Fri 8/23/13	Thu 9/5/13
104	Mechanical Distribution Level 1	30 days	Mon 8/19/13	Fri 9/27/13
105	Electrical Distribution Level 1	15 days	Mon 9/16/13	Fri 10/4/13
106	Plumbing Distribution Level 1	20 days	Mon 9/16/13	Fri 10/11/13
107	Fire System Distribution Level 1	14 days	Fri 9/6/13	Wed 9/25/13
108	Mechanical Equipment Level 1	12 days	Mon 9/30/13	Tue 10/15/13
109	Mechanical Finishes Level 1	12 days	Mon 9/30/13	Tue 10/15/13
110	Electrical Finishes Level 1	9 days	Mon 10/7/13	Thu 10/17/13
111	Plumbing Finishes Level 1	7 days	Mon 10/14/13	Tue 10/22/13
112	Fire System Finishes Level 1	7 days	Tue 9/24/13	Wed 10/2/13
113	**Building Enclosure**	**115 days**	**Fri 8/2/13**	**Thu 1/9/14**
114	**South Wing**	**115 days**	**Fri 8/2/13**	**Thu 1/9/14**
115	CMU Backup Masonry	5 days	Fri 8/2/13	Thu 8/8/13
116	Roof Insulation	15 days	Fri 8/2/13	Thu 8/22/13
117	Air and Vapor Barrier	10 days	Thu 8/22/13	Wed 9/4/13
118	Masonry Veneer	30 days	Fri 9/27/13	Thu 11/7/13
119	Curtain Wall	30 days	Fri 11/8/13	Thu 12/19/13
120	Metal Wall Panels	20 days	Fri 12/13/13	Thu 1/9/14



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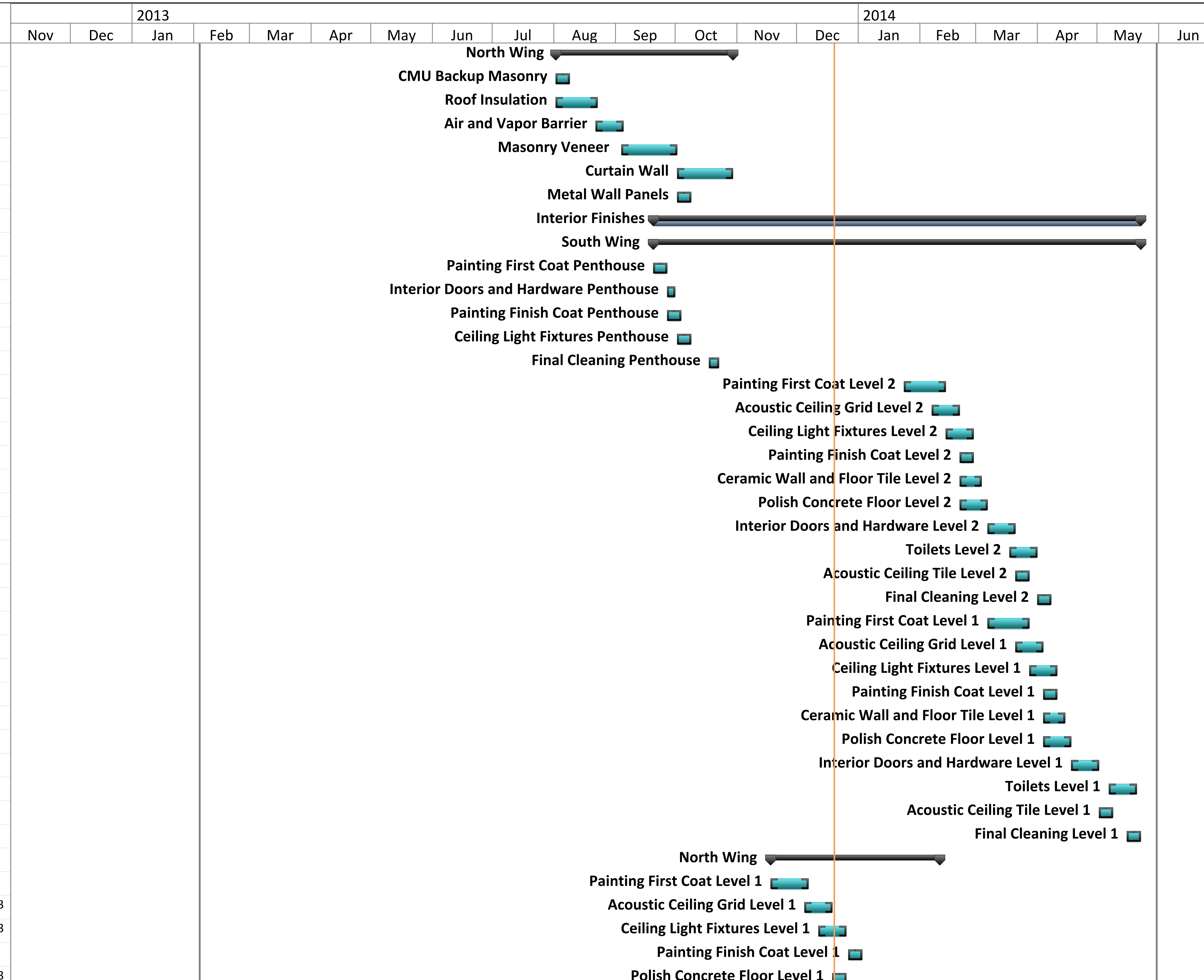
Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

ID	Task Name	Duration	Start	Finish
121	North Wing	63 days	Fri 8/2/13	Tue 10/29/13
122	CMU Backup Masonry	5 days	Fri 8/2/13	Thu 8/8/13
123	Roof Insulation	15 days	Fri 8/2/13	Thu 8/22/13
124	Air and Vapor Barrier	10 days	Thu 8/22/13	Wed 9/4/13
125	Masonry Veneer	20 days	Wed 9/4/13	Tue 10/1/13
126	Curtain Wall	20 days	Wed 10/2/13	Tue 10/29/13
127	Metal Wall Panels	5 days	Wed 10/2/13	Tue 10/8/13
128	Interior Finishes	175 days	Fri 9/20/13	Thu 5/22/14
129	South Wing	175 days	Fri 9/20/13	Thu 5/22/14
130	Painting First Coat Penthouse	5 days	Fri 9/20/13	Thu 9/26/13
131	Interior Doors and Hardware Penthouse	2 days	Fri 9/27/13	Mon 9/30/13
132	Painting Finish Coat Penthouse	5 days	Fri 9/27/13	Thu 10/3/13
133	Ceiling Light Fixtures Penthouse	5 days	Wed 10/2/13	Tue 10/8/13
134	Final Cleaning Penthouse	3 days	Fri 10/18/13	Tue 10/22/13
135	Painting First Coat Level 2	15 days	Fri 1/24/14	Thu 2/13/14
136	Acoustic Ceiling Grid Level 2	10 days	Fri 2/7/14	Thu 2/20/14
137	Ceiling Light Fixtures Level 2	10 days	Fri 2/14/14	Thu 2/27/14
138	Painting Finish Coat Level 2	5 days	Fri 2/21/14	Thu 2/27/14
139	Ceramic Wall and Floor Tile Level 2	7 days	Fri 2/21/14	Mon 3/3/14
140	Polish Concrete Floor Level 2	10 days	Fri 2/21/14	Thu 3/6/14
141	Interior Doors and Hardware Level 2	10 days	Fri 3/7/14	Thu 3/20/14
142	Toilets Level 2	10 days	Tue 3/18/14	Mon 3/31/14
143	Acoustic Ceiling Tile Level 2	5 days	Fri 3/21/14	Thu 3/27/14
144	Final Cleaning Level 2	5 days	Tue 4/1/14	Mon 4/7/14
145	Painting First Coat Level 1	15 days	Fri 3/7/14	Thu 3/27/14
146	Acoustic Ceiling Grid Level 1	10 days	Fri 3/21/14	Thu 4/3/14
147	Ceiling Light Fixtures Level 1	10 days	Fri 3/28/14	Thu 4/10/14
148	Painting Finish Coat Level 1	5 days	Fri 4/4/14	Thu 4/10/14
149	Ceramic Wall and Floor Tile Level 1	7 days	Fri 4/4/14	Mon 4/14/14
150	Polish Concrete Floor Level 1	10 days	Fri 4/4/14	Thu 4/17/14
151	Interior Doors and Hardware Level 1	10 days	Fri 4/18/14	Thu 5/1/14
152	Toilets Level 1	10 days	Wed 5/7/14	Tue 5/20/14
153	Acoustic Ceiling Tile Level 1	5 days	Fri 5/2/14	Thu 5/8/14
154	Final Cleaning Level 1	5 days	Fri 5/16/14	Thu 5/22/14
155	North Wing	61 days	Mon 11/18/13	Mon 2/10/14
156	Painting First Coat Level 1	15 days	Mon 11/18/13	Fri 12/6/13
157	Acoustic Ceiling Grid Level 1	10 days	Thu 12/5/13	Wed 12/18/13
158	Ceiling Light Fixtures Level 1	10 days	Thu 12/12/13	Wed 12/25/13
159	Painting Finish Coat Level 1	5 days	Fri 12/27/13	Thu 1/2/14
160	Polish Concrete Floor Level 1	5 days	Thu 12/19/13	Wed 12/25/13



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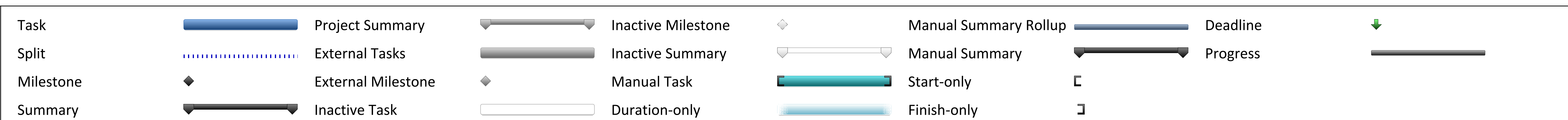
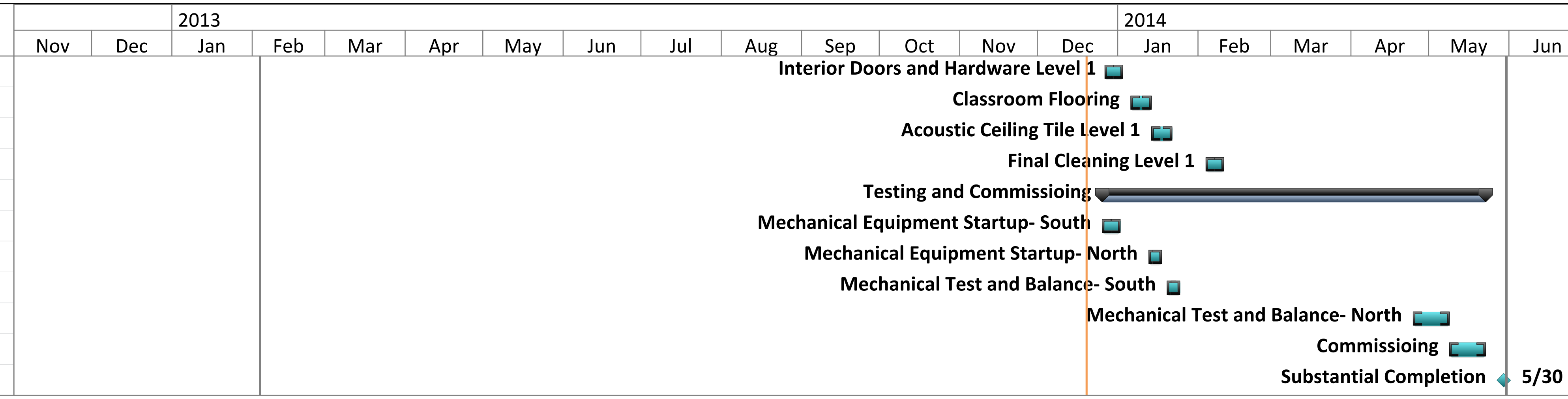


ID	Task Name	Duration	Start	Finish
161	Interior Doors and Hardware Level 1	5 days	Fri 12/27/13	Thu 1/2/14
162	Classroom Flooring	6 days	Mon 1/6/14	Mon 1/13/14
163	Acoustic Ceiling Tile Level 1	6 days	Tue 1/14/14	Tue 1/21/14
164	Final Cleaning Level 1	5 days	Tue 2/4/14	Mon 2/10/14
165	**Testing and Commissioing**	**106 days**	**Thu 12/26/13**	**Thu 5/22/14**
166	Mechanical Equipment Startup- South	5 days	Thu 12/26/13	Wed 1/1/14
167	Mechanical Equipment Startup- North	5 days	Mon 1/13/14	Fri 1/17/14
168	Mechanical Test and Balance- South	5 days	Mon 1/20/14	Fri 1/24/14
169	Mechanical Test and Balance- North	10 days	Fri 4/25/14	Thu 5/8/14
170	Commissioing	10 days	Fri 5/9/14	Thu 5/22/14
171	Substantial Completion	0 days	Fri 5/30/14	Fri 5/30/14



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Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

APPENDIX B- Detailed Project Estimate

Structural Steel

CSI Division	Item	Unit Costs						Quantity	Total Costs				
		Unit	Material	Labor	Equipment	Total	Total O&P		Material	Labor	Equipment	Total	Total O&P
05122375 0320	W8x15, bolted connections	L.F.	21.74	5.55	2.88	30.17	36.44	104	2260.96	577.20	299.52	3137.68	3789.76
05122375 0360	W8x24, bolted connections	L.F.	34.88	6.04	3.14	44.06	52.22	278	9696.64	1679.12	872.92	12248.68	14517.16
05122375 0500	W8x31, bolted connections	L.F.	44.99	6.04	3.14	54.17	63.34	13	584.87	78.52	40.82	704.21	823.42
05122375 0600	W10x12, bolted connections	L.F.	17.34	5.55	2.88	25.77	31.79	871	15103.14	4834.05	2508.48	22445.67	27689.09
05122375 0700	W10x19, bolted connections	L.F.	31.85	5.55	2.88	40.28	47.56	33	1051.05	183.15	95.04	1329.24	1569.48
05122375 1100	W12x14, bolted connections	L.F.	23.25	3.78	1.96	28.99	33.92	61	1418.25	230.58	119.56	1768.39	2069.12
05122375 1100	W12x16, bolted connections	L.F.	23.25	3.78	1.96	28.99	33.92	97	2255.25	366.66	190.12	2812.03	3290.24
05122375 1300	W12x19, bolted connections	L.F.	31.85	3.78	1.96	37.59	43.52	38	1210.30	143.64	74.48	1428.42	1653.76
05122375 1300	W12x22, bolted connections	L.F.	31.85	3.78	1.96	37.59	43.52	67	2133.95	253.26	131.32	2518.53	2915.84
05122375 1900	W14x22, bolted connections	L.F.	37.41	3.35	1.74	42.5	49.11	222	8305.02	743.70	386.28	9435.00	10902.42
05122375 1900	W14x26, bolted connections	L.F.	37.41	3.35	1.74	42.5	49.11	18	673.38	60.30	31.32	765.00	883.98
05122375 2100	W14x30, bolted connections	L.F.	43.47	3.69	1.91	49.07	55.93	46	1999.62	169.74	87.86	2257.22	2572.78
05122375 2700	W16x26, bolted connections	L.F.	37.41	3.33	1.72	42.46	49.04	65	2431.65	216.45	111.80	2759.90	3187.60
05122375 2900	W16x31, bolted connections	L.F.	44.99	3.69	1.91	50.59	57.95	130	5848.70	479.70	248.30	6576.70	7533.50
05122375 3100	W16x40, bolted connections	L.F.	57.63	4.15	2.16	63.94	73.21	76	4379.88	315.40	164.16	4859.44	5563.96
05122375 3140	W16x67, bolted connections	L.F.	97.06	4.37	2.28	103.71	116.17	18	1747.08	78.66	41.04	1866.78	2091.06
05122375 3140	W16x100, bolted connections	L.F.	97.06	4.37	2.28	103.71	116.17	87	8444.22	380.19	198.36	9022.77	10106.79
05122375 3300	W18x35, bolted connections	L.F.	50.55	5	1.97	57.52	66.43	411	20776.05	2055.00	809.67	23640.72	27302.73
05122375 3500	W18x40, bolted connections	L.F.	57.63	5	1.97	64.6	74.51	181	10431.03	905.00	356.57	11692.60	13486.31
05122375 3700	W18x50, bolted connections	L.F.	72.29	5.27	2.07	79.63	90.78	34	2457.86	179.18	70.38	2707.42	3086.52
05122375 3920	W18x60, bolted connections	L.F.	94.02	5.33	2.09	101.44	114.69	142	13350.84	756.86	296.78	14404.48	16285.98
05122375 3960	W18x86, bolted connections	L.F.	124.35	5.33	2.09	131.77	148.06	50	6217.50	266.50	104.50	6588.50	7403.00
05122375 3980	W18x97, bolted connections	L.F.	153.67	5.33	2.09	161.09	180.41	39	5993.13	207.87	81.51	6282.51	7035.99
05122375 3980	W18x119, bolted connections	L.F.	153.67	5.33	2.09	161.09	180.41	129	19823.43	687.57	269.61	20780.61	23272.89
05122375 3980	W18x158, bolted connections	L.F.	153.67	5.33	2.09	161.09	180.41	52	7990.84	277.16	108.68	8376.68	9381.32
05122375 4100	W21x44,bolted connections	L.F.	63.69	4.52	1.78	69.99	79.53	1027	65409.63	4642.04	1828.06	71879.73	81677.31
05122375 4300	W21x50, bolted connections	L.F.	72.29	4.52	1.78	78.59	89.13	493	35638.97	2228.36	877.54	38744.87	43941.09
05122375 4500	W21x62, bolted connections	L.F.	89.47	4.64	1.82	95.93	108.62	711	63613.17	3299.04	1294.02	68206.23	77228.82
05122375 4700	W21x68, bolted connections	L.F.	98.07	4.64	1.82	104.53	118.23	306	30009.42	1419.84	556.92	31986.18	36178.38
05122375 4720	W21x83, bolted connections	L.F.	120.31	4.8	1.89	127	142.82	71	8542.01	340.80	134.19	9017.00	10140.22
05122375 4740	W21x93, bolted connections	L.F.	134.46	4.8	1.89	141.15	157.99	124	16673.04	595.20	234.36	17502.60	19590.76
05122375 4760	W21x101, bolted connections	L.F.	145.58	4.8	1.89	152.27	171.13	115	16741.70	552.00	217.35	17511.05	19679.95
05122375 4780	W21x132, bolted connections	L.F.	175.91	4.8	1.89	182.6	204.49	141	24803.31	676.80	266.49	25746.60	28833.09
05122375 4780	W21x182, bolted connections	L.F.	175.91	4.8	1.89	182.6	204.49	32	5629.12	153.60	60.48	5843.20	6543.68
05122375 4900	W24x55, bolted connections	L.F.	79.36	4.32	1.7	85.38	96.83	2213	175623.68	9560.16	3762.10	188945.94	214284.79
05122375 5100	W24x62, bolted connections	L.F.	89.47	4.32	1.7	95.49	107.95	450	40261.50	1944.00	765.00	42970.50	48577.50
05122375 5300	W24x68, bolted connections	L.F.	98.07	4.32	1.7	104.09	117.56	223	21869.61	963.36	379.10	23212.07	26215.88
05122375 5500	W24x76, bolted connections	L.F.	110.2	4.32	1.7	116.22	130.7	178	19615.60	768.96	302.60	20687.16	23264.60

05122375 5700	W24x84, bolted connections	L.F.	121.32	4.44	1.75	127.51	143.06	317	38458.44	1407.48	554.75	40420.67	45350.02
05122375 5720	W24x94, bolted connections	L.F.	135.47	4.44	1.75	141.66	159.24	89	12056.83	395.16	155.75	12607.74	14172.36
05122375 5740	W24x103, bolted connections	L.F.	150.64	4.58	1.8	157.02	175.71	114	17172.96	522.12	205.20	17900.28	20030.94
05122375 5740	W24x104, bolted connections	L.F.	150.64	4.58	1.8	157.02	175.71	223	33592.72	1021.34	401.40	35015.46	39183.33
05122375 5760	W24x117, bolted connections	L.F.	168.84	4.58	1.8	175.22	195.93	125	21105.00	572.50	225.00	21902.50	24491.25
05122375 5780	W24x131, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	159	33596.70	728.22	286.20	34611.12	38547.96
05122375 5780	W24x146, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	160	33808.00	732.80	288.00	34828.80	38790.40
05122375 5780	W24x162, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	207	43739.10	948.06	372.60	45059.76	50185.08
05122375 5780	W24x229, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	45	9508.50	206.10	81.00	9795.60	10909.80
05122375 5780	W24x250, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	38	8029.40	174.04	68.40	8271.84	9212.72
05122375 5780	W24x279, bolted connections	L.F.	211.3	4.58	1.8	217.68	242.44	38	8029.40	174.04	68.40	8271.84	9212.72
05122375 6100	W30x90, bolted connections	L.F.	143.56	4	1.57	149.13	166.41	11	1579.16	44.00	17.27	1640.43	1830.51
05122375 0010	HSS6x4x3/16	Ea.	730	54	30	814	935	1	730.00	54.00	30.00	814.00	935.00
05122375 0010	HSS6x4x3/8	Ea.	730	54	30	814	935	4	2920.00	216.00	120.00	3256.00	3740.00
05122375 0010	HSS6x4x1/2	Ea.	730	54	30	814	935	16	11680.00	864.00	480.00	13024.00	14960.00
05122375 0010	HSS8x6x1/2	Ea.	730	54	30	814	935	3	2190.00	162.00	90.00	2442.00	2805.00
05122375 0010	HSS10x6x1/2	Ea.	730	54	30	814	935	6	4380.00	324.00	180.00	4884.00	5610.00
05122375 0010	C15x50	Ea.	730	54	30	814	935	2	1460.00	108.00	60.00	1628.00	1870.00
Structural Steel Total									965051.61	51923.48	22061.26	1039036.35	**1176407.86**

Columns

CSI Division	Item	Unit Costs						Quantity	Total Costs				
		Unit	Material	Labor	Equipment	Total	Total O&P		Material	Labor	Equipment	Total	Total O&P
05122317 6800	W8x21, splice plates, bolts	L.F.	34.88	3.08	1.6	39.56	45.44	165	5755.20	508.20	264.00	6527.40	7497.60
05122317 7000	W10x33, splice plates, bolts	L.F.	65.21	3.22	1.68	70.11	79.15	291	18976.11	937.02	488.88	20402.01	23032.65
05122317 7000	W10x39, splice plates, bolts	L.F.	65.21	3.22	1.68	70.11	79.15	122	7955.62	392.84	204.96	8553.42	9656.30
05122317 7000	W10x45, splice plates, bolts	L.F.	65.21	3.22	1.68	70.11	79.15	362	23606.02	1165.64	608.16	25379.82	28652.30
05122317 7050	W10x49, splice plates, bolts	L.F.	98.07	3.38	1.75	103.2	115.91	286	28048.02	966.68	500.50	29515.20	33150.26
05122317 7050	W10x54, splice plates, bolts	L.F.	98.07	3.38	1.75	103.2	115.91	182	17848.74	615.16	318.50	18782.40	21095.62
05122317 7050	W10x60, splice plates, bolts	L.F.	98.07	3.38	1.75	103.2	115.91	233	22850.31	787.54	407.75	24045.60	27007.03
05122317 7050	W10x68, splice plates, bolts	L.F.	98.07	3.38	1.75	103.2	115.91	60	5884.20	202.80	105.00	6192.00	6954.60
05122317 7100	W10x88, splice plates, bolts	L.F.	161.76	3.46	1.8	167.02	185.85	101	16337.76	349.46	181.80	16869.02	18770.85
05122317 7100	W10x100, splice plates, bolts	L.F.	161.76	3.46	1.8	167.02	185.85	60	9705.60	207.60	108.00	10021.20	11151.00
05122375 0010	HSS4x3x1/4	Ea.	730	54	30	814	935	9	6570.00	486.00	270.00	7326.00	8415.00
05122375 0010	HSS4x4x3/8	Ea.	730	54	30	814	935	2	1460.00	108.00	60.00	1628.00	1870.00
Columns Total									164997.58	6726.94	3517.55	175242.07	**197253.21**

Slab on Grade

CSI Division	Item	Unit Costs						Quantity	Total Costs				
		Unit	Material	Labor	Equipment	Total	Total O&P		Material	Labor	Equipment	Total	Total O&P
03310535 0200	Concrete, Slab on Grade	C.Y.	97.12	0	0	97.12	106.93	462	44869.44	0.00	0.00	44869.44	49401.66
03111345 0150	Forming	SFCA	0.85	4.53	0	5.38	7.91	565	480.25	2559.45	0.00	3039.70	4469.15
03310570 4300	Concrete Placement	C.Y.	0	16.05	0.68	16.73	25.1	462	0.00	7415.10	314.16	7729.26	11596.20

03220550 0300	Reinforcement, 6x6—W2.9xW2.9	C.S.F.	22.32	29.84	0	52.16	72	288	6422.58	8586.46	0.00	15009.04	20718.00
Slab on Grade Total									51772.27	18561.01	314.16	70647.44	**86185.01**

Footings

CSI Division	Item	Unit Costs						Quantity	Total Costs				
		Unit	Material	Labor	Equipment	Total	Total O&P		Material	Labor	Equipment	Total	Total O&P
03310535 0350	Concrete, 4500 psi	C.Y.	103.01	0	0	103.01	112.82	300	30903.00	0.00	0.00	30903.00	33846.00
03111345 0150	Forming	SFCA	2.09	2.57	0	4.66	6.26	2913	6088.17	7486.41	0.00	13574.58	18235.38
03310570 2450	Concrete Placement	C.Y.	0	37.28	13.64	50.92	72.16	300	0.00	11184.00	4092.00	15276.00	21648.00
03211060 0700	Reinforcing Steel, #3 to #7	Ton	992	575.05	0	1567.05	2002.6	7	7027.35	4073.67	0.00	11101.01	14186.46
03211060 0750	Reinforcing Steel, #8 to #18	Ton	992	434	0	1426	1774.75	6	6037.77	2641.52	0.00	8679.29	10801.94
Footings Total									50056.29	25385.60	4092.00	79533.89	**98717.78**

Metal Deck

CSI Division	Item	Unit Costs						Quantity	Total Costs				
		Unit	Material	Labor	Equipment	Total	Total O&P		Material	Labor	Equipment	Total	Total O&P
05311350 5300	Level 2, 2" 20 gauge Galvanized Metal Deck	S.F.	2.36	0.56	0.05	2.97	3.64	16590	39152.4	9290.40	829.50	49272.30	60387.60
05311350 5300	Penthouse, 2" 20 gauge Galvanized Metal Deck	S.F.	2.36	0.56	0.05	2.97	3.64	5400	12744	3024.00	270.00	16038.00	19656.00
05312350 2600	Roof, 1 1/2" 20 gauge Galvanized Metal Deck	S.F.	2.65	0.52	0.05	3.22	3.9	28775	76253.75	14963.00	1438.75	92655.50	112222.50
03310535 0200	Level 2, Penthouse and Roof, 3.25" Slab on Metal Deck	C.Y.	97.12	0	0	97.12	106.93	138	13401.5888	0.00	0.00	13401.59	14755.27
03111335 1150	Forming	S.F.	1.21	3.43	0	4.64	6.59	50765	61425.65	174123.95	0.00	235549.60	334541.35
03310570 1400	Concrete Placement	C.Y.	0	17.35	6.34	23.69	33.3	138	0	2394.30	874.92	3269.22	4595.40
03220550 0100	Level 2, Penthouse and Roof, Reinforcing, 6x6—W1.4xW1.4	C.S.F.	14.48	24.96	0	39.44	54.98	507.65	7350.772	12670.94	0.00	20021.72	27910.60
Metal Deck Total									210328.1608	216466.59	3413.17	430207.92	574068.72
Total Structural Costs												1794667.67	**2132632.58**

MEP Assembly Estimate

CSI Divison	Description	Unit	Material	Installation	Quantity	Total O&P	Ext. Total O&P
D2090810 1560	Copper tubing, hard temper, solder, type L, 1/2" diameter	L.F.	4.98	6.28	989	11.26	11136.14
D2090810 1600	Copper tubing, hard temper, solder, type L, 3/4" diameter	L.F.	7.69	6.7	450	14.39	6475.5
D2090810 1620	Copper tubing, hard temper, solder, type L, 1" diameter	L.F.	11.27	7.5	550	18.77	10323.5
D2090810 1640	Copper tubing, hard temper, solder, type L, 1-1/4" diameter	L.F.	16.07	8.81	128	24.88	3184.64
D2090810 1660	Copper tubing, hard temper, solder, type L, 1-1/2" diameter	L.F.	20.61	9.79	133	30.4	4043.2
D2090810 1680	Copper tubing, hard temper, solder, type L, 2" diameter	L.F.	32.57	12.13	77	44.7	3441.9
D2090810 1700	Copper tubing, hard temper, solder, type L, 2-1/2" diameter	L.F.	50.2	14.8	150	65	9750
D2090820 2500	Copper, wrought, solder joints, 90< elbow, 1/2" diameter	Ea.	3.32	25.3	159	28.62	4550.58
D2090820 2510	Copper, wrought, solder joints, 90< elbow, 3/4" diameter	Ea.	7.48	26.7	103	34.18	3520.54
D2090820 2520	Copper, wrought, solder joints, 90< elbow, 1" diameter	Ea.	18.37	31.86	119	50.23	5977.37
D2090820 2530	Copper, wrought, solder joints, 90< elbow, 1-1/4" diameter	Ea.	27.77	34.2	23	61.97	1425.31
D2090820 2540	Copper, wrought, solder joints, 90< elbow, 1-1/2" diameter	Ea.	43.25	39.35	10	82.6	826
D2090820 2550	Copper, wrought, solder joints, 90< elbow, 2" diameter	Ea.	79.03	46.38	37	125.41	4640.17
D2090820 2700	Copper, wrought, solder joints, tee, 1/2" diameter	Ea.	5.66	39.35	2	45.01	90.02
D2090820 2710	Copper, wrought, solder joints, tee, 3/4" diameter	Ea.	13.72	42.63	13	56.35	732.55
D2090820 2730	Copper, wrought, solder joints, tee, 1-1/4" diameter	Ea.	58.21	56.69	35	114.9	4021.5
D2090820 2740	Copper, wrought, solder joints, tee, 1-1/2" diameter	Ea.	89.18	63.72	16	152.9	2446.4
D2090820 2750	Copper, wrought, solder joints, tee, 2" diameter	Ea.	138.84	72.62	22	211.46	4652.12
D2090820 2880	Copper, wrought, solder joints, coupling, 1/2" diameter	Ea.	2.51	22.96	70	25.47	1782.9
D2090820 2890	Copper, wrought, solder joints, coupling, 3/4" diameter	Ea.	5.07	24.36	35	29.43	1030.05
D2090820 2900	Copper, wrought, solder joints, coupling, 1" diameter	Ea.	10.09	28.11	90	38.2	3438
D2090820 2920	Copper, wrought, solder joints, coupling, 1-1/2" diameter	Ea.	23.5	34.2	7	57.7	403.9
D2090820 2930	Copper, wrought, solder joints, coupling, 2" diameter	Ea.	39.52	39.35	6	78.87	473.22
D2090820 2940	Copper, wrought, solder joints, coupling, 2-1/2" diameter	Ea.	84.37	61.37	17	145.74	2477.58
D2090810 0860	Pipe cast iron, soil, B & S, service weight, 3" diameter	L.F.	15.01	15.27	155	30.28	4693.4
D2090810 0880	Pipe cast iron, soil, B & S, service weight, 4" diameter	L.F.	19.86	16.68	280	36.54	10231.2
D2090820 0820	Cast iron, soil, no hub, 1/8 bend, 2" diameter	Ea.	10.31	0	3	10.31	30.93
D2090820 0830	Cast iron, soil, no hub, 1/8 bend, 3" diameter	Ea.	13.83	0	30	13.83	414.9
D2090820 0970	Cast iron, soil, no hub, 1/4 bend, 2" diameter	Ea.	11.91	0	1	11.91	11.91
D2090820 0960	Cast iron, soil, no hub, 1/4 bend, 1-1/2" diameter	Ea.	11	0	17	11	187
D2090820 0980	Cast iron, soil, no hub, 1/4 bend, 3" diameter	Ea.	16.71	0	8	16.71	133.68
D2090820 5580	Plastic, PVC, high impact/pressure sch 40, tee, 6" diameter	Ea.	105.2	123.68	69	228.88	15792.72
D3020106 0720	Boiler, electric, steel, hot water, 720 KW, 2,452 MBH	Ea.	30972	5036.38	1	36008.38	36008.38
D3050155 4440	Rooftop, multizone, air conditioner, schools and colleges, 25,000 SF, 95.83 ton	S.F.	11	7.45	50410	18.45	930064.5
D3030110 3960	Packaged chiller, air cooled, with fan coil unit, schools and colleges,, 20,000 SF,76.66 ton	S.F.	8.92	3.61	50410	12.53	631637.3
D5010130 1100	Underground service installation, includes excavation, backfill, and compaction, 100' length, 4' depth, 3 phase, 4 wire, 277/480 volts, 1600 A	Ea.	34537.6	12755	1	47292.6	47292.6
D5010120 0520	Service installation, includes breakers, metering, 20' conduit & wire, 3 phase, 4 wire, 120/208 V, 1600 A	Ea.	17971.6	8145	1	26116.6	26116.6
D5010240 0600	Switchgear installation, incl switchboard, panels & circuit breaker, 277/480 V, 1600 A	Ea.	34939.2	6705	1	41644.2	41644.2
D5020115 0280	Receptacle systems, underfloor duct, 7' on center, low density	S.F.	5.57	2.08	50410	7.65	385636.5

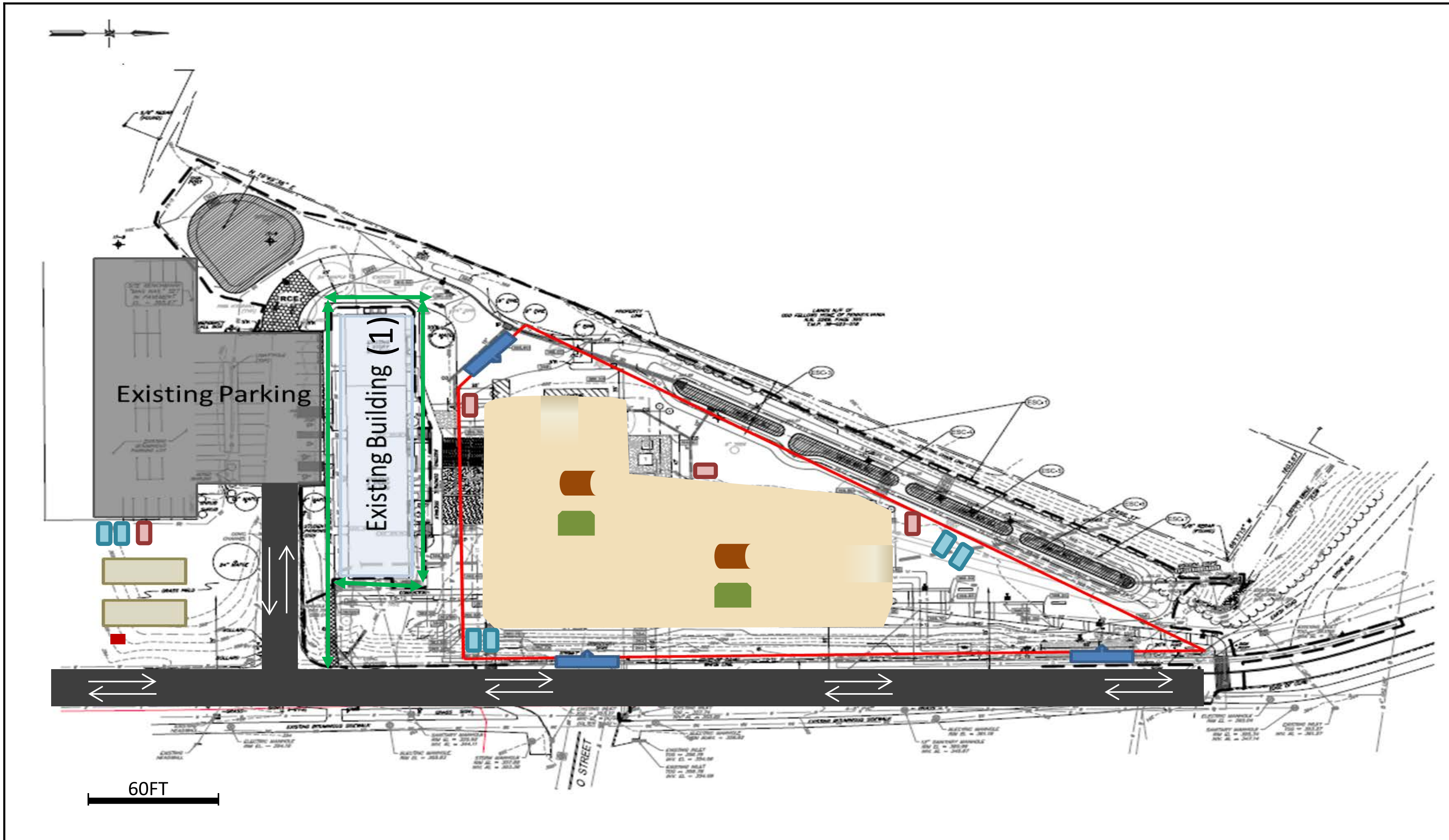
D5020130 0360	Wall switches, 5.0 per 1000 SF	S.F.	0.26	0.77	50410	1.03	51922.3
D5030310 0240	Telephone systems, underfloor duct, 5' on center, high density	S.F.	10.49	2.75	50410	13.24	667428.4
D5030910 0240	Communication and alarm systems, includes outlets, boxes, conduit and wire, sound systems, 30 outlets	Ea.	14859.2	18900	1	33759.2	33759.2
D5030910 0400	Communication and alarm systems, fire detection, non-addressable, 50 detectors, includes outlets, boxes, conduit and wire	Ea.	11445.6	17370	1	28815.6	28815.6
D5030920 0104	Internet wiring, 4 data/voice outlets per 1000 S.F.	M.S.F.	341.36	720	50.41	1061.36	53503.16
D5090210 0600	Generator sets, w/battery, charger, muffler and transfer switch, diesel engine with fuel tank, 50 kW	kW	507.02	65.25	40	572.27	22890.8
Total							**3079058.37**

APPENDIX C- General Conditions Estimate

General Conditions

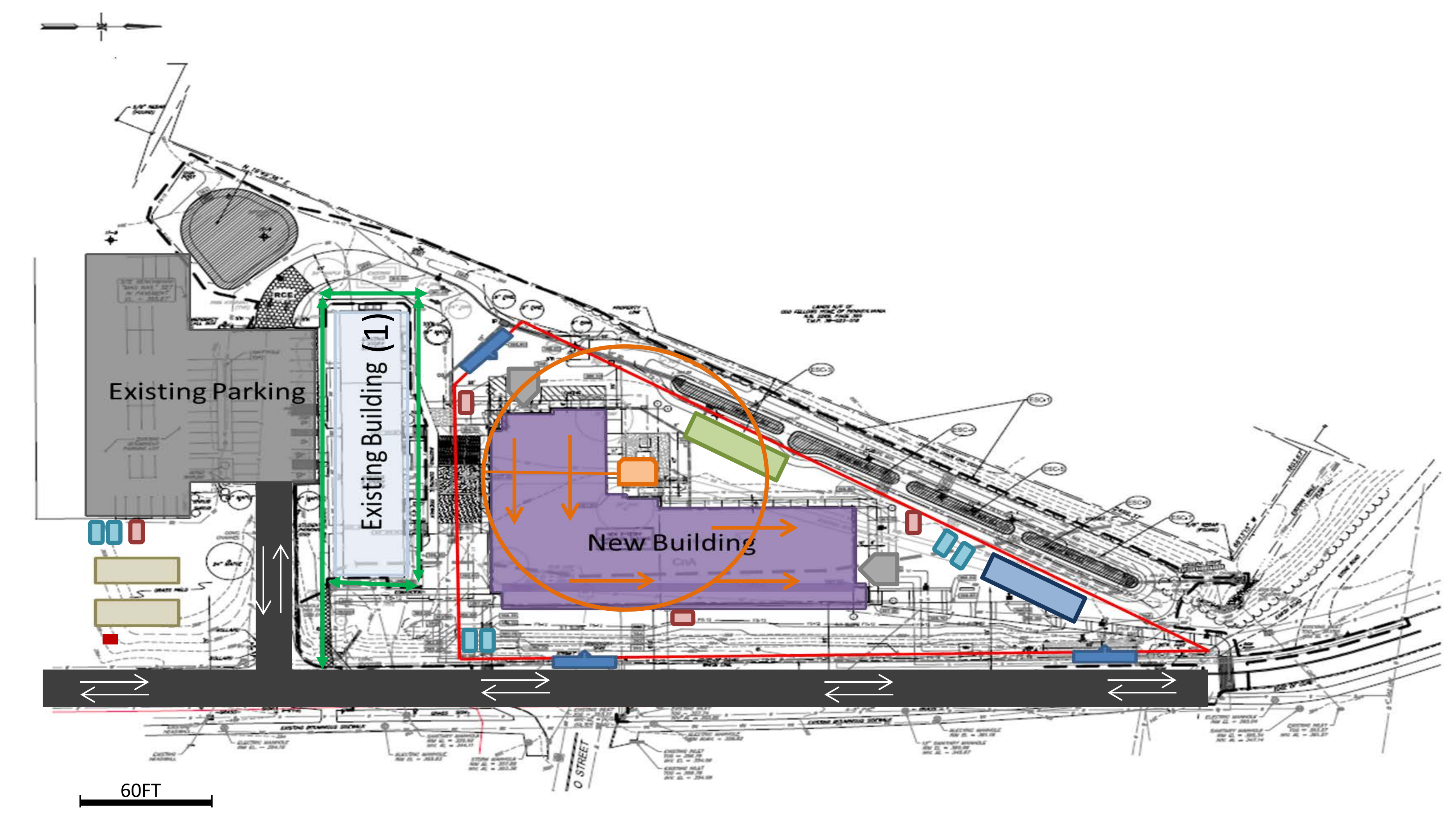
CSI Division	Description			Unit Costs					Total Costs				
		Quantity	Unit	Material	Labor	Equipment	Total	Total O&P	Material	Labor	Equipment	Total	Total O&P
01311320 0010	Field personnel												
01311320 0140	Field personnel, field engineer, maximum	68	Week	0.00	1500.00	0.00	1500.00	2325.00	0	102000	0	102000	158100
01311320 0220	Field personnel, project manager, maximum	68	Week	0.00	2475.00	0.00	2475.00	3825.00	0	168300	0	168300	260100
01311320 0280	Field personnel, superintendent, maximum	68	Week	0.00	2300.00	0.00	2300.00	3550.00	0	156400	0	156400	241400
01510000 0000	Temporary Utilities												
01511380 0100	Temporary Heat, per week, 12 hours per day, incl. fuel and operation	514	CSF Flr	28.57	3.63	0.00	32.20	37.28	14684.98	1865.82	0	16550.8	19161.92
01511380 0350	Temporary Power, lighting, incl. service lamps, wiring and outlets, min	514	CSF Flr	2.91	12.10	0.00	15.01	21.28	1495.74	6219.4	0	7715.14	10937.92
01511380 0430	Temporary Power, for temp lighting only, 11.8 KWH/month	514	CSF Flr	0.00	0.00	0.00	1.67	1.84	0	0	0	858.38	945.76
01521300 0000	Field offices and sheds												
01521320 0020	Office Trailer, furnished, buy, 20' x 8', excl. hookups	2	Ea.	8883.45	725.20	0.00	9608.65	10893.60	17766.9	1450.4	0	19217.3	21787.2
01521320 0700	Office Trailer, excl. hookups, air conditioning, rent per month, add	64	Ea.	47.79	0.00	0.00	47.79	52.47	3058.56	0	0	3058.56	3358.08
01521320 1200	Storage Boxes, buy, 20' x 8'	1	Ea.	3142.98	401.80	0.00	3544.78	4076.98	3142.98	401.8	0	3544.78	4076.98
01521320 1300	Storage Boxes, buy, 40' x 8'	1	Ea.	4130.03	519.40	0.00	4649.43	5344.33	4130.03	519.4	0	4649.43	5344.33
01521340 0010	FIELD OFFICE EXPENSE												
01521340 0100	Field Office Expense, office equipment rental, average	16	Month	207.80	0.00	0.00	207.80	228.58	3324.8	0	0	3324.8	3657.28
01543340 6430	Rent toilet, fresh water flush, garden hose, Excl. Hourly Oper. Cost.	16	Month	0.19	32.83	295.45	328.47	325.00	3.04	525.28	4727.2	5255.52	5199.92
01562650 0100	Temporary Fencing, chain link, 6' high, 11 ga	1039	L.F.	2.69	1.85	0.00	4.54	5.81	2794.91	1922.15	0	4717.06	6036.59
01741320 0100	Cleaning up	51.4	M.S.F.	1.94	54.39	6.57	62.90	93.12	99.716	2795.646	337.698	3233.06	4786.368
01311390 0010	Performance bond	Job	%				2.50	2.50				271600	271600
Total												**770,424.8**	**1,016,492**

APPENDIX D- Site Plans



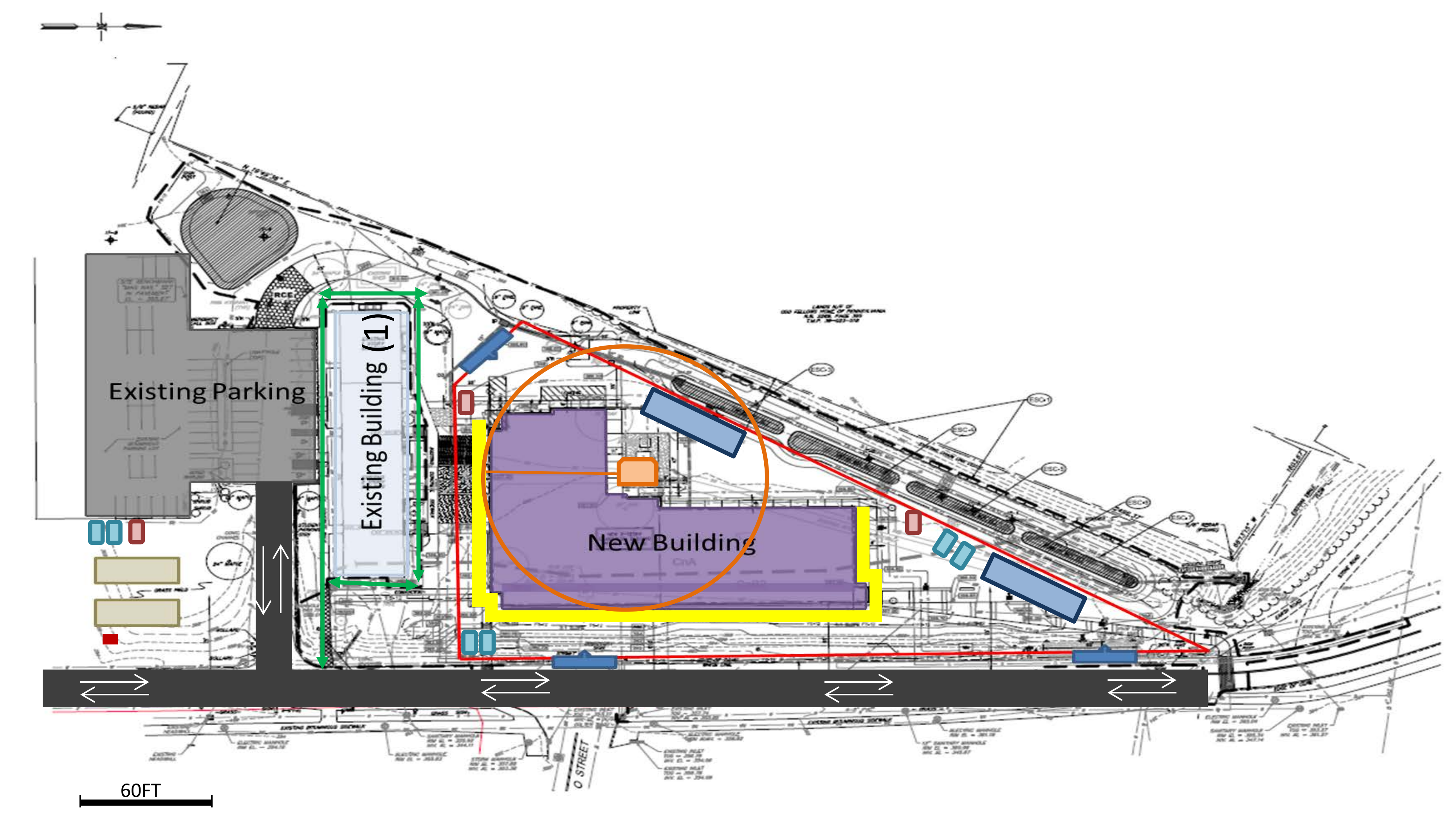
Office Trailers	Dumpster	Soil
Fence	Traffic Flow	Ramps
Site Access	Pedestrian Flow	Excavator
Portable Toilet	Temporary Power	Dump Truck

Penn State Harrisburg	Meshal Alenezi
Educational Activities Building	10/16/2013
Harrisburg, PA	Excavation Site Plan



Office Trailers	Dumpster	Concrete Truck
Fence	Traffic Flow	Steel Laydown
Site Access	Pedestrian Flow	Material Laydown
Portable Toilet	Temporary Power	Mobile Crane

Penn State Harrisburg	Meshal Alenezi
Educational Activities Building	10/16/2013
Harrisburg, PA	Superstructure Site Plan



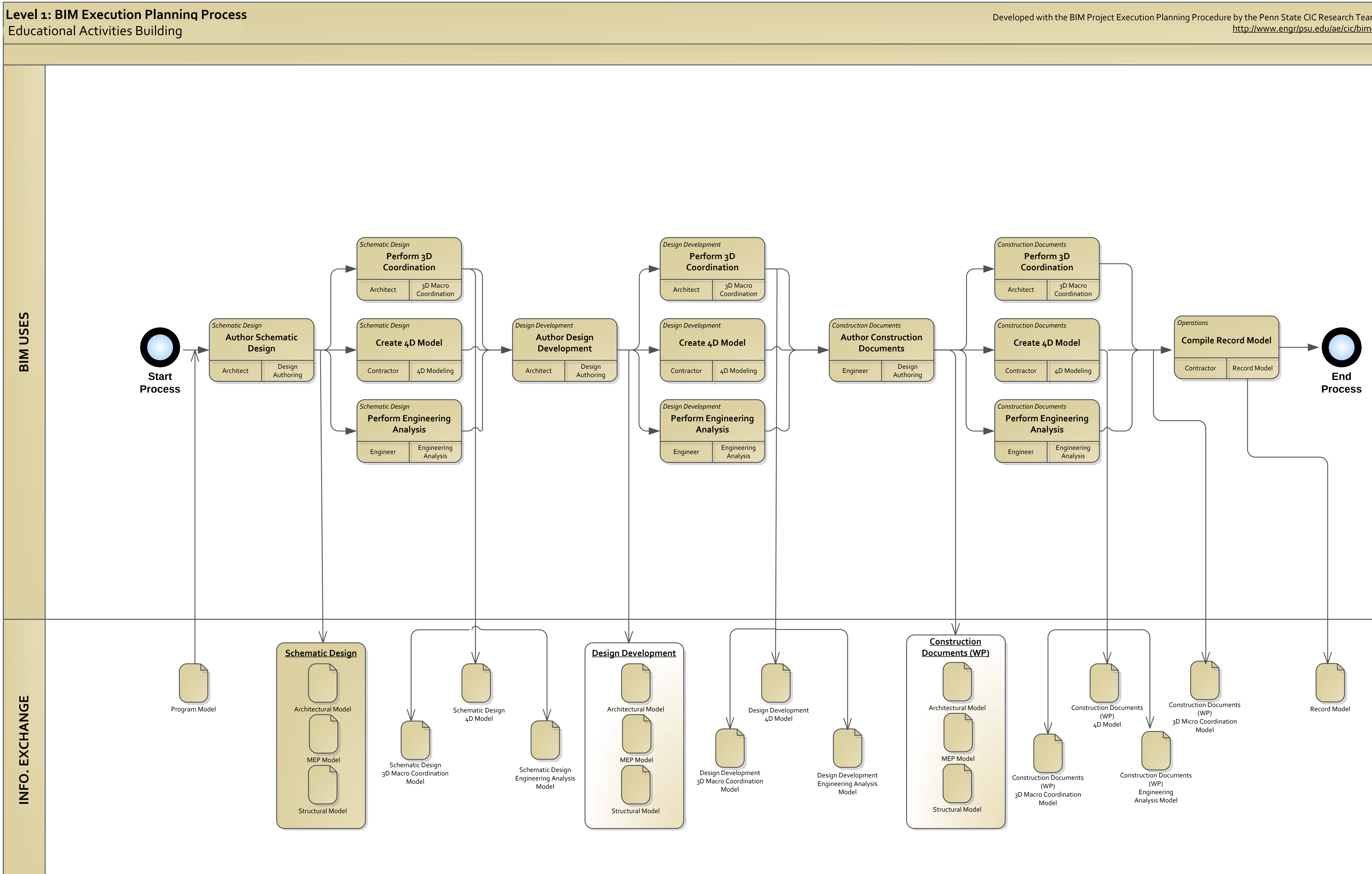
Office Trailers	Dumpster	Mobile Crane
Fence	Traffic Flow	Scaffolding
Site Access	Pedestrian Flow	Material Laydown
Portable Toilet	Temporary Power	

Penn State Harrisburg	Meshal Alenezi
Educational Activities Building	10/16/2013
Harrisburg, PA	Enclosure Site Plan

APPENDIX E- BIM Evaluation

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resources / Competencies Required to Implement	Notes	Proceed with Use
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)					YES / NO / MAYBE
				Resources	Competency	Experience			
Building Systems Analysis	Med	MEP Engineer	High	3	3	2			**Maybe**
Record Modeling	High	Contractor	Med	3	3	3			**Yes**
		Facility Manager	High	3	2	3			
		Architect	High	3	3	3			
Cost Estimation	Med	Contractor	High	3	2	1			**No**
4D Modeling	High	Contractor	High	3	2	2			**Yes**
		Subcontractors	Med	3	3	3			
3D Coordination (Construction)	High	Contractor	High	3	2	2			**Yes**
		Subcontractors	High	2	2	2			
Engineering Analysis	High	MEP Engineer	High	3	2	2			**Yes**
		Architect	Med	3	3	3			
3D Coordination (Design)	High	Architect	High	3	3	3			**Yes**
		MEP Engineer	High	2	2	2			
		Structural Engineer	High	2	2	2			
Existing Conditions Modeling	Low	Contractor	Med	3	2	2			**No**
Design Authoring	High	Architect	High	3	3	3			**Yes**
		MEP Engineer	High	3	3	2			
		Structural Engineer	Med	2	2	2			

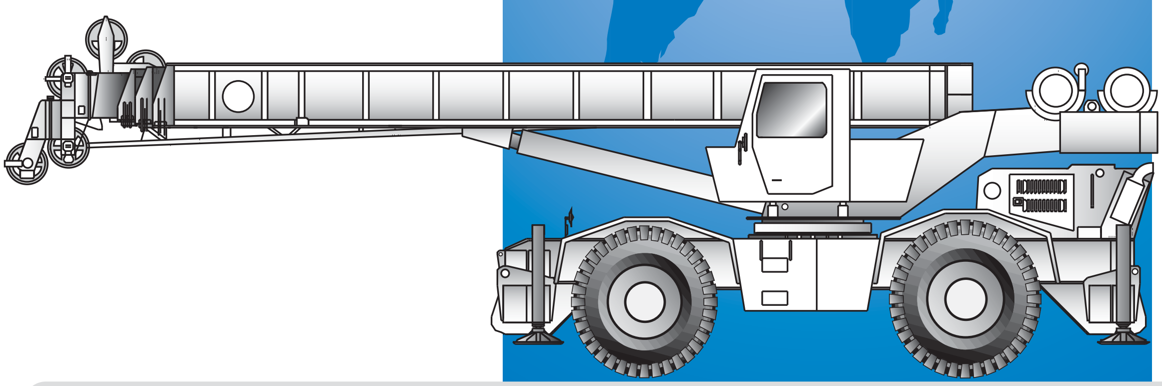
* Additional BIM Uses as well as information on each Use can be found at http://www.engr.psu.edu/ae/cic/bimex/


Level 1: BIM Execution Planning Process
Educational Activities Building
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr/psu.edu/ae/cic/bimex
BIM USES
INFO. EXCHANGE
Start Process
Schematic Design
Author Schematic Design
Architect
Design Authoring
Schematic Design
Perform 3D Coordination
Architect
3D Macro Coordination
Schematic Design
Create 4D Model
Contractor
4D Modeling
Schematic Design
Perform Engineering Analysis
Engineer
Engineering Analysis
Design Development
Author Design Development
Architect
Design Authoring
Design Development
Perform 3D Coordination
Architect
3D Macro Coordination
Design Development
Create 4D Model
Contractor
4D Modeling
Design Development
Perform Engineering Analysis
Engineer
Engineering Analysis
Construction Documents
Author Construction Documents
Engineer
Design Authoring
Construction Documents
Perform 3D Coordination
Architect
3D Macro Coordination
Construction Documents
Create 4D Model
Contractor
4D Modeling
Construction Documents
Perform Engineering Analysis
Engineer
Engineering Analysis
Operations
Compile Record Model
Contractor
Record Model
End Process
Program Model
Schematic Design
Architectural Model
MEP Model
Structural Model
Schematic Design 3D Macro Coordination Model
Schematic Design 4D Model
Schematic Design Engineering Analysis Model
Design Development
Architectural Model
MEP Model
Structural Model
Design Development 3D Macro Coordination Model
Design Development 4D Model
Design Development Engineering Analysis Model
Construction Documents (WP)
Architectural Model
MEP Model
Structural Model
Construction Documents (WP) 3D Macro Coordination Model
Construction Documents (WP) 4D Model
Construction Documents (WP) Engineering Analysis Model
Construction Documents (WP) 3D Micro Coordination Model
Record Model

APPENDIX F- Crane Specification

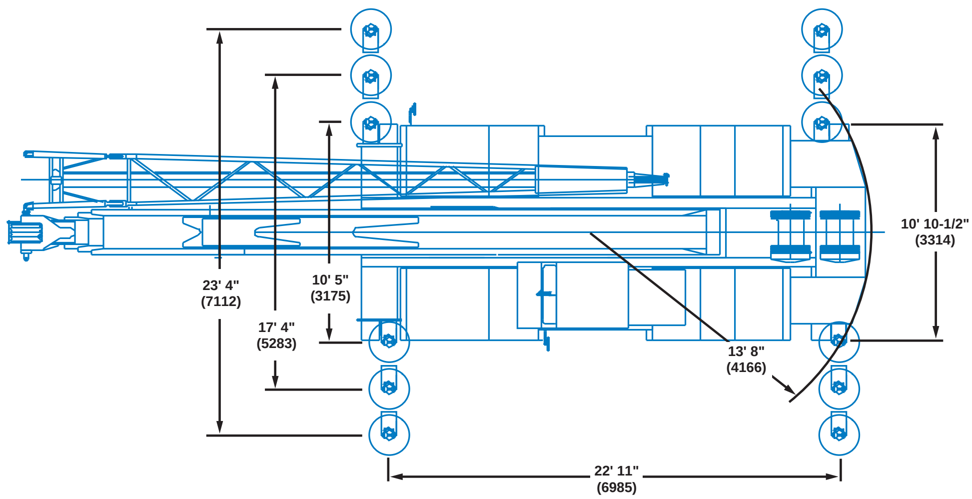
GROVE® CRANE
A GROVE WORLDWIDE COMPANY

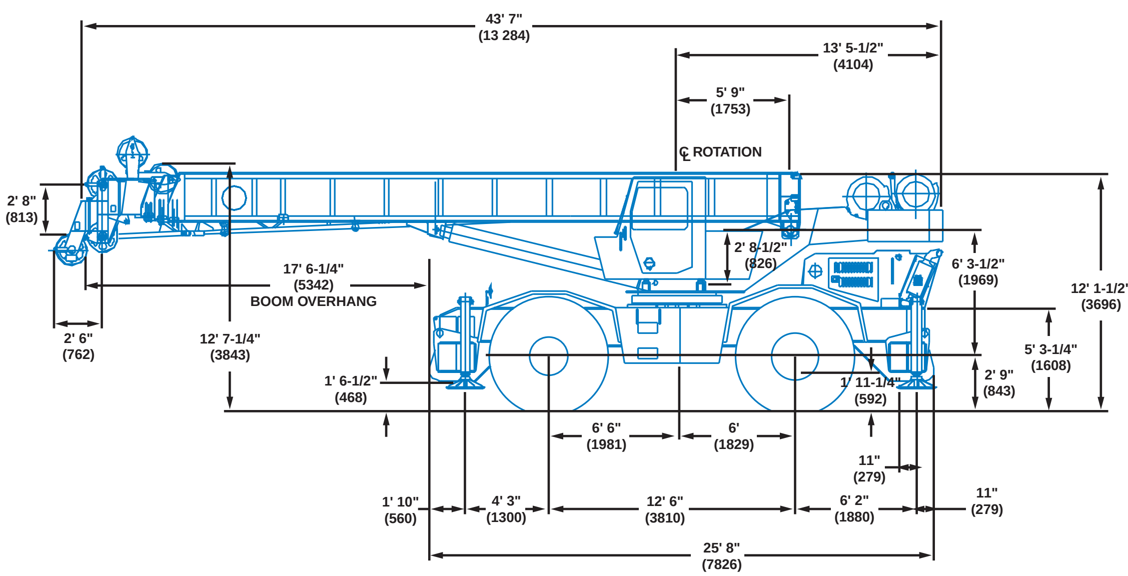
RT750



Rough Terrain Hydraulic Crane

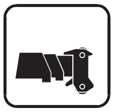
Dimensions



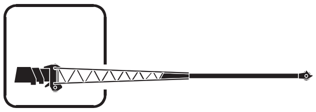


Note: ( ) Reference dimensions in mm

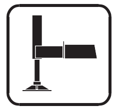
Working Range

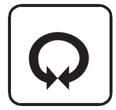


35 - 110 ft.
(10.6 - 33.5 m)

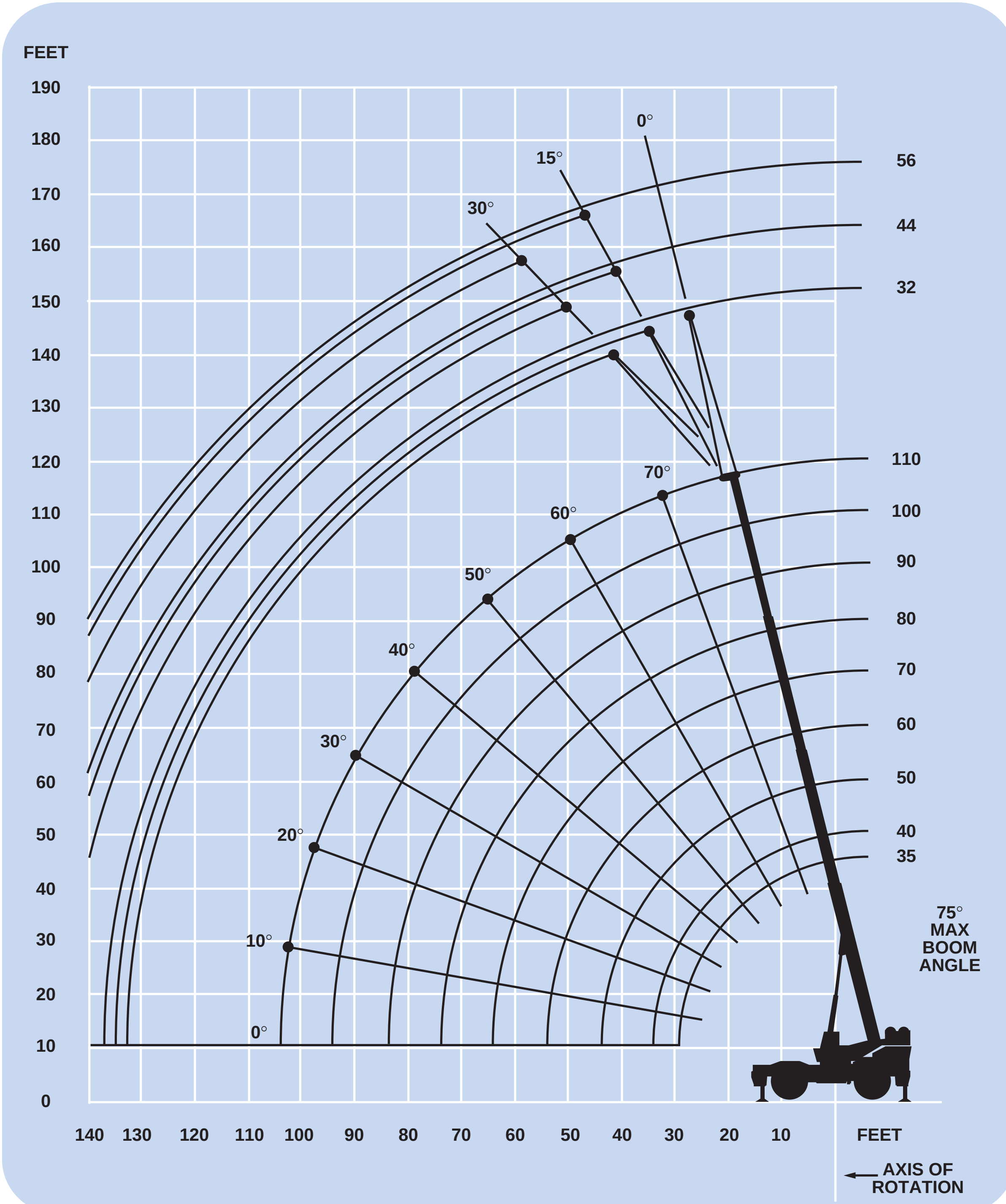


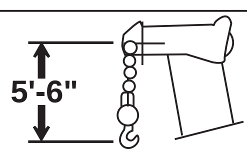
32 - 44 - 56 ft.
(9.8 - 13.4 - 17.1 m)

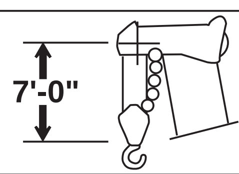




360°







DIMENSIONS ARE FOR LARGEST GROVE FURNISHED HOOK BLOCK AND HEADACHE BALL, WITH ANTI-TWO BLOCK ACTIVATED.

Superstructure specifications

Boom
35 ft. - 110 ft. (10.6 m - 33.5 m) four-section full power boom.
Maximum tip height: 117 ft. (35.6 m).

Lattice Extension
32 ft. (9.8 m) lattice swingaway extension. Offsettable at 0°, 15° or 30°. Stows alongside base boom section.
Maximum tip height: 147 ft. (44.8 m).

*Optional Telescoping Lattice Extension
32 ft. to 44 ft. or 56 ft. (9.8 m to 13.4 m or 17.1 m) telescoping lattice swingaway boom extension offsettable at 0°, 15° or 30°. Stows alongside base boom section.
Maximum tip height: 170 ft. (51.8 m).

Boom Nose
Four steel sheaves mounted on heavy duty tapered roller bearings with removable pin-type rope guards. Quick reeve type boom nose.
*Optional auxiliary boom nose.

Boom Elevation
Dual double acting hydraulic cylinders with integral holding valves provide elevation from -4° to 75°.

Load Moment & Anti-Two Block System
Standard load moment and anti-two block system with audio-visual warning and control lever lock-out. These systems provide electronic display of boom length, boom angle, radius, tip height, relative load moment, maximum permissible load and load indication and warning of impending two-block condition.

Cab
Full vision, all steel fabricated with acoustical lining and tinted safety glass throughout. Complete driving controls and engine instrumentation. Dash mounted control levers for all craning functions. Other standard features include: hinged skylight, sliding left side door and sliding right side window, electric windshield wash-wipe, propane heater, circulating air fan, fire extinguisher, seat belt and two front mounted worklights.

Swing
Ball bearing swing circle with 360° continuous rotation. Planetary glide swing with foot applied multi-disc brake. Spring applied, hydraulically released parking brake, plunger type one position and 360° mechanical house lock, operated from cab.
Maximum speed: 2.6 RPM.

Counterweight
Integral with turntable mast.

With main hoist only:	12,000 lbs. (5443 kg)
With main & aux.:	10,350 lbs. (4695 kg)

Hydraulic System
4 main pumps with a combined capacity of 146 G.P.M. (553 LPM).
Maximum operating pressure: 2,500 PSI (172.4 bar).

Four individual valve banks.

Return line type filter with full flow by-pass protection and service indicator. Replaceable cartridge with micron filtration rating of 15/30/38.

154 gallon (583 L) reservoir.

Remote-mounted oil cooler with thermostatically controlled electric motor driven fan/air to oil.

System pressure test ports with quick release type fittings for each circuit.

HOIST SPECIFICATIONS
Main and Auxiliary Hoist
Planetary reduction with automatic spring applied multi-disc brake. Electronic hoist drum rotation indicator, hoist drum cable followers and wire rope.

	High	Low
Maximum Single Line Pull:	9,280 lbs. (4209 kg)	18,560 lbs. (8419 kg)
Maximum Single Line Speed:	532 FPM (162 m/min)	266 FPM (81 m/min)
Maximum Permissible Line Pull:	12,920 lbs. (5860 kg)	
Rope Diameter:	3/4” (19 mm)	
Rope Length:	500 ft. (152 m)	
Maximum Rope Stowage: (3/4” 18 x 19 Class)	690 ft. (210 m)	

Denotes optional equipment

Carrier specifications

Chassis
Box section frame fabricated from high strength, low alloy steel. Integral outrigger housings and front/rear towing and tie down lugs.

Outrigger System
Four hydraulic telescoping, single stage, double box beam outriggers with inverted jacks and integral holding valves. Three position setting, all steel fabricated, quick release type outrigger floats, 24 in. (610 mm) diameter.
Maximum outrigger pad load: 73,344 lbs. (33 269 kg).

Outrigger Controls
Controls and crane level indicator located in cab.

Engine
Cummins 6BTA 5.9 L diesel, six cylinders, turbocharged and after cooled, 200 bhp (149 kW) (Gross) @ 2,500 RPM.
Maximum torque: 600 ft. lbs. (814 Nm) @ 1,500 RPM.

*Optional Engine
Cat 3116TA diesel, six cylinders, turbocharged and after cooled, 190 bhp (142 kW) (Gross) @ 2,600 RPM.
Maximum torque: 490 ft. lbs. (664 Nm) @ 1,650 RPM.

Fuel Tank Capacity
60 gallons (227 L).

Electrical System
Two 12 V - maintenance free batteries. 12 V starting.

Drive
4 x 4

Steering
Full independent power steering:
Front: Full hydraulic steering wheel controlled.
Rear: Full hydraulic hand lever controlled.
Provides infinite variations of 4 main steering modes: front only, rear only, crab and coordinated. Rear steer indicating gauge.

Transmission
Full powershift with 6 forward and 6 reverse speeds. Rear axle disconnect for 4 x 2 travel.

Axles
Front: Drive/steer with differential and planetary reduction hubs rigid mounted to chassis.
Rear: Drive/steer with differential and planetary reduction hubs pivot mounted to chassis.
*Optional: Cross axle differential lock front and rear.

Oscillation Lockouts
Automatic full hydraulic lockouts on rear axle permit oscillation only with boom centered over the front.
*Optional oscillation lockout override control.

Tires
29.5 x 25-28 PR earthmover type, bias tubeless.

*Optional Tires
29.5R25 radial.

Brakes
Full air split circuit operating on all wheels. Spring-applied, air released parking brake operating on front and rear axles.

Lights
Full lighting package including turn indicators, head and tail lights, brake and hazard warning lights.

Maximum Speed
20.3 mph (32.7 kph).

Gradeability (Theoretical)
128% (Based on 87,500 lbs. [39 690 kg] GVW) 29.5 x 25 tires, pumps disengaged, 110 ft. (33.5 m) boom, plus 32 ft. (9.8 m) swingaway.

Miscellaneous Standard Equipment
Full width steel fenders, dual rear view mirrors, hook block tiedown, electronic back-up alarm, front stowage well, light package, air dryer, 360° mechanical house lock, tachometer/hourmeter, low oil pressure/high water temperature a/v warning system.

*Optional Equipment
* 360° flashing light
* Cab spotlight
* Engine block heater
* Manual skylight wiper
* Hookblocks (quick reeve type)
* Headache ball
* Tow winch (15,000 lbs. [6804 kg] single line pull
* Tire inflation kit
* Tool kit
* Pintle hooks - front and rear
* Diesel heater/defroster
* Hydraulic oil cab heater
* Air conditioner
* LMI light bar

Denotes optional equipment

35 - 110 ft. (10.6 - 33.5 m)	12,000 lbs. (5443 kg)	100%	360°

Pounds

(Feet)	35	40	50	*60	70	80	90	100	110
10	100,000 (63.5)	80,400 (66.5)	74,400 (71.5)	44,600 (75.5)					
12	88,050 (60)	79,050 (63.5)	70,900 (69)	44,600 (74)	@35,600 (75.5)				
15	74,500 (54)	67,450 (59)	63,350 (65.5)	44,600 (71)	35,600 (74)	@33,000 (75.5)			
20	54,700 (43)	53,850 (50.5)	50,900 (59)	44,600 (66)	35,600 (70)	33,000 (72.5)	25,500 (75)	@23,300 (75.5)	
25	41,450 (29)	41,150 (40.5)	40,700 (52.5)	40,350 (60.5)	35,550 (65.5)	33,000 (69)	25,500 (71.5)	23,300 (74)	@18,500 (75.5)
30		32,450 (28)	32,050 (45)	31,750 (55)	30,550 (61)	28,950 (65)	25,500 (68)	23,300 (71)	18,500 (73)
35			25,950 (36.5)	25,650 (48.5)	26,500 (56.5)	24,900 (61)	23,000 (64.5)	21,200 (68)	18,500 (70.5)
40			21,400 (25)	21,150 (41.5)	22,000 (51.5)	21,750 (57)	20,000 (61)	18,450 (65)	18,000 (67.5)
45				17,600 (33.5)	18,500 (46)	19,100 (53)	17,600 (57.5)	16,300 (61.5)	15,750 (65)
50				14,600 (23)	15,250 (39.5)	15,700 (48)	15,650 (53.5)	14,400 (58)	13,950 (62)
55					12,650 (32.5)	13,100 (43)	13,550 (49.5)	12,850 (54.5)	12,450 (59)
60					10,500 (23)	11,000 (37.5)	11,450 (45)	11,550 (51)	11,150 (55.5)
65						9,350 (31)	9,780 (40.5)	10,200 (47)	10,050 (52.5)
70						7,870 (22)	8,370 (35)	8,780 (43)	9,090 (49)
75							7,180 (28.5)	7,590 (38.5)	7,980 (45)
80							6,120 (20)	6,560 (33)	6,950 (41)
85								5,680 (27)	6,060 (37)
90								4,910 (19)	5,280 (32)
95									4,600 (26)
100									3,990 (18.5)
Minimum boom angle (deg.) for indicated length									0
Maximum boom length (ft.) at 0 deg. boom angle (no load)									110

Note: ( ) Boom angles are in degrees.
@ This capacity is based upon maximum boom angle.
* 60 ft. boom length is with inner-mid extended and outer-mid & fly retracted.

Boom Angle	35	40	50	*60	70	80	90	100	110
0°	20,750 (29.2)	16,750 (34.3)	11,300 (44.3)	7,720 (54.1)	5,960 (64.3)	4,680 (74.3)	3,680 (84.3)	2,880 (94.3)	2,240 (104.1)

NOTE: ( ) Reference radii are in feet.

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APPENDIX G- Breath Topics

Structural Breadth- Analysis 1

As a part of the Green Roof System Analysis, a Structural Breadth was performed to ensure safety of the building structural frame and its ability to withstand the additional load of the green roof. The current roof is a composite metal deck over structural steel members. The composite metal deck consists is a 1.5 inches type B 20 gauge galvanized roof deck with a 3.25 inches cover of light weight concrete. The structural component of the roof is covered with 0.5 inch gypsum sheathing, a 4 inches rigid insulation, 0.5 inch gypsum cover bored and a single ply membrane roof system. Table 1 shows the detailed dead and live loads of the Educational Activities Building roof.

The extensive green roof system adds 15 to 25 pounds per square foot, however only the maximum weight will be considered for the analysis of worst case scenario. The rest of the dead loads were obtained from the structural engineer and the live load was found in table 4-1 of the ASCE. To test the structural roof loads a typical bay of the building roof was selected to examine both beams and grinders. Dr. Linda Hanagan's AE 404 class and Dr. Thomas Boothbys AE 308 class provided the background knowledge on how to analyze the building structural system. There are several assumptions that have been made when conducting this structural breadth.

Beams:	38.5' W21x44	**Grinders:**	11' W24x55
5" spacing	44.5' W24x55		31.5' W24x131
0.C.	44.5' W24x62		31.5' W24x162
	44.5' W24x76		37.5' W24x162
	44.5' W24x84		37.5' W24x229
	44.5' W24x117		
	44.5' W24x131		

Assumptions:

- The Beam/Grinder Self-Weight is 5psf
- The Membrane weight will not be used when the green roof is applied.

Beam with a length of 38.5 ft:

- Live Load Reduction: $L = L_O\left(0.25 + \frac{15}{\sqrt{K_{LL}A_t}}\right)$
  - K_{LL} = 2 for beams and A_t = 38.5 ftX5 ft=192.5 ft^2; $K_{LL}A_t$ = 385 $ft^2 \leq$ 400, then no live load reduction

- Factored Distributed Load: W=1.2D_L+1.6L
  - W = (1.2X97) + (1.6X100) =276.4 psf

- $w_u = \frac{W\text{X}5}{1000} = \frac{276.4\text{X}5}{1000}$=1.38 klf

- Factored Bending Moment: $M_u = \frac{w_u l^2}{8}$
  - $M_u = \frac{1.38X38.5^2}{8}$ = 256.06 k-ft

- Factored Shear: $V_u = \frac{w_u l}{2}$
  - $V_u = \frac{1.38X38.5}{2}$ = 25.99 kips

Beam with a length of 44.5 ft:

- Live Load Reduction: $L = L_O\left(0.25 + \frac{15}{\sqrt{K_{LL}A_t}}\right)$
  - K_{LL} = 2 for beams and A_t = 44.5 ftX5 ft=222.5 ft^2; $K_{LL}A_t$ = 445 ft^2≥ 400, then live load reduction is allowed, L_o=100 psf
  - $L = 100\left(0.25 + \frac{15}{\sqrt{445}}\right)$ = 96.11 psf

- Factored Distributed Load: W=1.2D_L+1.6L
  - W = (1.2X97) + (1.6X96.11) =270.18 psf
  - $w_u = \frac{W\text{X}5}{1000} = \frac{270.18\text{X}5}{1000}$=1.35 klf

- Factored Bending Moment: $M_u = \frac{w_u l^2}{8}$
  - $M_u = \frac{1.35X44.5^2}{8}$ = 334.17 k-ft

- Factored Shear: $V_u = \frac{w_u l}{2}$
  - $V_u = \frac{1.35X44.5}{2}$ = 30.04 kips

Grinder with a length of 11 ft:

- Live Load Reduction: $L = L_O\left(0.25 + \frac{15}{\sqrt{K_{LL}A_t}}\right)$
  - K_{LL} = 2 for grinder and A_t = 22.25 ftX11 ft= 244.75 ft^2; $K_{LL}A_t$ = 489.5 ft^2≥ 400, then live load reduction is allowed, L_o=100 psf
  - $L = 100\left(0.25 + \frac{15}{\sqrt{489.5}}\right)$ = 92.79 psf

- Factored Distributed Load: W=1.2D_L+1.6L
  - W = (1.2X97) + (1.6X92.79) =264.86 psf

- Beam Point Load: $P_L = \frac{W\ x\ Tributary\ Width\ x\ Tributary\ Width}{1000}$
  - $P_L = \frac{264.86\ x\ 5\ x\ 22.25}{1000}$ = 29.47 k

- Uniformly Distributed Load: $w_u = \frac{P_L \text{X Point Loads}}{Length}$
  - $w_u = \frac{29.47\text{X } 1}{11}$ = 2.68 klf
- Factored Shear: $V_u = \frac{W_u x\ l}{2}$
  - $V_u = \frac{2.68x\ 11}{2}$ =14.74 kips
- Factored Bending Moment: $M_u = \frac{w_u l^2}{8}$
  - $M_u = \frac{2.68\ x\ 11^2}{8}$ = 40.53 k-ft

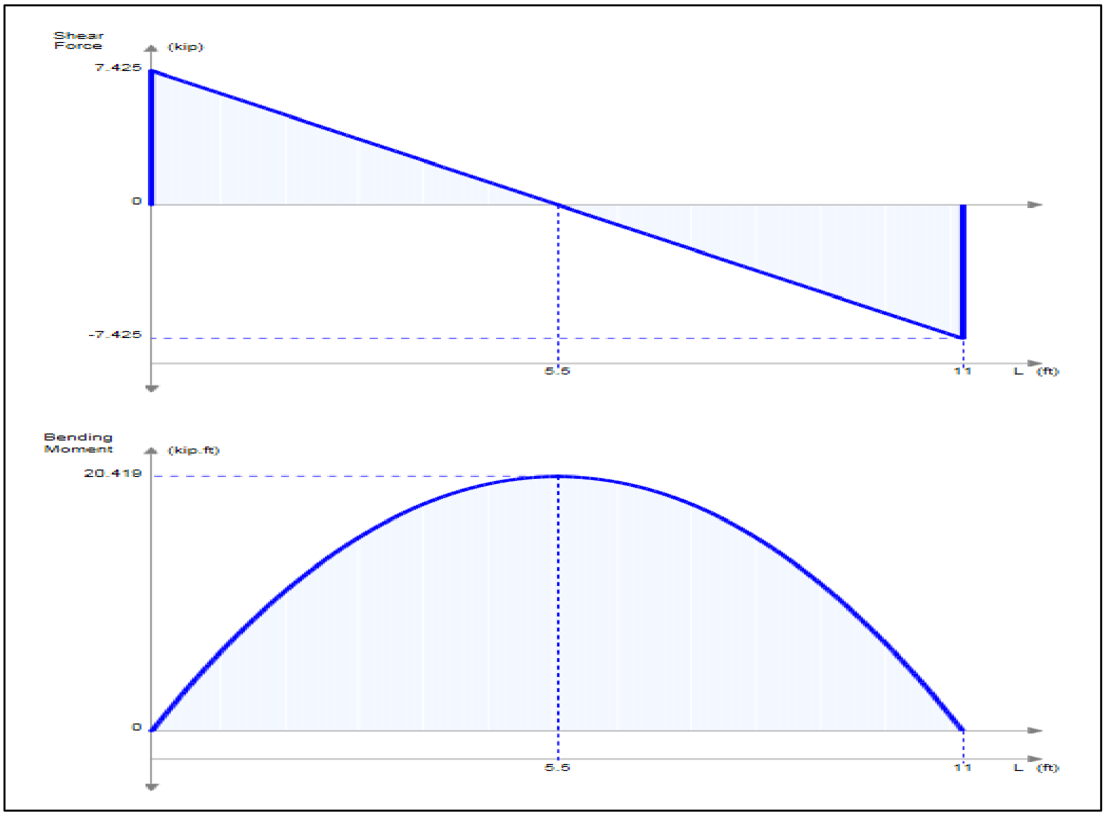


Figure 53 the shear force and bending moment diagram of the 11' Grinder, courtesy of bendingmomentdiagram.com

Grinder with a length of 31.5 ft:

- Live Load Reduction: $L = L_O\left(0.25 + \frac{15}{\sqrt{K_{LL}A_t}}\right)$
  - K_{LL} = 2 for grinder and A_t = 44.5 ftX31.5 ft= 1,401.75 ft^2; $K_{LL}A_t$ = 2,803.5 ft^2≥ 400, then live load reduction is allowed, L_o=100 psf
  - $L = 100\left(0.25 + \frac{15}{\sqrt{2{,}803.5}}\right)$ = 53.3 psf

- Factored Distributed Load: W=1.2D$_L$+1.6L
  - W = (1.2X97) + (1.6X53.3) =201.68 psf

- Beam Point Load: $P_L = \frac{W\ x\ Tributary\ Width\ x\ Tributary\ Width}{1000}$
  - $P_L = \frac{201.68\ x\ 5\ x\ 22.25}{1000}$ = 22.44 k

- Uniformly Distributed Load: $w_u = \frac{P_L \text{X Point Loads}}{Length}$
  - $w_u = \frac{22.44 \text{ X } 5}{31.5}$ = 3.56 klf
- Factored Shear: $V_u = \frac{W_u x\ l}{2}$
  - $V_u = \frac{3.56x\ 31.5}{2}$ = 56.07 kips

- Factored Bending Moment: $M_u = \frac{w_u l^2}{8}$
  - $M_u = \frac{3.56\ x\ 31.5^2}{8}$ = 441.55 k-ft

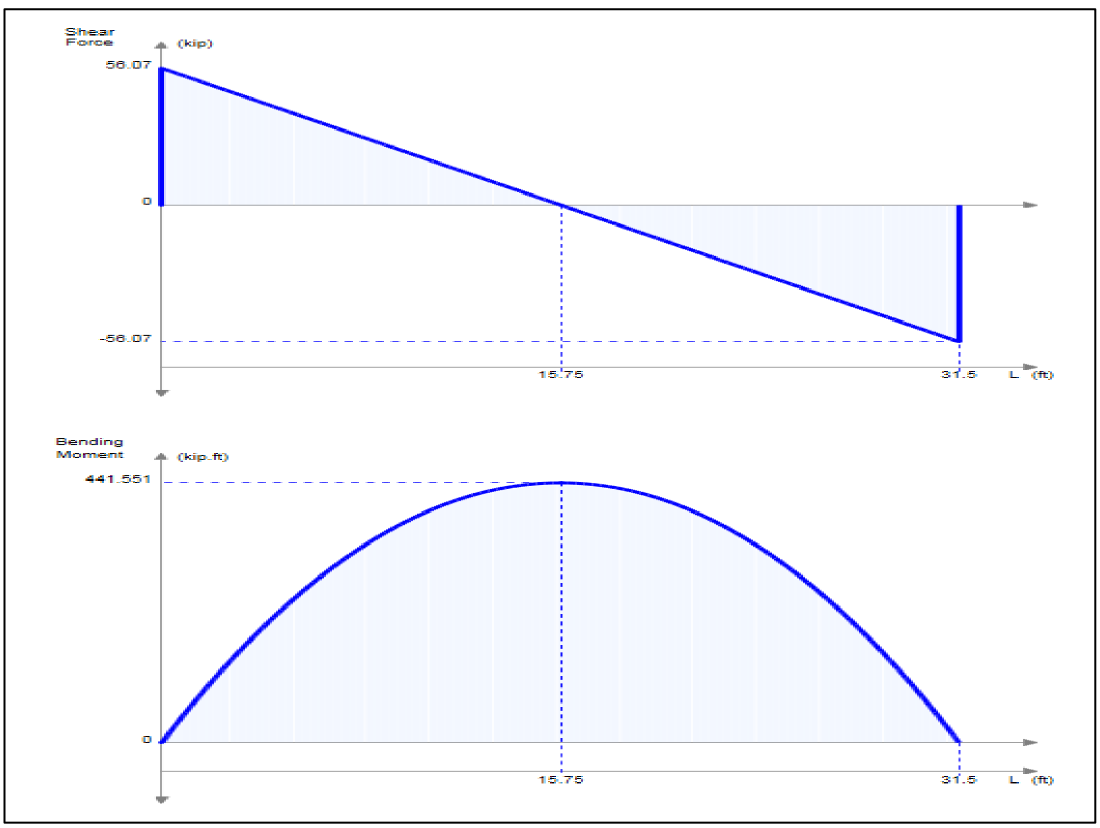


Figure 54 the shear force and bending moment diagram of the 31.5' Grinder, courtesy of bendingmomentdiagram.com

Grinder with a length of 37.5 ft:

- Live Load Reduction: $L = L_O\left(0.25 + \frac{15}{\sqrt{K_{LL}A_t}}\right)$

- K_{LL} = 2 for grinder and A_t = 44.5 ftX37.5 ft= 1,668.75 ft^2; $K_{LL}A_t$ = 3,337.5 ft^2≥ 400, then live load reduction is allowed, L_o=100 psf
- $L = 100\left(0.25 + \frac{15}{\sqrt{3{,}337.5}}\right)$ = 50.9 psf

❖ Factored Distributed Load: W=1.2D_L+1.6L
- W = (1.2X97) + (1.6X50.9) =197.84 psf

❖ Beam Point Load: $P_L = \frac{W\ x\ Tributary\ Width\ x\ Tributary\ Width}{1000}$
- $P_L = \frac{197.84\ x\ 5\ x\ 22.25}{1000}$ = 22.01 k

❖ Uniformly Distributed Load: $w_u = \frac{P_L \text{X Point Loads}}{Length}$
- $w_u = \frac{22.01 \text{ X } 7}{37.5}$ = 4.11 klf

❖ Factored Shear: $V_u = \frac{W_u x\ l}{2}$
- $V_u = \frac{4.11\ x\ 37.5}{2}$ = 77.06 kips
-

❖ Factored Bending Moment: $M_u = \frac{w_u l^2}{8}$
- $M_u = \frac{4.11\ x\ 37.5^2}{8}$ = 722.46 k-ft

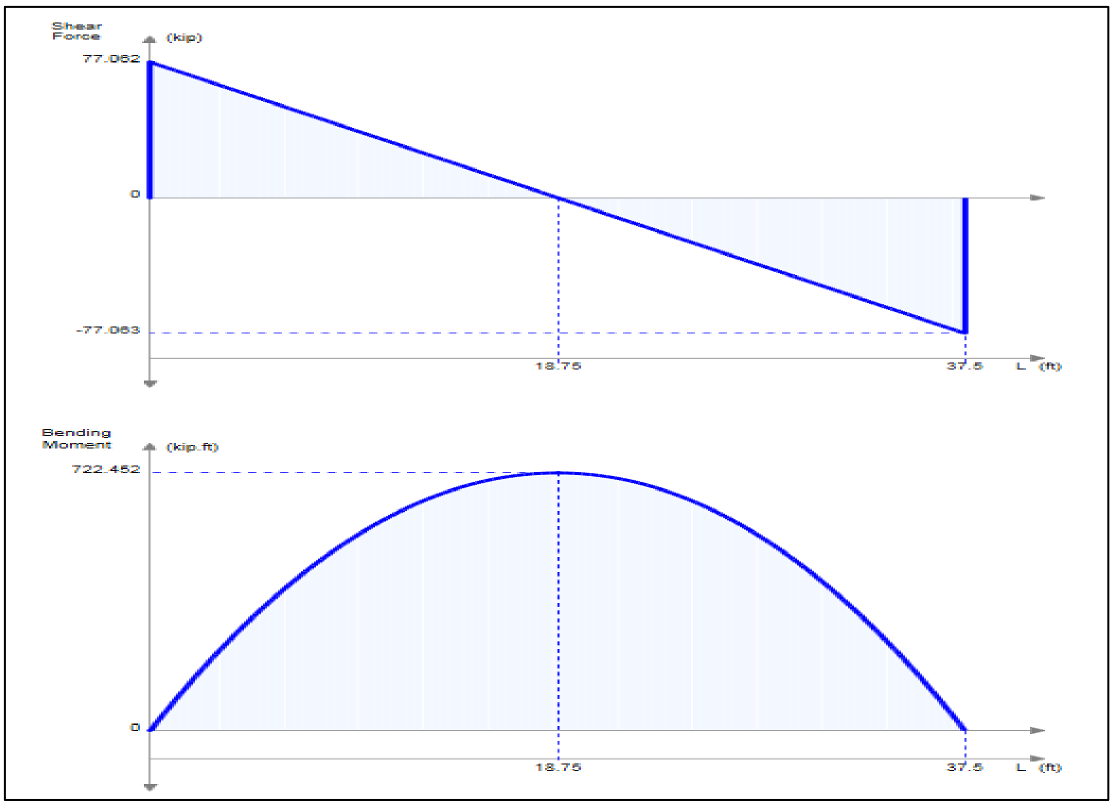


Figure 55 the shear force and bending moment diagram of the 37.5' Grinder, courtesy of bendingmomentdiagram.com

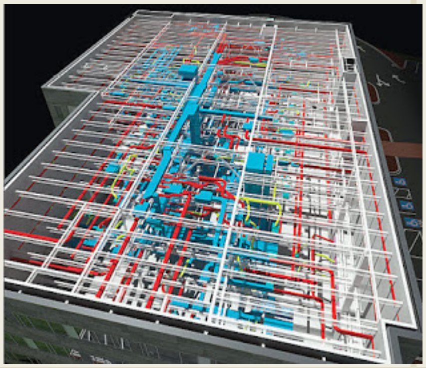
The maximum allowable strength of the beams and grinders can be found from ASCE Flexural Design tables. The shear and bending moments values found in the calculations above will be compared to these values from the ASCE Tables. If the calculated value doesn't exceeds the given maximum values then the members can withstand the additional weight of the green roof system. The following tables show these results for the beams and grinders.

Beams	Moment (k-ft)	Max. Moment (k-ft)	Shear (Kips)	Max. Shear (Kips)	Result
W21x44	256.06	**358**	25.99	**217**	Passing
W24x55	334.17	**503**	30.04	**252**	Passing
W24x62	334.17	**574**	30.04	**306**	Passing
W24x76	334.17	**750**	30.04	**315**	Passing
W24x84	334.17	**840**	30.04	**340**	Passing
W24x117	334.17	**1230**	30.04	**400**	Passing
W24x131	334.17	**1390**	30.04	**444**	Passing

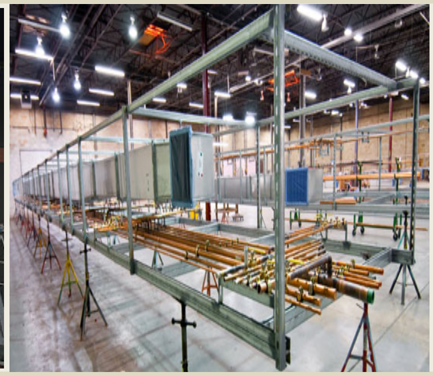
Grinder	Moment (k-ft)	Max. Moment (k-ft)	Shear (Kips)	Max. Shear (Kips)	Result
W24x55	40.53	**503**	14.74	**252**	Passing
W24x131	441.55	**1390**	56.07	**444**	Passing
W24x162 (31.5 ft)	441.55	**1760**	56.07	**529**	Passing
W24x162 (37.5 ft)	722.46	**1760**	77.06	**529**	Passing
W24x229	722.46	**2530**	77.06	**749**	Passing

As seen from the above table each member is capable of supporting the additional weight for the new green roof system. Therefore the current structural roof system does not require any changes in design.

Mechanical Breadth- Analysis 2



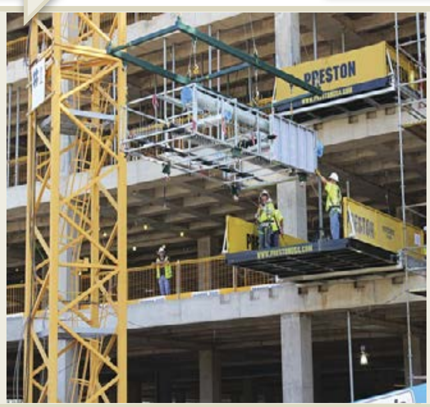
BIM is utilized to create a 3D Model of the MEP system components



The MEP system compenets are assembled in a prefabrication shop with a controlled environmnet

The MEP system compenets are dilevered to the site.

Workers are doing the final steps of the installation process



Manpower is used to assist the placing process

Different euipement are used to place the MEP system compenets to their final location

The BIM 3D model and the actual final product

Figure 56 the coordination between the different trades, Images courtesy of www.CIF.org

For the Mechanical Breadth, “Coordination with other trades” topic was chosen from the Mechanical Breadth Analysis provided by Professor Moses Ling. The process first starts with the information received from the MEP system designers so a 3D Model can be created. When the prefabricated parts are determined, the prefabrication shop will be notified to start the building process in a workshop of site.

As mentioned above, some parts of the MEP systems will be prefabricated off site. However, there are several steps that need to be completed before the delivery of the prefabricated MEP systems. For each area of the building, as soon as the composite metal deck is in place the steel hangers and clips should be installed as shown in figure 57.

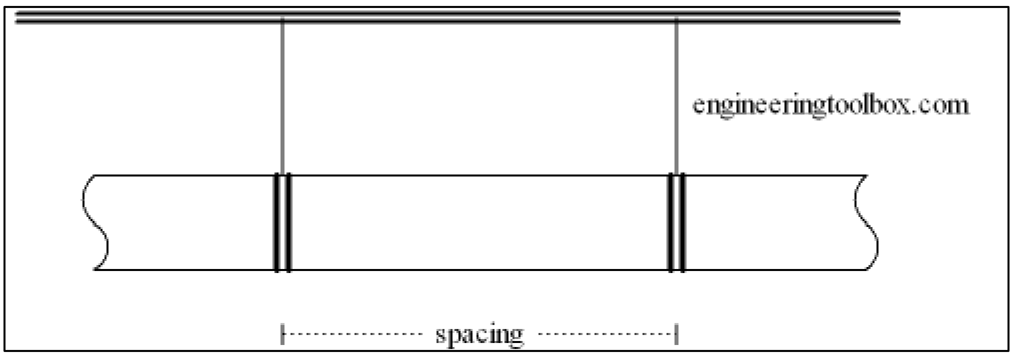


Figure 57 the steel hangers for the MEP system, Image courtesy of www.engineeringtoolbox.com

When the prefabricated MEP system is delivered to the construction site from the workshop man power and crane will be used to place the components to its final location. As mentioned before there will be few openings in the building exterior to assist the placing process. One of the main benefits of this method is to eliminate the need of skilled labor, so the sole purpose of the workers used for this task is installation and that will eliminate the congestion on site. The workers with the help of a construction hoist [figure 58], will let the parts to the right height so they can be attached to the steel hangers. Finally, the 3D Model used in the beginning can be utilized for easy access and plan future maintenance schedule of the MEP system.

Figure 58 an example of construction hoist used to lift the MEP system parts to the ceiling. Image courtesy of www.indiamart.com