Senior Thesis Final Report

Research and Technology Applications for Phased Renovations in Construction

Submitted 4/7/2011

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Construction Management
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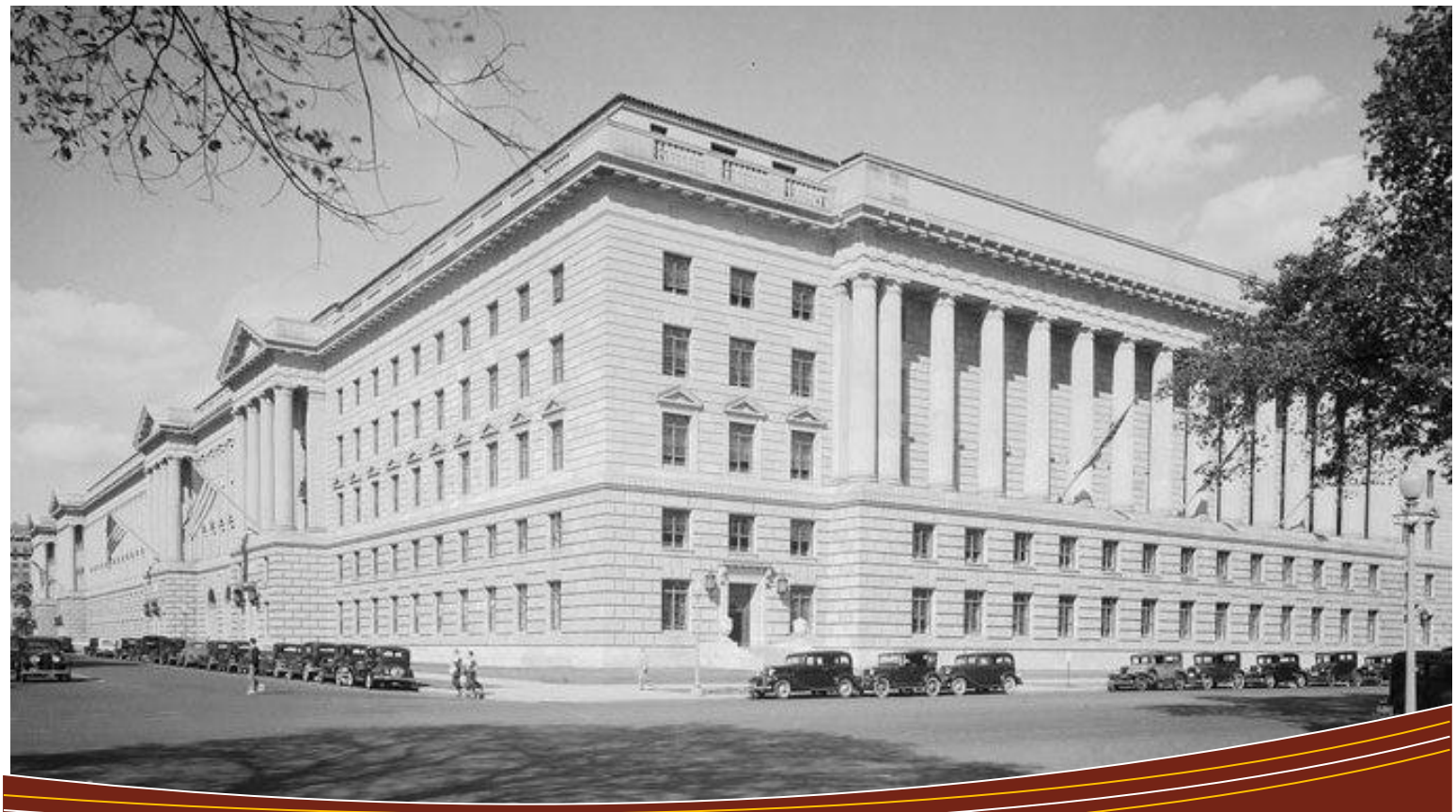


[The following report presents a total of three in depth architectural engineering analyses. A General Services Administration building was utilized as the case study to research and apply concepts used in the architectural, engineering, and construction industry. The analyses presented cover the topics of schedule acceleration with the use of prefabricated materials, photovoltaic feasibility applications, and the further utilization of building information modeling technologies.]

Office Renovation Building

Northeast, United States

ARCHITECTURE

- Bearing the similarities of its neighbors, the 1930s structure displays a prominent reference to the neoclassical architectural style
- The building façade is constructed of Indiana limestone to help solidify its Greek revival design that is often affiliated with civic structures within the United States
- The renovation project will refurbish the building's façade and other architectural details to restore the historic building to its original state

MEP SYSTEMS

Phase II of construction includes a complete upgrade of MEP services:

- A major component of the project includes a 2 story Electrical Equipment Enclosure designated to house the building's new emergency generators, transformers and switchgear
- Upgrade from shell and tube heat exchangers to the utilization of a water source heat transfer system.

STRUCTURAL

- The existing structural system is composed of steel columns, girders, beams, and columns encased in concrete. This was common practice before modern applications of fireproofing material.
- The interior walls and utilizes dense terra cotta blocking, another common practice for its time of construction

PROJECT TEAM

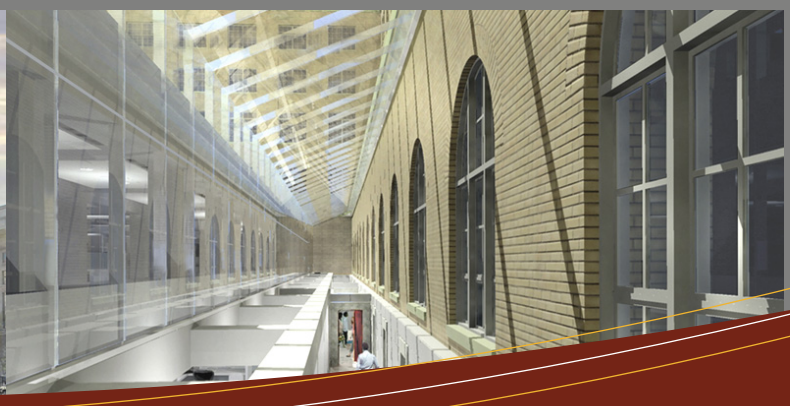
Owner:	General Services Administration
Architect:	Group Goetz Architects
Construction Manager:	Jacobs Engineering
General Contractor:	Grunley Construction Gilbane Building Company
Structural Engineer:	Thornton Tomasetti, Inc.
MEP Engineer:	URS Corporation

PROJECT INFORMATION

Function:	Office Building
Project Cost:	$115 Million
Total Stories	9 (Including Basement)
Size:	64,000 SF (Phase II)
Construction Dates:	11/15/09-11/15/11 (24 Months)
Delivery Method:	Design-Bid-Build with CM Agency

CONSTRUCTION LOGISTICS

- The Office Renovation Building project is an 8 phase process set to include the demolition, renovation, and new construction of building components
- Phase II is primarily comprised of the building's exterior refurbishment in addition to the construction of the structure's new Electrical Equipment Enclosure



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Architectural Engineering | Construction Management

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2.0 Executive Summary

The following Senior Thesis Final report presents the findings and final recommendations of three in depth analyses performed on the Office Renovation Building project. The report will focus on the second renovation phase of the 1.8 million square foot facility. Phase 2 includes approximately 260,000 SF of renovated office space in addition to a newly constructed 20,000 SF electrical equipment enclosure. These research topics are intended to improve the quality of the project while increasing the efficiency of the construction team's efforts. The analyses will cover a variety of industry issues including: Building Information Modeling and technologies, prefabricated design, and renewable energy.

Analysis 1: Schedule Acceleration through Prefabrication

The current phase of the Office Renovation Building involves the construction of an electrical equipment enclosure to be erected within one of the building's interior courtyards. The activities associated with the 20,000 SF facility contribute to increased cost and schedule delays. This analysis proposed a prefabricated hollow core plank floor system to accelerate the project's structural schedule. Results of this application include a total savings of $98,000 while reducing the schedule by 25 working days.

Analysis 2: Feasibility and Design Study for Photovoltaic Energy System

The General Services Administration is making major commitments to transition into sustainable building. The Office Renovation Building is currently listed to receive LEED® Gold Status but does not present any initiatives to create on-site renewable energy. This analysis incorporates a photovoltaic energy system than will help power the facility's electrical equipment enclosure. Results show that the investment will present a payback period of approximately 8 years.

Analysis 3: BIM Execution and Utilization/Phase Planning

The Gilbane Grunley Joint Venture team currently utilized a 3D Revit Model for the renovation project. However, the model is used only for visual presentation to the owner. Aside from 3D coordination, there are no substantial BIM efforts for the project. This analysis develops a project specific BIM execution guide to further utilize the existing 3D Model. The results of this segment demonstrate how integrating facility management software with the 3D Revit Model can drastically facilitate move management and phase planning will be presented.

3.0 Acknowledgements

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Dr. David Riley

Dr. John Messner

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Mark Taylor, President *Nitterhouse Concrete Products*

Gerad Johnson, *FM Systems*

Andy Mackey, Eric Fedder, and Matthew Dabrowski, *AE Alumni*

Denise Zervas, *General Services Administration*

Table of Contents

4.0 Project Overview

4.1 Project Introduction

The Office Renovation Building is one of the largest civil buildings owned by the General Services variety of government agencies. Located in a downtown metropolitan area in the northeastern part of the United States, the $500 million project is scheduled for completion in multiple phases during the next 13 years. While over 3,500 workers continue to occupy the historic building, the project will use a swing space completed in phase 1 of its construction to move employees out of the construction zones. Gilbane Buildng Company and Grunley Construction have formed a joint venture to act as the project's general contractor for phases 1, 2, and 3.

The seven story Indiana limestone façade and granite base structure will be undergo a major modernization to upgrade all major building systems. Once complete, the building will sport new fire and life-safety systems, enhanced perimeter security, and high-efficiency electrical and HVAC systems. A major focus of the project is to achieve LEED silver certification for the Office Renovation Building. This accreditation will be attained primarily through energy efficient systems and the re-use and recycling of existing materials.

Figure 1: Sectioned rendering of phase 2 work including the building's Electrical Equipment Enclosure

4.2 Building Location and Existing Conditions

The Office Renovation Building is located in the downtown historical business district of a northeastern metropolitan area. The specific location of this project may not be disclosed due to owner restrictions. Due to the building's urban setting, the construction site of the project is confined within the structure's perimeter.

Because of the high pedestrian traffic surrounding the facility, public safety is a primary concern for the project's logistics planning and site management. To ensure the safety of the area's pedestrians, the construction zone will be enclosed within appropriate construction fencing as needed. Also, because Phase 2 is comprised of the building's exterior restoration; temporary fencing and overhead protection will be present wherever work is being put in place.

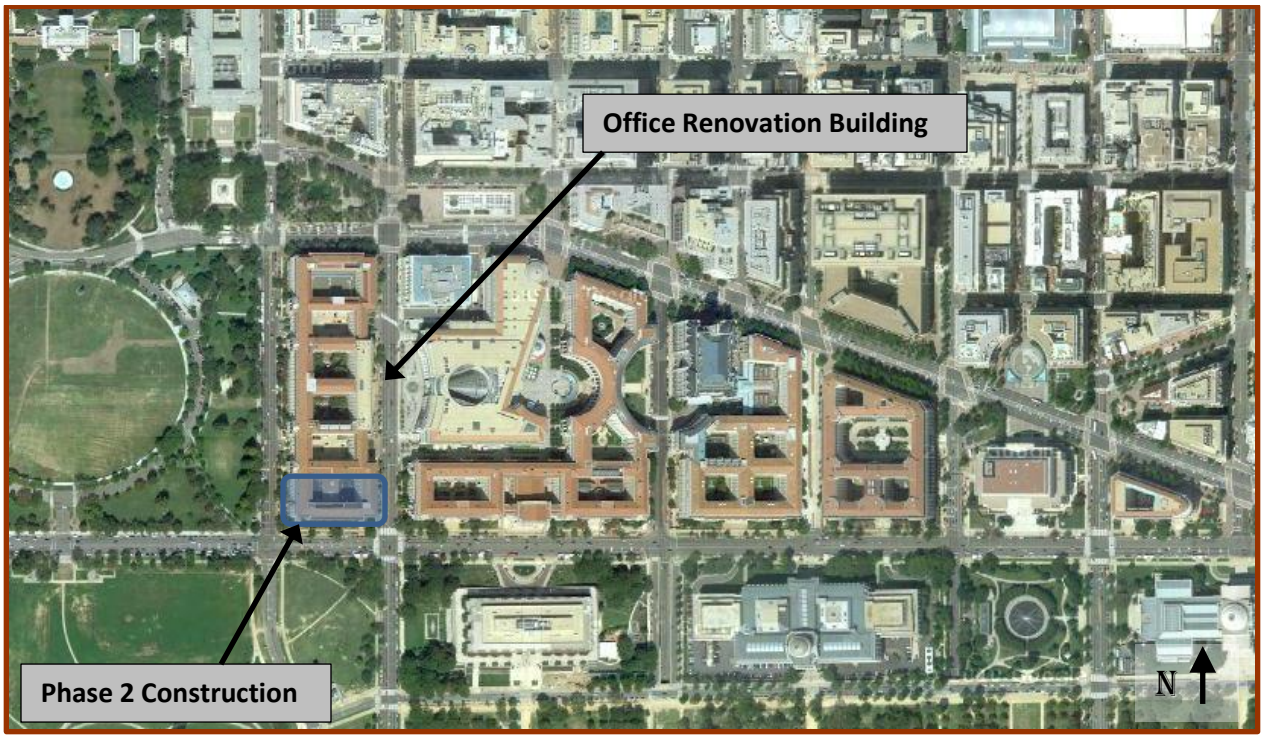


Figure 2: Aerial map of the Office Renovation Building and adjacent structures courtesy of Google Maps

Underground utilities are present all throughout the building's perimeter; fortunately, the project's scope is limited towards the replacement of the facility's electrical ductbank that runs along the eastern side of the building. During the excavation and replacement of this ductbank, Gilbane-Grunley will close the 14th Street sidewalk in phases to allow occupant foot traffic to be redirected towards the other side of the street. For a further, more in depth analysis of the project's existing conditions please reference the site plans listed within **Appendix A: Overall Site Plan and Existing Conditions**.

Local Conditions

The site conditions and preferred construction methods are typical in comparison to the Office Renovation Building's metropolitan area. The specific location of the building is restricted at the request of the owner. The area is commonly known for reinforced concrete structural systems for low to mid-rise buildings. However, similar to other structures of its time of construction and location, the Office Renovation Building utilizes a steel structural frame encased in cast-in-place concrete. The time of the building's original construction took place prior to today's practice of reinforced concrete and modern day fireproofing systems.

Due to the high density area of which the Office Renovation Building resides, parking availability for construction vehicles is very limited. Project superintendents have acquired minimal parking within one of the building's courtyards. The majority of any on-site parking is reserved for pre-designated building occupants. However, the lower level loading dock under courtyard 5 may be used to park other small construction vehicles only on a day-to-day basis. As per the contract agreement, there is no parking for subcontractors. Fortunately, many workers utilize the metro rail system located within a city block of

the building's location. Delivery trucks and other large construction vehicles may only use the west side of the building's designated loading area adjacent to the material hoist; a detail of the staging area can be seen in figure 8 on page 17. (Please refer to Figure A-2 in Appendix A for further detail).

For the metropolitan area, Gilbane-Grunley expenses a standard material dumpster each for $650. Complying with the project's efforts to attain LEED certification, the storage and collection of recyclables is a highly tracked process. The project delivers and loads the appropriate dumpsters through the courtyard 2 15th Street loading dock; all materials are taken to this area via a designated service elevator within the building.

The subsurface investigations natural soils weathered from bedrock and uncontrolled soil and rock fill. The subsurface explorations identified several ground water conditions close to the bedrock surface. Because the renovation project does not include any structural foundation work, limited detailed information on occurring subsurface condition is available

4.3 Client Information

The General Services Administration is the acting owner on the project. The government organization has taken the initiative to undergo construction for the Office Renovation Building largely in fact that the building's systems are very out of date and inefficient. The Office Renovation Building is the last GSA owned building within the area to undergo a systems and exterior renovation. Also, the Office Building Renovation project is partially funded by the American Reinvestment and Recovery act; a movement established in 2009 to help stimulate the economy during the nation's present day financial downturn.

It is important to understand that though the General Services Administration is the owner of the project, they are not the primary client for the structure's renovation. The Office Renovation Building is home to several federal departments of which will not be listed at the request of the owner. However, it can be noted that the primary clients are typical to that of any office building. Additionally, the project's cliental consists of those associated with tourism within the National Aquarium and the Whitehouse Visitor Center.

The project clients have specifically expressed their greatest concerns and expectations for the building's renovation. Fortunately, this is of great benefit to the Gilbane-Grunley team to help minimize any negative impacts toward the client during construction. Considering that the building is to remain occupied throughout the project's duration, the client is primarily concerned with any distractions that may hinder the productivity of its employees; this includes any fumes, noises, and vibrations during construction. Furthermore, the owner and its affiliates fear that issues may arise in regards to the abatement of any asbestos containing materials. With this, it is crucial to consider the health and safety of the building's occupants and workers as a major priority. Finally, a particular department within the building is concerned about the loss of its premium parking spaces located within the courtyards of the building.

As the general contractor, Gilbane-Grunley has taken a deliberate initiative to insure that the client's concerns are tended to while having minimal impact on the building's occupants. The GGJV team has elaborated on proactive planning and early communication with the owner and the project clients so that they may be fully aware of any impacts during construction. A HAZMAT notification initiative has also been implemented to let the building occupants know if any work is being done relative to their location. Communication has been an essential step in regards to reassuring the client that Gilbane-Grunley is continuously working to meet the owner's expectation for the project.

As previously stated, the Office Building Renovation is designated to remain occupied throughout its construction. Being that the structure houses more than 4,000 employees, it is important that the phased sequencing of construction is successfully implemented. Please refer to Appendix B: Phase Sequencing for a brief overview has to how the progress of the Office Building Renovation will move to have minimal impact on the building's occupants.

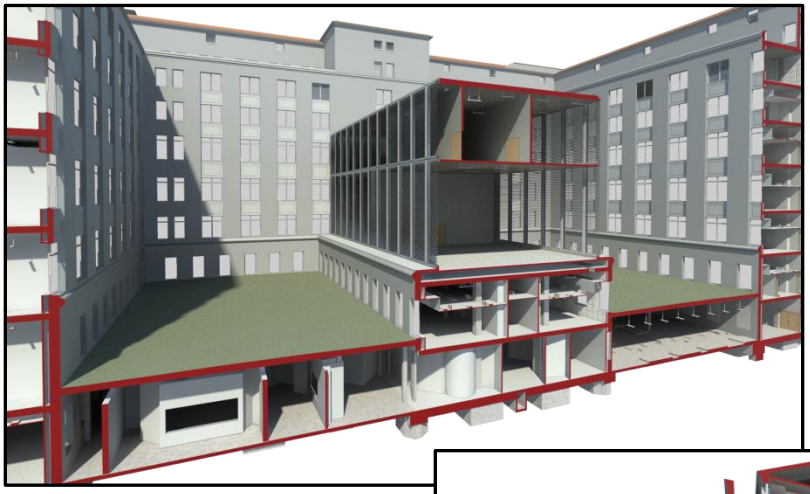


Figure 3: East West Section of the Phase 2 construction work planned for the ORB. the EEE is centered in the image

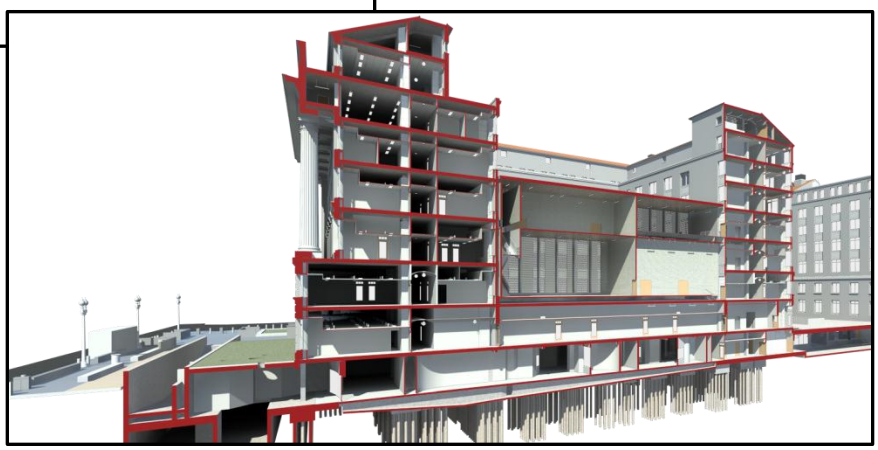
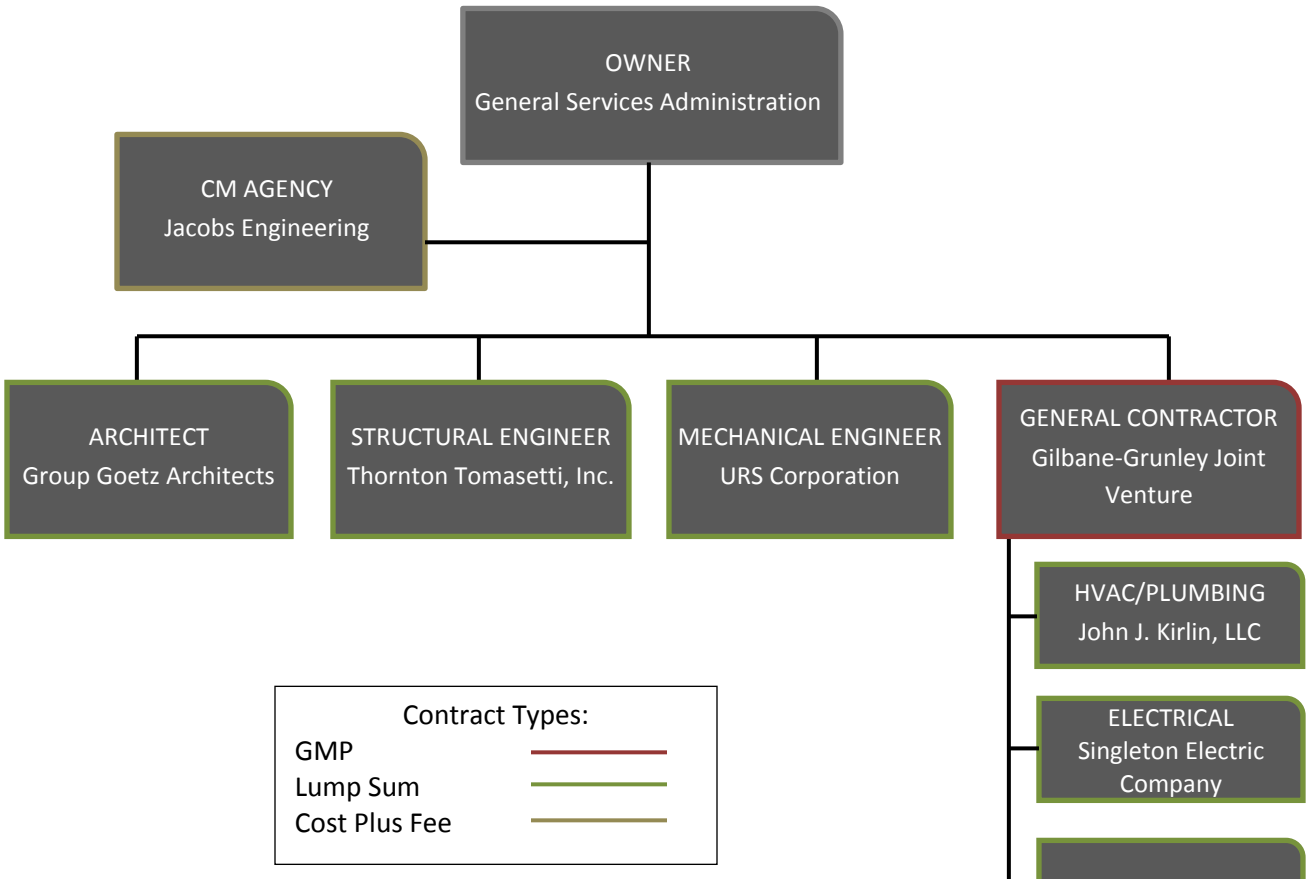


Figure 4 North/South Section of the Phase 2 construction area. The EEE is the smaller structure located within the courtyard

4.4 Project Delivery System



Project Organizational Chart
Contact Information is not listed at the request of the owner

The Office Building Renovation Project utilizes a **Design-Bid-Build with CM Agency** delivery system. The owner has selected to hire a CM Agency due to the project's size, complexity, and duration. The Design-Bid-Build delivery method is a direct result of the project's design being completed far earlier than construction had begun. Due to its federal association, the project was forced to wait until funding became readily available. Fortunately, the building's design was able to benefit from the early contributions of Jacobs Engineering in addition to the Structural and MEP engineering firms. The Office Building Renovation Project is funded largely due to the American Recovery and Reinvestment Act.

Shortly after the building's design was completed, Gilbane-Grunley Joint Venture was awarded the project due to its 'Best Value' bid and past experiences with federal building renovations within the area. Largely in result to the Joint Venture approach, GGJV's large bonding capacity has allowed the company to carry Builders Risk, General Liability, and Worker's Compensation Insurance per Federal Law for the project.

4.5 Gilbane-Grunley Staffing Plan

GGJV Staffing Plan
Gilbane: Red, Grunley: Gray

Figure 5: GGJV Logo

The Gilbane-Grunley Joint Venture team has been specifically created for the sole purpose of the Office Building Renovation project. Both Gilbane Building Company and Grunley Construction have come together for this project in an effort to effectively exchange their backgrounds and expertise to deliver a final product that will meet the client's needs. In addition to the complexity of the renovation, a major reason for such a particularly large project team is to assure that individuals that are well experienced with the project's conditions remain on the job. This is done in an effort to secure involvement in the project's future phases as well as streamlining the construction process of work to come.

All of the project members shown in the organizational chart are fully dedicated to the project while always being on-site. This is done to better facilitate the communication between all the active parties associated with the project. The management staff, particularly the project executive, benefit from the constant on-site interaction between the building's owner and the construction management agency representatives. The entire project staff is housed in a temporary office within a fully occupied and functional portion of the facility.

While each member of the management team carries their own responsibilities specific to the project, the field staff also benefits from their size and specialties. Each superintendent on the project has their own particular focus, ranging from exterior work to sprinkler installment, this is done to help facilitate the progression of the project's construction. For example, one superintendent can be fully dedicated to the site's exterior and utility work while another concentrates on the close out and punch list for a particular area within the facility.

The Gilbane-Grunley Joint Venture benefits from its resourceful project team as it is able to deliver a better quality project more effectively and efficiently.

5.0 Building Design and Construction Overview

5.1 Building Systems

Demolition

Considering that the Office Renovation Building project is mostly comprised of renovation work, demolition is the first major step of the structure's modernization. With the building's first major renovation since its original completion, much of the demolition work will be comprised of the abatement of all asbestos containing materials.

Gilbane-Grunley has organized a top-down sequencing schedule for the Phase 2 demolition of interior spaces. Crews will begin on the project's seventh floor proceeding with the removal of any furniture and asbestos free materials. The abatement subcontractor will follow with their scope of work as soon as each floor is cleared accordingly. Because of the size of the phase 2 space and the amount of asbestos containing materials present throughout the structure, abatement crews will be working both day and night shifts. A heavy emphasis has been placed on night abatement to pose minimal impact on any other work that may be put in place. Interior abatement has already begun and will not conclude until October of 2011, a month prior to the project's scheduled completion.

The restoration of all exterior windows also portrays a major process within the demolition of the project. The windows have not been renovated since the building's construction in 1932 and most of which are no longer operable. All 5,700 windows are historically designated and covered in lead paint. At the building's exterior, crews will strip each window and repaint them to match their initial state. Within the interior of the building, Gilbane-Grunley has scheduled to dismantle and reinstall each counter-weight system to make the windows operable as originally designed.

Other work within phase 2 includes the demolition of the courtyard 1 roof and existing chiller plant located in the building's courtyard 1 basement.

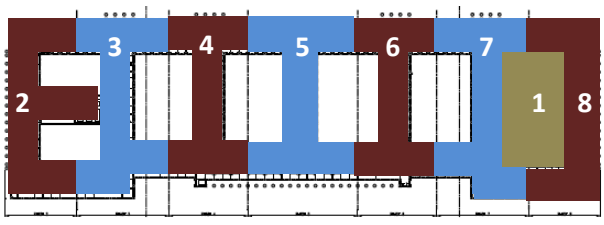


Figure 6: Office Renovation Building Phase Breakdown

Electrical and Lighting

The building electric service is primarily 208V and is supplied through various transformers and switchgear that have been modified over the years. Most of the electrical work is comprised within the construction of the structure's new Electrical Equipment Enclosure. Four (4) 13.8 KV feeders from PEPco Power, an electric and natural gas utility subsidiary of The Exelon Corporation, will be provided will to (4) Medium Voltage (MV) switchgear. Also, MV power will be distributed to (4) transformer vaults. One transformer vault will be dedicated to the new courtyard 1 chiller plant and the remaining (3) vaults will provide building power. The entire electrical system will be backed up by three (3) emergency generators each rated at 2000Kw.

A key element to the project scope strictly defines that there is to be no interruption of the electric services to facilities occupied by the Government or others unless permitted. This is due to the sensitive nature of government work taking place within the building during construction. Gilbane-Grunley has been sure to take every precautionary measure in regards to the project's electrical work and will support the temporary feeding within the existing building electric service. PEPCO Power is the main provider of electrical energy for the Office Renovation Building.

The new lighting fixtures to be installed throughout the Office Renovation Building Primarily consist of generic Office and Corridor lighting design. Most offices will present high efficient Ledalite (Purefx) T5 recessed fluorescent lights with die-formed, 22 gauge cold-rolled steel housing, flat acrylic panels and extruded curved acrylic lenses with electric ballasts. Most corridors will utilize Hubbel compact fluorescent vapolet luminaries with glass globes. Also, a number of fixtures within the building's first floor lobbies are historic; they are to be restored to their original state operating at the discretion of the lighting engineer and architect.

Mechanical

The Herbert Hoover Building was built in the late 1920s. The building is heated by means of steam radiators along the perimeter of the building combined with a dual duct HVAC system. The steam is supplied from a central steam plant that feeds multiple buildings throughout the District of Columbia. Chilled water for cooling is supplied from an onsite chiller plant.

The Office Renovation Building project includes a complete upgrade of MEP systems during phase 2 of construction. New open-circuit, induced draft, cross flow cooling towers were in installed above the eighth floor penthouse adjacent to courtyard 5 in phase 1.

During phase 2, Gilbane-Grunley Joint Venture (GGJV) is to replace the existing steam utilization system with a new hot water heating system that will feed several thousand fan coil units. GGJV is to also upgrade the structure's mechanical system with new shell-and-tube heat exchangers in addition to the utilization of gasketed plate heat exchangers. For the building's cooling, three (3) new electrical centrifugal water chillers will be installed in the chiller plant located in the courtyard 1 basement, they

will also feed into the structure's numerous fan coil units. Finally, direct outside air handlers will provide ventilation air for the mechanical system.

The systems are to perform in compliance with ASHRAE 90.1-1999 minimum energy performance at full and part load conditions. This is to help the building operate with greater efficiency while earning 7 LEED points under EA credit 1: Optimization of Energy Performance; the renovation is scheduled to earn at least 10 points in the Energy and Atmosphere division of LEED version 2.2 for New Construction and Major Renovations.

Structural

Limited new construction work will regard the building's structural system. With the Office Renovation Building's completion in the late 1920's, the existing structural system is composed of steel columns, girders, and beams encased in concrete. To the contrast of the typical construction practice of reinforced concrete structures in the area; the Office Renovation Building was completed prior to today's modern day applications of reinforcement and fireproofing. Terra cotta tile blocks compose the existing building's structural floor spans, the 305 mm wide blocks are placed between 102 mm wide reinforced concrete ribs. This was also common practice for the area's building construction means and methods during the building's time of erection.

The Electrical Equipment Enclosure to be built in courtyard 1 is to be erected of structural steel columns and beams and cast in place flat plate slabs.

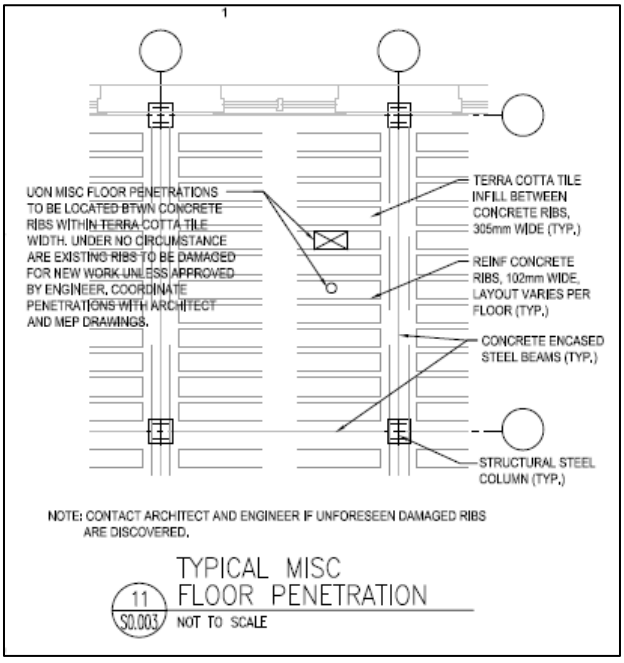


Figure 7: Existing Floor Construction Details

Limited cast in place concrete will be put in place on the Office Renovation building project. The Electrical Equipment Enclosure is the only segment of phase 2 that will require any new construction. Two additional floors will be erected on top of an existing structure in courtyard 1. Following the placement of the enclosure's structural steel, CIP flat plate slabs will be placed at the two corresponding floor levels. Horizontal slab formwork consisting of standard plywood sheets will be utilized. This floor structure has been chosen because of the electrical equipment designated for the area. Concrete slabs will be poured via pump. Concrete trucks will utilize the closely located material staging area to park their trucks while pumps will be brought in through the building and into the adjacent courtyard.

Fire Suppression

A Wet-Type, Manual Class I Standpipe system is to be installed throughout the Office Renovation Building. The system is to include DN 65 hose valves with DN 85 65 x DN 40 reducer connections while operating under standard pressure (minimum of 1200 kPa for working pressures).

Additionally, the project scope requires GGJV to provide a complete wet-pipe automatic sprinkler system that is to be in compliance with the National Fire Protection Association (NFPA) in addition to amendment NFPA 241- Safeguarding Construction, Alteration, and Demolition Operations. GGJV has proceeded with the installation of a temporary wet-pipe sprinkler system that is to be installed throughout all occupied portions of the building. The Gilbane-Grunley team is also responsible for the design and installation of an automatic dry-pipe sprinkler system that is to be operational in the building's loading docks, basement level, and emergency generator areas located on the second and fourth floor in courtyard 1.

Conveying System

The Office Renovation Building currently houses a total of 28 elevators throughout its layout. During phase 2 of construction, Gilbane-Grunley is responsible for the maintenance and restoration of 4 elevators located within the project's phase line. GGJV will also provide materials, labor, and services necessary for the complete installation of two elevators (specified as elevators 29 and 30). At the request of the owner, manufactured standard pre-engineered type equipment will not meet the requirements of the installation. The new elevators are to comply with ANSI/ASME A17.1, Safety Code for Elevators and Escalators in addition to the ADA and Architectural Barriers Act Accessibility Guidelines 2004. The 4500 lb capacity elevators have explicit operating performance criteria of which will require the conveying systems to have a floor-to-floor time of less than 12 seconds and a completely independent self-leveling system to help correct for the over travel/under travel of the elevators.

5.2 Site Layout Plan

The Office Renovation Building is located in the downtown historical business district of a northeastern metropolitan area. The specific location of this project may not be disclosed due to owner restrictions. Due to the building's urban setting, the construction site of the project is confined within the structure's perimeter.

Because of the high pedestrian traffic surrounding the facility, public safety is a primary concern for the project's logistics planning and site management. To ensure the safety of the area's pedestrians, the construction zone will be enclosed within appropriate construction fencing as needed. Also, because

Phase 2 is comprised of the building's exterior restoration; temporary fencing and overhead protection will be present wherever work is being put in place.

Superstructure Site Layout

During the erection of the building's Electrical Equipment Enclosure, the site will be more congested than any other stage of construction. This is largely due to the concrete and steel contractors presence on site at this time. Due to the urban area's high congestion, coordination of trades will be crucial. Steel delivery trucks will utilize the reserved traffic lane at the Western end of the building for the erection of the EEE. Because there is no shake down area reserved for the steel; the crane located at the Southern end of the building will be forced to pick all steel members directly from the delivery trucks. Logistically, this is a crucial stage of construction, ensuring that deliveries are on time and efficiently processed. The safety of building occupants, pedestrians, and construction laborers is also a major concern during the erection of the Electrical Equipment Enclosure. In an effort to ensure the safety of all stakeholders, Gilbane-Grunley has planned to close the South-Western location of the building adjacent to the steel staging area; all concurring interior construction work will commence only on the Eastern side of Phase II in addition to the use of egress protection adjacent to the Material Staging Area.

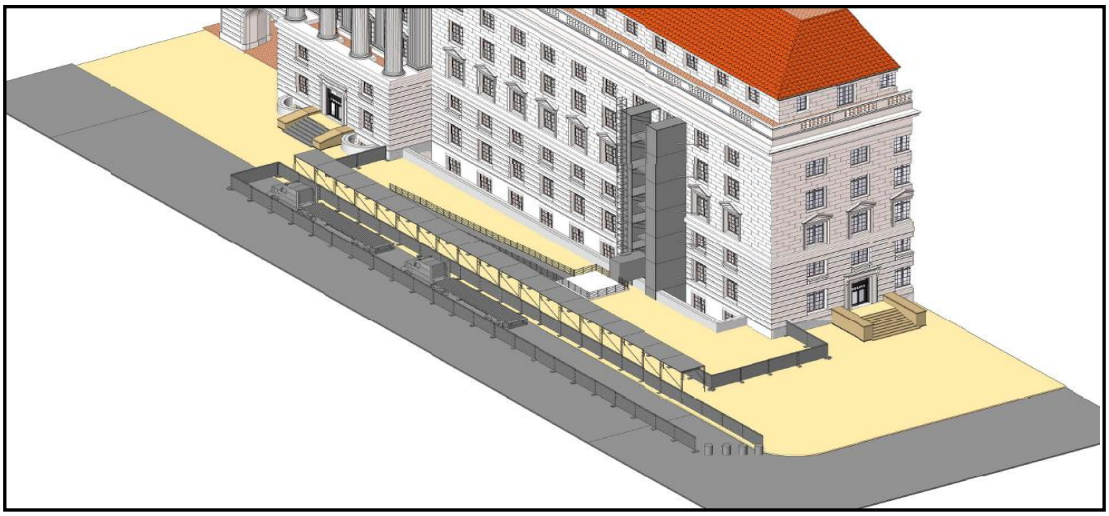


Figure 8: A rendering of the Material Staging Area located at the South-Western end of the building. the crane was originally scheduled to pick steel members directly off of delivery trucks utilizing one lane of the parallel road

Gilbane-Grunley has recently altered their plan for coordinating the arrival of the project's concrete trucks. Originally, these trucks were to share the designated Material Staging Area, but do to congestion, the trucks will now utilize the Southern end of the building. This will also put the concrete trucks at the Southern end of the building bringing them closer to the EEE; this will make it easier to coordinate and execute the pumping of the concrete. Most of the EEE's concrete will be pumped through the existing structure into courtyard 1. Gilbane-Grunley also intends to use the crane to place concrete at the structure's 4th floor roof level.

Considering the significance of this stage of construction, a detailed study will be presented later in this report better analyze the site logistics regarding the Electrical Equipment Enclosure. Ensuring the efficient delivery of steel members and concrete will be a major factor in the successful implementation of this sit layout plan.

5.3 Detailed Project Schedule

The General Services Administration began the conceptual design for the Office Renovation Building in July of 2007. GSA worked with the architect, Group Goetz Architects, and alongside with the project's structural and MEP engineering firms to develop an acceptable design for the structure's renovation design. At the 75% completion of the project's design documents, Gilbane-Grunley Joint Venture submitted a bid for phases 2 and 3 of the project. On August 5, 2009, the General Services Administration awarded GGJV a Guaranteed Maximum Price contract based on the general contractor's 'best-value' bid. Gilbane-Grunley received a Notice to Proceed on November 15th, 2009 and immediately followed with planning and procurement initiatives.

In order to properly interpret the Detailed Project Schedule, several key features must be addressed. The construction phase of the schedule is broken down in segments of major building sections: Renovation of Existing Interior Spaces, Exterior Sitework, Construction of the building's new Electrical Equipment Enclosure, and a summarized breakdown of the Exterior Façade Restoration. These subsections are displayed in order of which has the earliest starting date. Referencing **Appendix C: Detailed Project Schedule (page #)**, let it be noted that many events simultaneously take place during the project's development. This has been done to help facilitate the progression of the project.

In an effort to keep the Detailed Project Schedule within the prescribed limit of 200 line items, only two floors of the project's interior renovation are displayed in detail. The top-down progression of each floor contains similar scopes of work in comparable sequences; because of this, only the 8th and 7th floors are displayed in detail. Floors 1 through 6 closely resemble the progression of work described on the 7th floor. Also, please note that the schedule for the erection of the Electrical Equipment Enclosure is more extensive than other schedule elements. The effort of this schedule was focused on the EEE because future technical assignments and thesis research will be focused primarily on this building section. Furthermore, the final segment of the Detailed Project Schedule summarizes the Exterior Façade Restoration of the building. The durations and sequences of the actual restoration work are phased in smaller subsections beginning at the Southern end of the building progressing counterclockwise around the structure. The schedule element was summarized to prevent continuous redundancies.

Detailed Project Schedule

The entire restoration of the Office Renovation Building project has been broken down into 8 phases. This technical assignment pertains specifically to the second phase of the project of which will be completed over a 2 year time span. As previously stated, the interior renovations of existing spaces will follow a top-down sequencing schedule with the exception of the building's basement. Also, many activities will occur simultaneously to help facilitate the project's completion. This includes the erection of the structure's Electrical Equipment Enclosure and exterior façade restoration. **Figure 9** illustrates the area of the building specific to Phase 2.

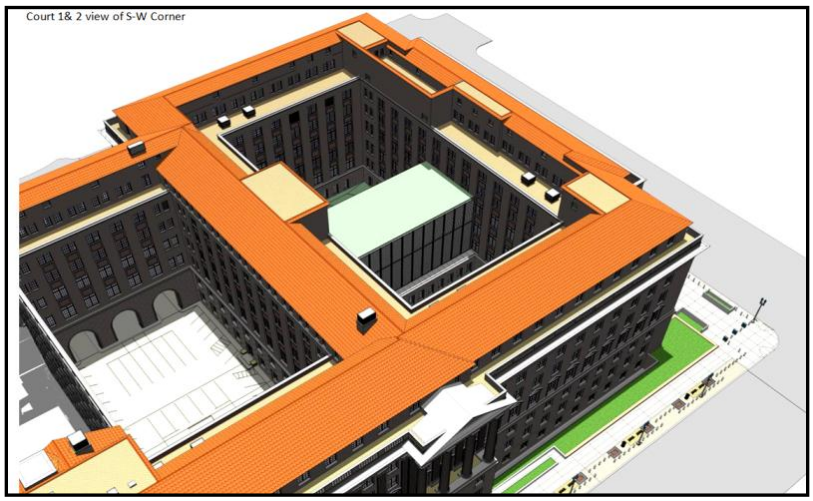


Figure 9: A rendering of the completed Office Renovation Building with the Electrical Equipment Enclosure (EEE) located in the center of courtyard 1. Interior renovations will begin on the 8th floor and will conclude on the 1st floor

5.4 Project Cost Estimate

The following estimate values are based on the research performed by the Gilbane-Grunley Joint Venture. As per the request of the building owner, some figures have been slightly altered and do not completely portray the actual costs of the project. The costs shown do not represent the actual bid costs for the project.

Project Overview		
Square Footage of Ph2 Renovation:	260,000 SF	
Construction Cost:	**Actual Cost**	**Cost/SF**
Actual (without general requirements):	$ 96,132,063	$ 369.74
Actual (with general requirements):	$ 98,397,753	$ 378.45
Total Project Cost:		
Actual GMP Cost (Allowance Included):	$ 114,687,300	$ 441.10

Table 1: Project Overview and Cost Breakdown

Building System	Actual Cost	Cost/SF	% of Building
Demolition and Abatement	$ 3,637,118.00	$ 13.99	3.70
Site Utilities	$ 2,881,000.00	$ 11.08	2.93
Exterior Stone and Masonry Restoration	$ 7,653,110.00	$ 29.44	7.78
Structural Steel and Mis. Metals	$ 2,338,600.00	$ 8.99	2.38
Roofing and Waterproofing	$ 2,068,000.00	$ 7.95	2.10
Window Restoration	$ 3,997,113.00	$ 15.37	4.06
Plumbing and HVAC	$ 23,670,625.00	$ 91.04	24.06
Electrical	$ 18,153,000.00	$ 69.82	18.45

Table 2: Building Systems Cost Estimate (Selective Systems)

With reference to Table 2: Building Systems Cost Estimate, please note that significantly large cost contribution within the Plumbing, HVAC, and Electrical systems. This is because the replacement of the structure's corresponding systems takes place during Phase 2 of construction. In contrast to this phase, future phases of the building's renovation will have significantly lower mechanical, electrical, and plumping construction costs.

5.4 General Conditions Estimate

The general conditions estimate for the Office Renovation Building is comprised of various elements that combine to help facilitate the project. The estimate prepared in this report has been broken down into four categories of which summarize the overall general conditions estimate for the project. Table 3 shows a summarized representation of these values. Let it be noted that these numbers do not reflect the actual amounts contracted between Gilbane-Grunley and the General Services Administration.

GENERAL CONDITIONS ESTIMATE SUMMARY	
LINE ITEM	COST
Supervision & Personnel	$ 3,379,366.00
General Requirements	$ 1,150,670.00
Field Office Support	$ 130,580.00
Miscellaneous Costs	$ 2,037,650.00

Table 3: General Conditions Estimate Summary

This estimate included the general condition categories of Supervision & Personnel, General Requirements, Field Office Support, and Miscellaneous Costs. *Supervision and Personnel* includes an in depth breakdown of the entire management and support staff for the Office Renovation Building Project. Only staff members that are on-site for the majority of the project have been included in the data provided. Because Grunley has contracted some self-performing work, this estimate includes the value for the project's carpentry work. The *General Requirements* category incorporates items that help the field staff to facilitate the project. Such items include: dumpster services, small tools, staff travel, and cellular phones. The cost for renting on-site office space for Gilbane-Grunley is not included in the general conditions estimate because it is at no additional expense to the general contractor. *Field Office*

Support is a category that covers all expenses that predominantly take place within the on-site office; these costs include office supplies, internet services, bottled water, etc. Finally, *Miscellaneous Costs* account for items such as permits, insurance, safety incentives, and document reproduction expenses.

Figure 10 illustrates a visualized breakdown of the four categories discussed. As expected, the Field Staff is the greatest expense within the project's general conditions; the miscellaneous costs are relatively high but that is largely due to the significant insurance and bonding costs included in the section.

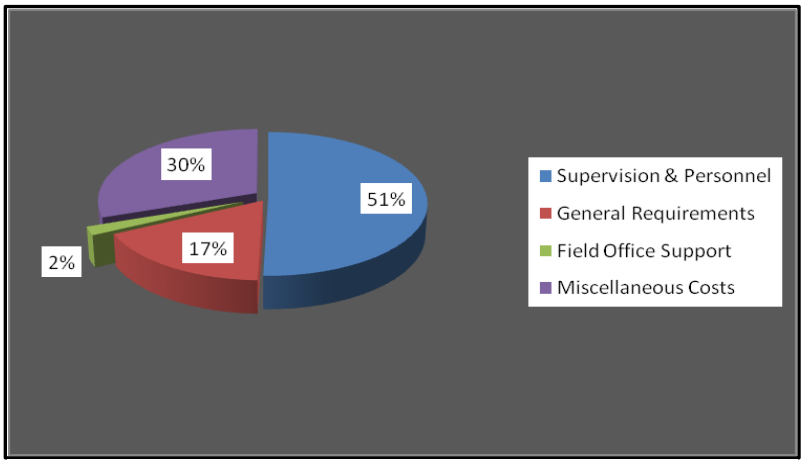


Figure 10: General Conditions Percent Breakdown

The following set of tables and figures provide a detailed breakdown of the project's General Conditions Cost. The specific categories that comprise these figures reflect those illustrated in Figure 3.

SUPERVISION and PERSONNEL				
Grunley Construction				
Line Item	Unit Rate	Unit	Quantity	Cost
Project Executive	$ 128.00	Hour	2,642	$ 338,176.00
Project Manager	$ 88.00	Hour	2,642	$ 232,496.00
General Superintendent	$ 111.00	Hour	2,642	$ 293,262.00
Shift Superintendent	$ 71.00	Hour	2,642	$ 187,582.00
Shift Superintendent	$ 58.00	Hour	2,642	$ 153,236.00
Exteriors Superintendent	$ 125.00	Hour	2,642	$ 330,250.00
Assistant Superintendent	$ 45.00	Hour	2,598	$ 116,910.00
Assistant Project Manager	$ 61.00	Hour	2,642	$ 161,162.00
Quality Control Engineer	$ 80.00	Hour	2,642	$ 211,360.00
Intern	$ 36.00	Hour	304	$ 10,944.00
Field Labor	$ -	LS	-	$ 114,250.00
Gilbane Building Company				
Line Item	Unit Rate	Unit	Quantity	Cost
Senior Project Manager	$ 88.00	Hour	2,598	$ 228,624.00
General Superintendent	$ 120.00	Hour	2,598	$ 311,760.00
MEP Coordinator	$ 94.00	Hour	2,598	$ 244,212.00
Senior Project Engineer	$ 56.00	Hour	2,598	$ 145,488.00
BIM Coordinator/ PE	$ 77.00	Hour	2,598	$ 200,046.00
Administrator	$ 36.00	Hour	2,598	$ 93,528.00
Intern	$ 20.00	Hour	304	$ 6,080.00
			TOTAL:	**$ 3,379,366.00**

GENERAL REQUIREMENTS				
Line Item	Unit Rate	Unit	Quantity	Cost
Project Fire Ext.	$ 2,000.00	LS	1	$ 2,000.00
Removable Fence & Gates	$ 316,000.00	LS	1	$ 316,000.00
Project Signage	$ 7,500.00	LS	1	$ 7,500.00
First Aid Kits	$ 2,400.00	LS	1	$ 2,400.00
Precondition Survey	$ 1,000.00	LS	1	$ 1,000.00
BIM Project Setup	$ 100,000.00	LS	1	$ 100,000.00
Dumspter Service	$ 128,130.00	LS	1	$ 128,130.00
Small Tools & Equipment	$ 11,250.00	LS	1	$ 11,250.00
Securty/Watchmen	$ 319,700.00	LS	1	$ 319,700.00
Final Cleanup	$ 45,000.00	LS	1	$ 45,000.00
Field Staff Travel	$ 30,500.00	LS	1	$ 30,500.00
Electrical Consumption	$ 25,000.00	LS	1	$ 25,000.00
Automobile Allowance/ Fuel	$ 47,060.00	LS	1	$ 47,060.00
Employee Parking	$ 61,500.00	LS	1	$ 61,500.00
Misc. Computer Programs	$ 11,130.00	LS	1	$ 11,130.00
Cellular Phones	$ 37,500.00	LS	1	$ 37,500.00
Misc. Supplies & Equipment	$ 5,000.00	LS	1	$ 5,000.00
			TOTAL:	**$ 1,150,670.00**

FIELD OFFICE SUPPORT				
Line Item	Unit Rate	Unit	Quantity	Cost
Misc. Office Supplies	$ 38,750.00	LS	1	$ 38,750.00
Postage & Shipping	$ 22,500.00	LS	1	$ 22,500.00
Mailing Machine & Scale	$ 1,250.00	LS	1	$ 1,250.00
Computer Ntwk & Wiring	$ 14,000.00	LS	1	$ 14,000.00
Telephone Service	$ 27,250.00	LS	1	$ 27,250.00
TV, DVD, and Tapes	$ 700.00	LS	1	$ 700.00
Copier/Printer/Fax	$ 1,780.00	LS	1	$ 1,780.00
Internect Connection	$ 20,000.00	LS	1	$ 20,000.00
Bottled Water	$ 2,000.00	LS	1	$ 2,000.00
Digital Camera & Software	$ 350.00	LS	1	$ 350.00
Records Retention	$ 2,000.00	LS	1	$ 2,000.00
			TOTAL:	**$ 130,580.00**

MISCELLANEOUS COSTS				
Line Item	Unit Rate	Unit	Quantity	Cost
Safety Incentives	$ 5,000.00	LS	1	$ 5,000.00
Bid Set Reproduction	$ 40,000.00	LS	1	$ 40,000.00
Misc. Permits	$ 30,000.00	LS	1	$ 30,000.00
Misc. Blueprinting	$ 6,250.00	LS	1	$ 6,250.00
Progress Photos	$ 25,000.00	LS	1	$ 25,000.00
Misc. Supplies/Equip	$ 5,000.00	LS	1	$ 5,000.00
Insurance	$ 1,097,600.00	LS	1	$ 1,097,600.00
Bonds	$ 828,800.00	LS	1	$ 828,800.00
			TOTAL:	**$ 2,037,650.00**

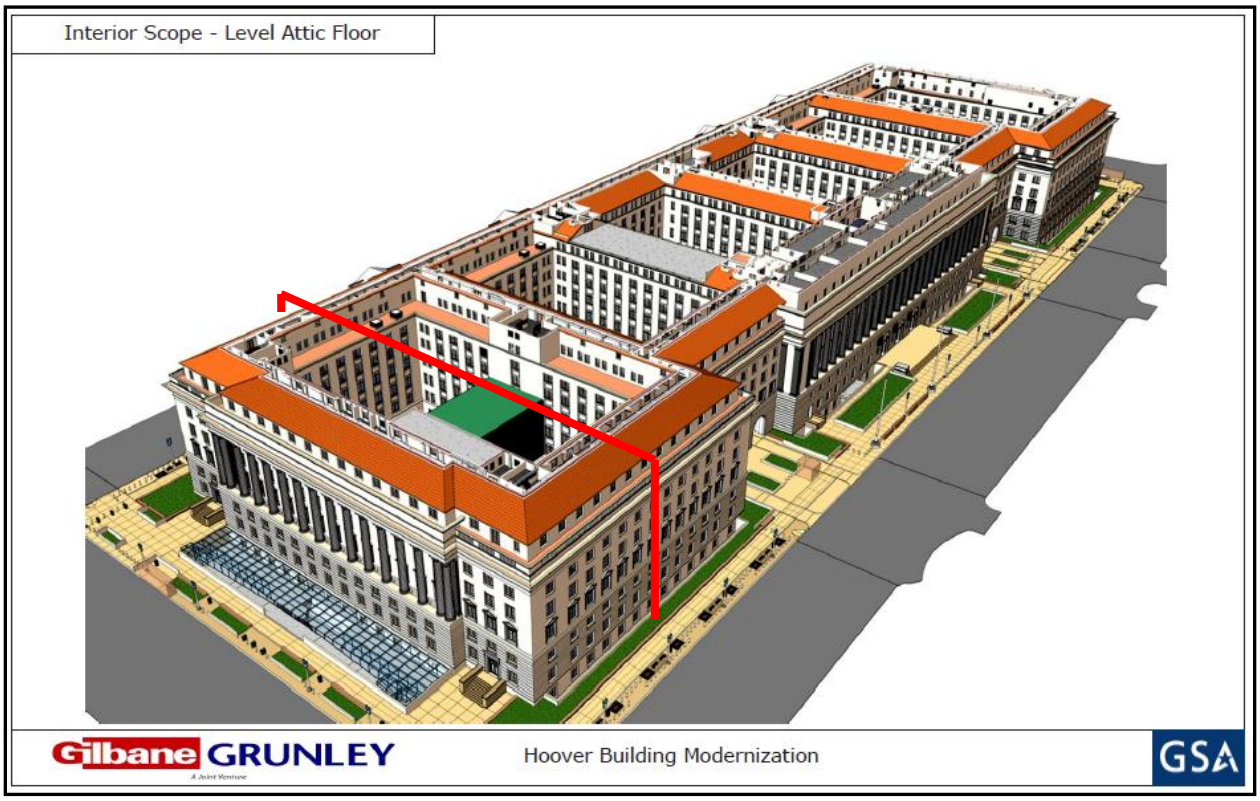


Figure 11: Rendering of the Office Renovation Building, the red line illustrates the phase line between the current construction zone (left) and the occupied spaces of the building (right)

6.0 Schedule Acceleration with Prefabrication

6.1 Problem

The 20,000 SF Electrical Equipment Enclosure designed to be erected in courtyard 1 of the Office Renovation Building is the only new construction to take place on the project. The structural steel facility's floor slabs are currently designed to be cast in place composite concrete slab on one way metal decking. The area of each level is relatively small totaling approximately 6,600 SF. The roof of the structure is also designed to be cast in place concrete to support the loads relative to the currently proposed green roof. Following the completion of the 2nd floor, large electrical equipment is scheduled to be put in place before the pouring of the 4th floor; the same is scheduled for the 4th floor prior to the placement of the roof. Each floor must achieve its appropriate curing strength prior to the placement of floor's electrical equipment. Waiting for each floor slab to reach appropriate strength before proceeding with other activities demonstrates an opportunity for improvement in the EEE's design and construction.

Figure 12: Rendering of the EEE with green roof located in the center of Courtyard 1

6.2 Research Goal

The duration and cost of mobilization, formwork, concrete pouring, and curing time associated with placing concrete are significant to the project schedule and total cost for the Electrical Equipment Enclosure. Due to the size of the EEE and because of site congestion, incorporating a precast concrete floor structure has been researched in an effort to demonstrate a more cost efficient design while decreasing the schedule duration for the project.

6.3 Existing Design and Construction Means

A complete analysis of the existing design and delivery of construction was required to compare the actual benefits of the prefabricated system. This section includes a thorough breakdown of the cost, schedule, and site logistics of the Electrical Equipment Enclosure

Cost Breakdown

Because this analysis is focused on the structural erection of the EEE, only the costs of the structure's steel and concrete were completed. Finishes and other building components were not included in this cost breakdown because it is expected that they will remain consistent between both building designs. The following tables present the structural costs provided by the Gilbane-Grunley project team for the EEE in addition to personal calculations that include quantity takeoffs and associated material costs for the structure. Both estimates are included in this analysis to minimize the variances in calculating the structural costs when being compared to the new structural system. Additionally, another valuable cost associated with the erection of the building's structure is the crane rental; the project team provided the GMP value of $31,200.00 for appropriate crane rental.

Structural Estimate General Breakdown Original Design				
	ACTUAL		ESTIMATED	
SYSTEM	TOTAL	$/SF	TOTAL	$/SF
CIP Concrete	$123,770.00	$6.18	$66,139.84	$3.34
Structural Steel	$865,945.00	$43.29	$508,824.28	$25.77

Table 4: Estimated vs. Actual Structural Systems Cost Breakdown

Following the comparison of the final estimated values, it is evident that the system estimate performed within this analysis is significantly lower than the actual contract value. The considerable variance between the two values must be discussed to justify the quantity take offs and cost application of the estimate performed. Considering the renovation nature of the project, there is considerable concrete work present throughout the building. However, many of these concrete costs affiliated with other building elements are difficult to quantify with this estimate because they cannot be directly applied to the structural estimate of the Electrical Equipment Enclosure. One specific application of this discrepancy involved the concrete work associated with the construction of the building's electrical ductbank. Furthermore, Table 1 illustrates that the structural steel estimate performed is also significantly lower than the actual contract amount (%48). It is assumed that this variance is largely due to the lack of being able to accurately apply the costs associated with structure's steel connections. This variance of cost may be easily compensated with the application of connection and detailing costs.

Furthermore, the costs of both the CIP concrete and the structural steel are most likely to include the costs of delivery for all associated materials. A breakdown of the transportation costs for the steel and concrete were unable to be provided by the general contractor.

These variances in scope of work and quantifiable values that are applicable to the erection of the Electrical Equipment Enclosure are a major contributor to the differences presented in Table 1.The table below summarizes the cost and quantity for each CSI Masterformat division included in the estimate. The per

Component	Unit Cost	Unit	Quantity	Cost
033100- Concrete Formwork	$ 8.51	SFCA	1092	$ 9,289.86
032100- Welded Wire Fabric	$ 48.15	CSF	204	$ 9,823.01
033000- CIP Concrete	$ 146.96	CY	320	$ 47,026.97
051223- Steel Columns	$ 5,230.00	TON	13	$ 66,222.70
052113- Steel Beams	$ 49,011.00	TON	80	$ 395,963.97
053133- Metal Decking	$ 2.36	SF	19755	$ 46,637.60
		TOTAL:		$ 574,964.11

Table 5: Estimate Summary by CSI Format Divisions

Several factors and assumptions were accounted for throughout the estimate to produce a final cost of the Electrical Equipment Enclosure's superstructure cost. *RS Means Cost Data 2011* was used for all material, labor, and equipment unit costs. The prices listed in this manual were all adjusted for accordingly in regards to the location of the Office Renovation Building. Additionally, appropriate waste factors were applied for the estimating the quantities for WWF, formwork, and concrete (10%). For the concrete placement, the elevated slabs are assumed to be pumped with an appropriately sized crew referencing the *RS Means Cost Data*. Finally, the majority of the structural steel member sizes had pricing available from *RS Means.* If a particular size was not listed, the next available member was used for unit pricing.

These values, particularly the quantity takeoffs associated with the structure's steel members, will be used to assess the difference in material and labor costs between the original and prefabricated design systems. The comparison between these two systems will be evaluated later within this report.

The following figures represent the quantity takeoffs and their associated costs. The estimate presented within these tables were completed with reference to RS Means Cost Data 2011

STRUCTURAL STEEL ESTIMATE PRICING								
Description	**Quantity**	**Unit**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total O & P**	**Total Cost**
COLUMNS								
W12x65	510	LF	$ 83.80	$ 3.84	$ 2.16	$ 89.80	$ 93.39	$ 47,630.19
W12x72	180	LF	$ 92.65	$ 4.14	$ 2.53	$ 99.32	$ 103.29	$ 18,592.52
							TOTAL:	**$ 66,222.70**
BEAMS								
W10x12	137	LF	$ 15.46	$ 4.42	$ 2.70	$ 22.58	$ 23.48	$ 3,217.03
W12x14	135	LF	$ 20.61	$ 3.01	$ 1.84	$ 25.46	$ 26.48	$ 3,574.84
W12x16	805	LF	$ 20.61	$ 3.01	$ 1.84	$ 25.46	$ 26.48	$ 21,316.62
W12x30	17	LF	$ 39.30	$ 3.11	$ 1.90	$ 44.31	$ 46.08	$ 783.36
W14x22	1361	LF	$ 33.31	$ 2.68	$ 1.64	$ 37.63	$ 39.14	$ 53,265.84
W14x38	27	LF	$ 52.05	$ 3.27	$ 2.00	$ 57.32	$ 59.61	$ 1,609.55
W16x31	24	LF	$ 40.08	$ 2.95	$ 1.80	$ 44.83	$ 46.62	$ 1,118.92
W18x35	290	LF	$ 45.28	$ 3.99	$ 1.80	$ 51.07	$ 53.12	$ 15,403.77
W18x40	138	LF	$ 51.53	$ 3.99	$ 1.80	$ 57.32	$ 59.61	$ 8,226.49
W18x50	36	LF	$ 163.44	$ 6.54	$ 5.49	$ 175.47	$ 182.49	$ 6,569.48
W21x44	51	LF	$ 56.73	$ 3.60	$ 1.63	$ 61.96	$ 64.44	$ 3,286.60
W24x55	790	LF	$ 181.13	$ 7.14	$ 6.23	$ 194.50	$ 202.28	$ 159,804.49
W24x68	170	LF	$ 97.85	$ 3.45	$ 1.56	$ 102.86	$ 106.98	$ 18,186.36
W24x76	266	LF	$ 198.83	$ 7.74	$ 6.97	$ 213.54	$ 222.08	$ 59,073.98
W24x84	93	LF	$ 108.26	$ 3.55	$ 1.60	$ 113.41	$ 117.95	$ 10,969.40
W24x94	145	LF	$ 120.76	$ 3.55	$ 1.60	$ 125.91	$ 130.94	$ 18,986.62
W27x84	90	LF	$ 108.26	$ 3.22	$ 1.45	$ 112.93	$ 117.45	$ 10,570.62
							TOTAL:	**$ 395,963.97**
METAL DECKING								
20 Ga. G60	19755	SF	$ 1.71	$ 0.52	$ 0.04	$ 2.27	$ 2.36	$ 46,637.60
							TOTAL:	**$ 46,637.60**
							TOTAL ESTIMATE:	**$ 508,824.28**

CAST-IN-PLACE CONCRETE ESTIMATE PRICING								
Description	**Quantity**	**Unit**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total O & P**	**Total Cost**
REBAR								
Elevated Slabs	204	CSF	$ 23.10	$ 23.20	$ -	$ 46.30	$ 48.15	$ 9,823.01
CONCRETE								
Slabs (3,000 PSI)	320	CY	$ 121.02	$ 14.31	$ 5.98	$ 141.31	$ 146.96	$ 47,026.97
FORMWORK								
Elevated Slabs	1092	SFCA	$ 1.27	$ 6.91	$ -	$ 8.18	$ 8.51	$ 9,289.86
							TOTAL ESTIMATE:	**$ 66,139.84**

Erection Schedule

The primary intention of altering the EEE's floor structure to precast hollow core planks is to accelerate the schedule for the building's completion. The original design and project schedule identifies the starting date for structural erection of the EEE began on Monday May 10th, 2010. The Electrical Equipment Enclosure's structural system was originally scheduled to be completed on Wednesday October 27th, 2010.

Following the final activity of pouring concrete on the structure's roof, the entire structural system is scheduled to take place over the course of 123 working days. This duration is predominately occupied with time for each concrete floor to properly cure and become up to strength to support the EEE's electrical equipment. A total of 45 working days for curing contributes to the duration of this schedule. This is a significant amount of time in regards to the structural schedule. Below is a table that summarizes the major structural durations originating from the project team's project schedule.

Summary of Major Activities Structural Schedule	
Activity	Duration
Steel Framing	15 Days
Concrete 2nd Floor	7 Days
Concrete to Strength	15 Days
Set/Connect Equipment	22 Days

Table 6: Typical Schedule of Events for 2nd and 4th Floors

Please refer to **Appendix D: Detailed EEE Schedule** for a more in depth look at all the activities associated with the building's construction.

Site Congestion and Coordination

Working within a congested urban site makes delivery coordination a crucial part of keeping a project on schedule. Because of the location of the project, coordinating the structural work and crane placement with the city legislation was a crucial part in ensuring the construction of the building's EEE.

Due to the high traffic area, the project was permitted to place its crane in the appropriate location only on the weekends. The permit to occupy the adjacent street space is only to be in effect from Saturday 4:00 AM to Sunday at 7:00 PM. Coordinating this 39 hour window of operation involved particular logistical planning between the GGJV team and the steel and concrete manufacturers. The delivery of steel, in addition to the set up and tear down time of the crane had to be efficiently planned to maximize the opportunity for production. A copy of the project's permit can be found in Appendix E: Public Space Occupancy/Parking Permit.

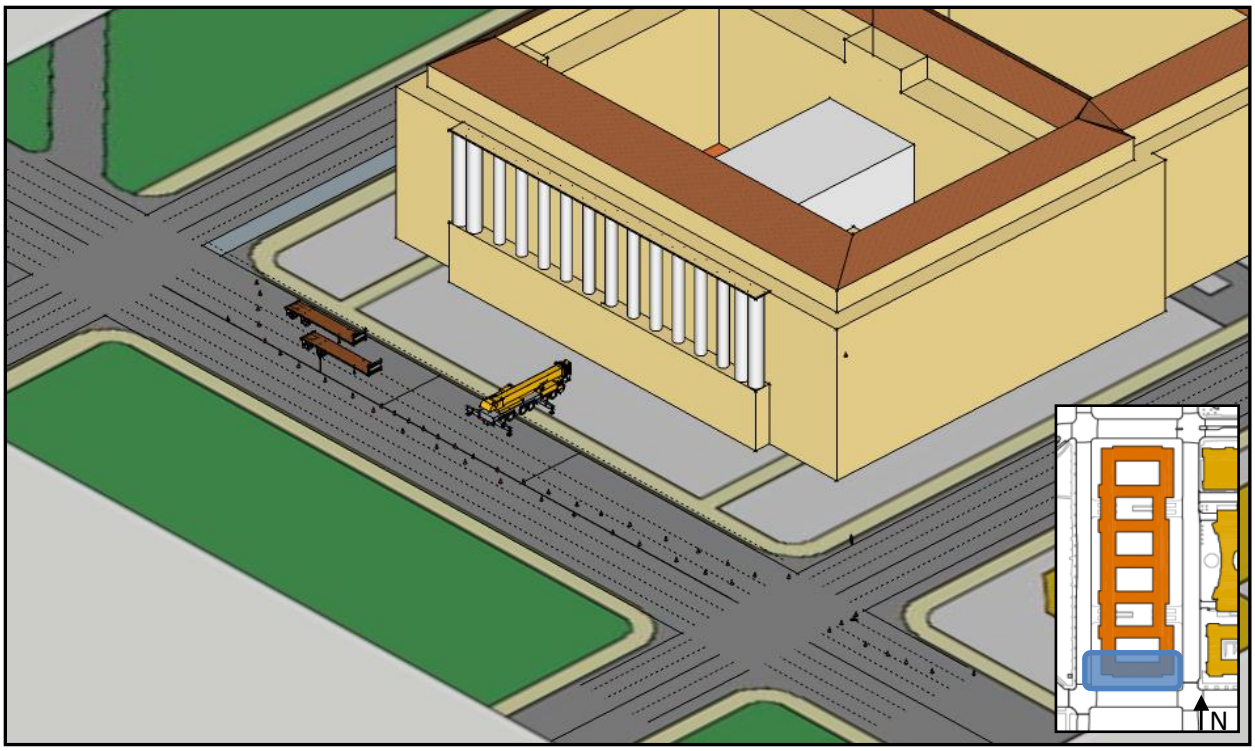


Figure 13: SketchUp rendering of the permit plan for the EEE steel erection

The rendering above summarizes what the weekend set up for the crane will look like. 3 traffic lanes and a parking lane will be occupied as a construction space each weekend for the duration of the EEE steel erection. The flat beds shown in the rendering demonstrate where steel deliveries will park as they are unloaded and placed in their corresponding places within the EEE's structure. For the existing cast in place concrete floor system, trucks delivering quantities of concrete will also occupy the southern end of the Office Renovation Building. Because the concrete trucks do not require nearly as much space as the steel erection process, they are scheduled to work during the week. Concrete will be pumped through the building and onto the EEE floor levels.

In an effort to minimize redundancy, a more detailed, phased logistics plan will be presented in the next section of this analysis. The logistics plan for delivering and erecting the steel and precast members of the newly designed system will closely resemble that of the existing delivery approach.

Additionally within Appendix E, the crane specifications for the project can be found. These specifications illustrate the maximum pick loads and boom lengths required to erect the steel and electrical equipment for the EEE (Appendix E: Crane Plans). The Liebherr LTM 1250 Crane will be used for the duration of the EEE's erection. The most critical picks will involve an approximate 5,000 lb load spanning a distance of 248 feet. During these picks, a jib length of 207 feet will be used at an offset angle of 47.3 degrees. These are well within the limits of the crane.

The images below demonstrate how the cranes jib was able to be constructed. A smaller crane was used to help align and attached the components of the jib. Other photos are also provided to help better illustrate the cranes placement and coordination with picking steel components.

Figure 14: Erecting the cranes jib. A smaller crane was used to attach the components along the southern end of the staging area

Figure 16: Crane with fully constructed job setting the EEE's furthest structural steel members

Figure 15: Steel column being set within the courtyard of the building for the EEE

6.4 System Redesign (Structural Breadth)

Structural Breadth

Within this section of the analysis are the quantities associated with the newly designed EEE with pre cast hollow core planks. Calculations for sizing the structural members of the facility can be found in Appendix: F Structural Breadth Calculations. Additionally, specifications for the precast hollow core planks including connection and penetration details can be found in Appendix G: Hollow Core Plank Details. An example of the calculations for sizing the precast planks and steel beams and girders is shown on the next page.

Based on the calculations presented in Appendix G, 6”x4’-0” prestressed concrete hollow core planks have been selected. The manufacturer is Nitterhouse Concrete Products located in Chambersburg, PA. They have been selected because of their experience in the building’s associated area and because of their extensive help with completing all the requirements for this analysis. The calculations include the safe superimposed service loads of a 2 Hour Fire Resistance rated plank with 2” concrete topping. 2” topping was included to ensure a rigid diaphragm and to avoid further structural complications. Also, though the floor to ceiling height will be decreased by less than 4 inches, the Gilbane Grunley project teams considered this change to have no impact on the MEP ceiling coordination or architectural preferences.

Floor Slab System Redesign

Superimposed Dead Load: 25 psf

Dead Load: 243.75 psf (Refer to Structural Appendix for detailed calculations-Plank self-weight included)

Live Load: 40 psf

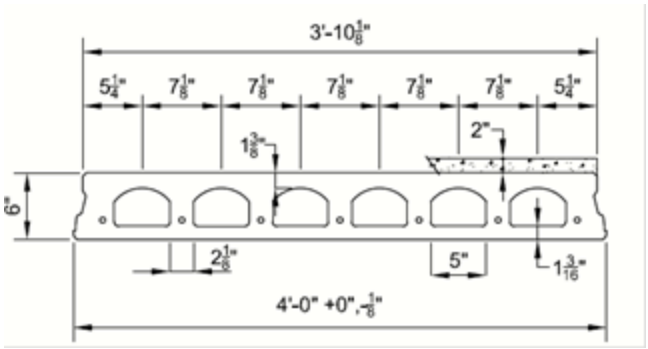
Total Loads: 243.75 psf

Prestressed Concrete
6"x4'-0" Hollow Core Plank

2 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

A_c = 253 in.^{2}	Precast b_w = 16.13 in.
I_c = 1519 in.^{4}	Precast S_{bcp} = 370 in.^{3}
Y_{bcp} = 4.10 in.	Topping S_{tct} = 551 in.^{3}
Y_{tcp} = 1.90 in.	Precast S_{tcp} = 799 in.^{3}
Y_{tct} = 3.90 in.	Precast Wt. = 195 PLF
	Precast Wt. = 48.75 PSF



SAFE SUPERIMPOSED SERVICE LOADS — IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)

Strand Pattern		SPAN (FEET)																		
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
4 - 1/2"ø	LOAD (PSF)	349	317	290	258	227	197	174	149	127	108	92	78	66	55					
6- 1/2"ø	LOAD (PSF)	524	478	437	377	334	292	269	237	215	188	165	142	122	104	88	73	61	49	39
7 - 1/2"ø	LOAD (PSF)	541	492	451	416	364	331	293	274	242	214	190	167	144	124	107	91	77	64	53

The pre-stressed concrete plank was selected based off the Nitterhouse specifications for 6" Hollow Core Plank with 2" Topping after calculating the capacity needed to carry the loads for the 2nd floor of the EEE. A bay with the greatest load of electrical equipment was chosen. The system will be replacing a 4 ½" composite steel deck with normal weight concrete. The plank was checked for all appropriate deflection. Below is the beam and girder sizing calculations.

BEAM REDESIGN:

W_{TL} = 1.2D + 1.6L

Weight of Pre-stressed Plank – 48.75 psf

W_{TL} = 1.2(268.74) + 1.6(40) = 386.48 psf

$M_U = (386.48)(10.7)(16.4)^2 / 8$ = 139 ft*kip

From the Steel Construction Manual – W12X35 @ 192 ft-kp capacity

Check Beam for Self Weight:

M_U = [(386.48)(10.7) + 35] $(16.4)^2 / 8$ = 140.2 ft-kip <192 ft-kip therefore W12X35 is OK

TOTAL LOAD DEFLECTION:

$\Delta_{TL} = 5\ W_{LL}\ L^4\ (\ 1728)\ /\ (\ 384\ E\ I\ )$

$E = 29{,}000{,}000$

$I_{W12X35} = 285\ in^4$

$\Delta_{TL} = 5\ (4{,}135)\ 16.4^4\ (\ 1728)\ /\ (384 \times 29{,}000{,}000 \times 285\ ) = 0.80$ inches

Allowable Total Load Deflection:

$\Delta_{TL} = L / 240 = (\ 16.4$ ft * 12 in/ft) / 240 = 0.82 inches

0.80 inches < 0.823 inches therefore OK

LIVE LOAD DEFLECTION:

$\Delta_{LL} = 5\ W_{LL}\ L^4\ (\ 1728)\ /\ (\ 384\ E\ I\ )$

$E = 29{,}000{,}000$

$I_{W12X35} = 285\ in^4$

$\Delta_{TL} = 5\ (64)\ 16.4^4\ (\ 1728)\ /\ (384 \times 29{,}000{,}000 \times 285\ ) = 0.012$ inches

Allowable Live Load Deflection:

$\Delta_{TL} = L / 360 = (\ 16.4$ ft * 12 in/ft) / 360 = 0.546 inches

0.012 inches < 0.546 inches therefore OK

Similar calculations were applied to the Precast Hollow Core Planks and the Girders supported the internal beams. The calculations that check the plank and steel framing members with the appropriate load and select size can be found in the Structural Breadth Calculations Appendix.

After sizing the precast hollow core planks, it was discovered that a much more efficient structural steel design could be implemented. This is largely because the planks are structural components. In fact, each bay was originally designed to have 3 interior beams, the new structural plan requires only 1. Also, all girders were able to be down sized for a more cost efficient design. A comparison of the steel framing layout can be seen on the following page.

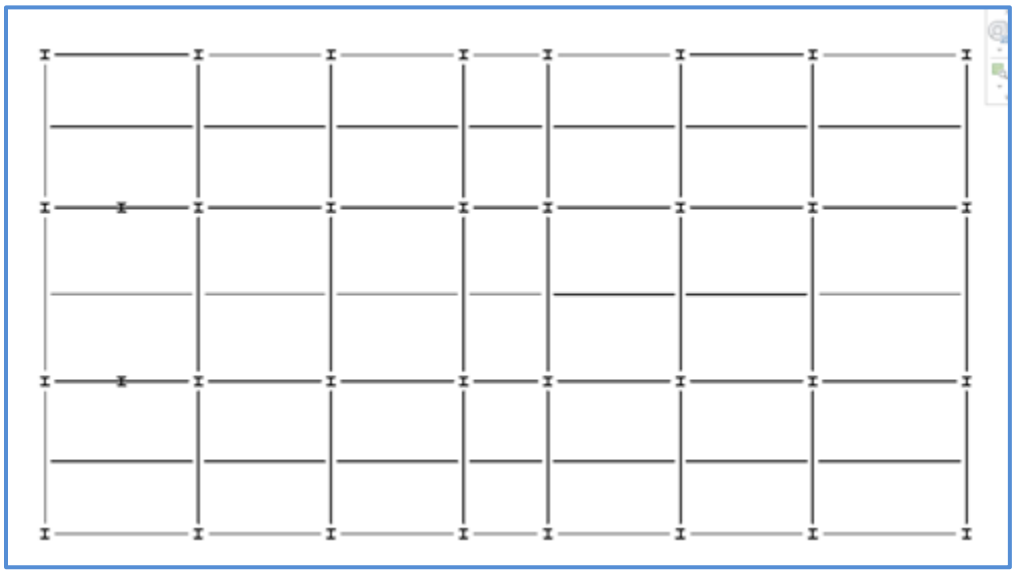


Figure 17: New Structural Design- 2nd Floor

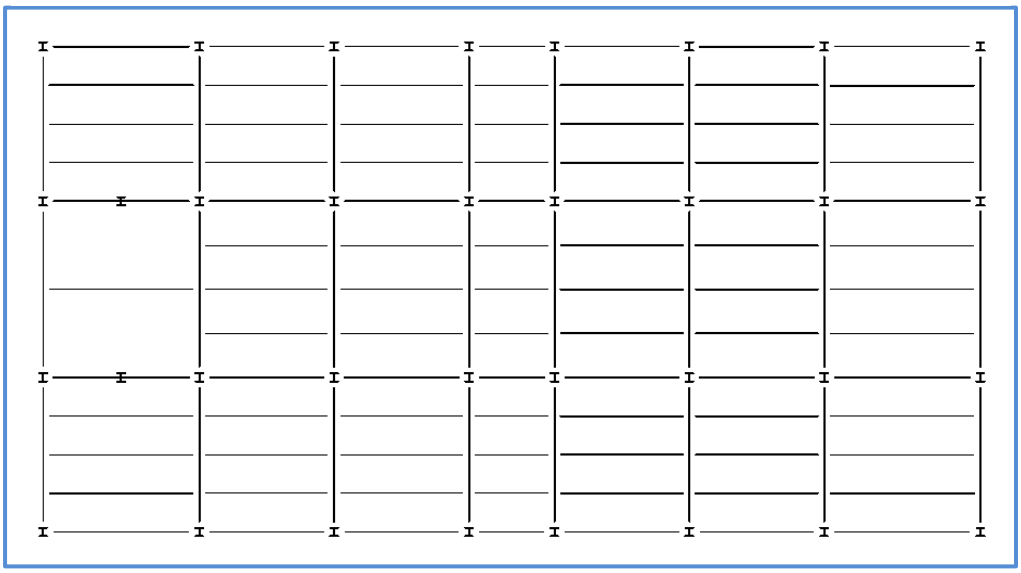


Figure 18: EEE Original Design Steel Member Layout- 2nd Floor

Quantity takeoffs of the newly designed steel framing plan can be seen on the following page. Also illustrated are the quantities associated with the 2" topping for each level of hollow core plank. It is worth noting that within these tables are the steel and cast in place quantities that are to remain for the EEE's roof structure. This was left in the tables to evaluate a total cost comparison of the original design.

STRUCTURAL STEEL ESTIMATE TAKE-OFF CHARTS					
Columns					
	Type	Unit	Length (ft)	Quantity	Total
All Floors	W12x65	LF	30	17	510
	W12x72	LF	30	6	180
Beams					
	Type	Unit	Length (ft)	Quantity	Total
2nd Floor	W12x35	LF	10.4	7	72.8
	W12x35	LF	16.4	28	459.2
	W12x35	LF	19	14	266
	W21x48	LF	19	16	304
	W21x48	LF	21	8	168
	Type	Unit	Length (ft)	Quantity	Total
4th Floor	W12x35	LF	9.5	9	85.5
	W12x35	LF	10.4	7	72.8
	W12x35	LF	16.4	28	459.2
	W12x35	LF	19	7	133
	W21x48	LF	19	18	342
	W21x48	LF	21	9	189
	Type	Unit	Length (ft)	Quantity	Total
Roof	W12x14	LF	8.5	2	17
	W12x30	LF	8.5	2	17
	W14x22	LF	8	4	32
	W18x35	LF	17	4	68
	W18x35	LF	17.5	4	70
	W18x35	LF	18.5	2	37
	W18x40	LF	15	2	30
	W18x40	LF	17	2	34
	W18x40	LF	18.5	4	74
	W24x55	LF	48	14	672

Table 8: New EEE Design Steel Member Takeoffs

TOPPING ESTIMATE TAKE-OFF CHART				
2" Topping and Cast In Place Roof (3000 psi)				
	ID	Depth (Ft)	Area (SF)	Concrete (CY)
2nd Floor	S2-1	0.166	1067	6.5
	S2-2	0.166	1067	6.5
	S2-3	0.166	1250	7.7
	S2-4	0.166	1067	6.5
	S2-5	0.166	1067	6.5
	S2-6	0.166	1067	6.5
4th Floor	S4-1	0.166	1067	6.5
	S4-2	0.166	1067	6.5
	S4-3	0.166	1250	7.7
	S4-4	0.166	1067	6.5
	S4-5	0.166	1067	6.5
	S4-6	0.166	1067	6.5
Roof	SR-1	0.33	1067	14.0
	SR-2	0.33	1067	14.0
	SR-3	0.33	1250	16.0
	SR-4	0.33	1067	14.0
	SR-5	0.33	1067	14.0
	SR-6	0.33	1067	14.0

Table 7: New EEE Design Concrete Takeoffs (2" Topping and CIP Roof)

6.5 Cost Breakdown and Comparison

The following tables summarize the results of the structural calculations. They illustrate that the amount of steel required is significantly less than the originally designed EEE. Further analysis of the final estimated cost will be discussed later in this section.

STRUCTURAL STEEL ESTIMATE PRICING (NEW DESIGN)								
Description	**Quantity**	**Unit**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total O & P**	**Total Cost**
COLUMNS								
W12x65	510	LF	$ 83.80	$ 3.84	$ 2.16	$ 89.80	$ 93.39	$ 47,630.19
W12x72	180	LF	$ 92.65	$ 4.14	$ 2.53	$ 99.32	$ 103.29	$ 18,592.52
							TOTAL:	**$ 66,222.70**
BEAMS								
W10x12	17	LF	$ 15.46	$ 4.42	$ 2.70	$ 22.58	$ 23.48	$ 399.19
W12x30	17	LF	$ 39.30	$ 3.11	$ 1.90	$ 44.31	$ 46.08	$ 783.36
W12x35	1548.5	LF	$ 42.50	$ 3.11	$ 1.93	$ 47.54	$ 49.44	$ 76,560.32
W14x22	1361	LF	$ 33.31	$ 2.68	$ 1.64	$ 37.63	$ 39.14	$ 53,265.84
W18x35	173	LF	$ 45.28	$ 3.99	$ 1.80	$ 51.07	$ 53.12	$ 9,189.14
W18x40	138	LF	$ 51.53	$ 3.99	$ 1.80	$ 57.32	$ 59.61	$ 8,226.49
W21x48	1003	LF	$ 60.50	$ 3.27	$ 1.64	$ 65.41	$ 68.03	$ 68,230.48
W24x55	672	LF	$ 181.13	$ 7.14	$ 6.23	$ 194.50	$ 202.28	$ 135,934.96
							TOTAL:	**$ 204,165.43**
						TOTAL ESTIMATE:		**$ 270,388.14**

ESTIMATED COST FOR STEEL CONNECTIONS								
Research has shown that approximately 10% of the total cost of steel equates to the total cost associated with structural connections. This includes labor, material, equipment, and O&P.								
	99.25 Tons	Cost/Ton:	$ 2,724.31	QTY (tons):	9.93	Cost/Ton	$ 2,724.31	$ 27,052.40
						TOTAL ESTIMATE:		**$ 27,052.40**

CAST-IN-PLACE CONCRETE ESTIMATE PRICING								
Description	**Quantity**	**Unit**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total O & P**	**Total Cost**
REBAR								
Elevated Slabs	68	CSF	$ 23.10	$ 23.20	$ -	$ 46.30	$ 48.15	$ 3,274.20
CONCRETE								
Slabs (3,000 PSI)	86	CY	$ 121.02	$ 14.31	$ 5.98	$ 141.31	$ 146.96	$ 12,638.56
2" Topping	80.4	CY	$ 97.00	$ 14.31	$ 5.70	$ 117.01	$ 121.69	$ 9,783.91
Admixture	80.4	per CY	$ 5.00	$ -	$ -	$ -	$ -	$ 402.00
FORMWORK								
Elevated Slabs	364	SFCA	$ 1.27	$ 6.91	$ -	$ 8.18	$ 8.51	$ 3,096.62
METAL DECKING								
20 Ga. G60	6585	SF	$ 1.71	$ 0.52	$ 0.04	$ 2.27	$ 2.36	$ 15,545.87
						TOTAL ESTIMATE:		**$ 44,741.16**

Nitterhouse representative, and Penn State AE alum, provided the estimate cost of the selected plank system. His analysis concluded that the 6”-4’-0” plank with a 6.5” diameter strand pattern will cost $7.50 per square foot of applied space. This value includes manufacturing, delivery, erection, and grouting of the selected material. Mr. Taylor also noted that total overhead and profit for Nitterhouse is also included in the $7.50/SF estimate. The estimate cost for the hollow core plank system is listed on the following page.

NITTERHOUSE PRESTRESSED HOLLOW CORE PLANK ESTIMATE					
Description	**Quantity**	**Unit**	**QTY Planks**	**Total O & P**	**Total Cost**
6"-4'-0" Plank with 2Hr Fire Rating	$ 13,170.00	SF	168	$ 7.50	$ 98,775.00
			TOTAL ESTIMATE:		**$ 98,775.00**

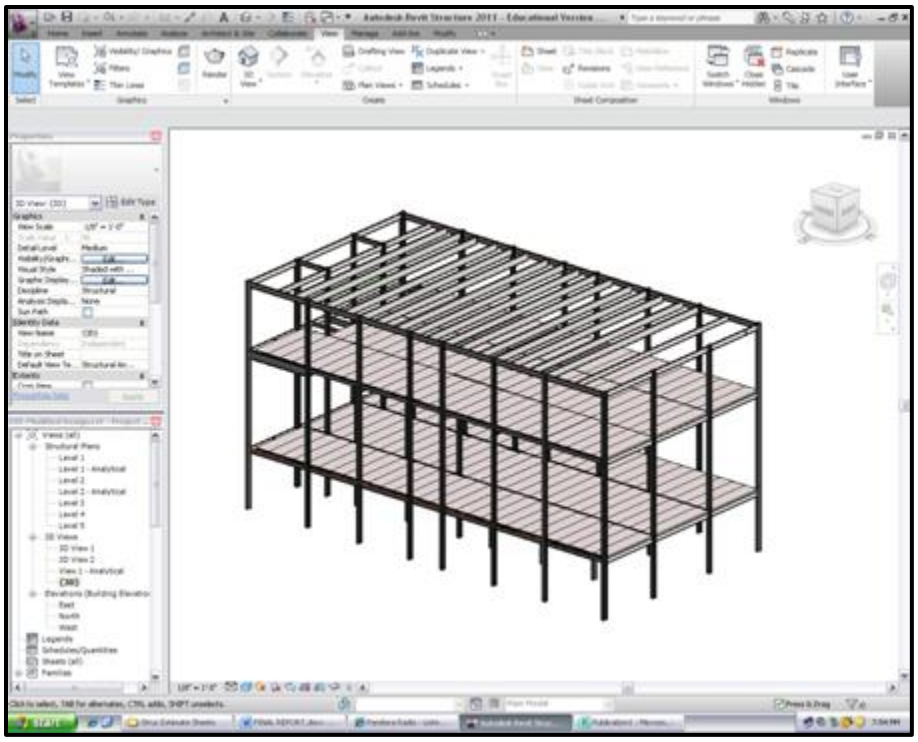
As mentioned earlier, these calculations will be compared to the structural systems estimate shown in the previous section of this analysis. This direct comparison will limit any details that have been omitted due to lack of estimate experience with structural steel and concrete. The figure below summarizes the results of each category associated with the newly designed Precast Electrical Equipment Enclosure. An estimate for steel connections was added to the original estimate to better compare the two designs. It is worth noting that only the 2nd and 4th floors of the structure will be composed of precast hollow core planks. Research has shown that the significant loads associated with green roofs make it impractical to integrate with a hollow core plank system.

SYSTEM COMPARISON ESTIMATE								
	Original Design				Precast Plank System Design			
Component	Unit Cost	Unit	Quantity	Cost	Unit Cost	Unit	Quantity	Cost
Concrete Formwork	$ 8.51	SFCA	1092	$ 9,289.86	$ 8.51	SFCA	364	$ 3,096.62
Welded Wire Fabric	$ 48.15	CSF	204	$ 9,823.01	$ 48.15	CSF	68	$ 3,274.34
CIP Concrete	$ 146.96	CY	320	$ 47,026.97	$ 135.08	CY	166	$ 22,422.47
Steel Columns	$ 2,879.25	TON	23	$ 66,222.70	$ 2,879.25	TON	23	$ 66,222.70
Steel Beams	$ 4,380.13	TON	90.4	$ 395,963.97	$ 3,548.40	TON	76.2	$ 270,388.14
Steel Connections	$ 2,724.31	TON	11.31	$ 30,811.95	$ 2,724.31	TON	9.93	$ 27,052.40
Metal Decking	$ 2.36	SF	19755	$ 46,637.60	$ 2.36	SF	6585	$ 15,540.60
Precast Planks	$ -	SF	0	$ -	$ 7.50	SF	13170	$ 98,775.00
Admixture	$ -	TON	0	$ -	$ 5.00		80.4	$ 402.00
	TOTAL:			**$ 605,776.06**	**TOTAL:**			**$ 507,174.27**

Table 9: Cost Comparison- EEE Structural System

As table 7 illustrates, the Precast Plank System is less expensive than the original design. **The results of this analysis present that the owner would save an approximated $98,600.00** by switching the structural system of the Electrical Equipment Enclosure. Though the combined cost of 2" topping and the plank material and installation is significantly higher than the cost of concrete in original design, it is compensated with the reduction of steel. The steel associated with the 2nd and 4th floors is reduced by 14.2 tons with the utilization of hollow core precast planks. Including the costs of steel connections, the total savings in steel erection is $98,500.00. These savings in addition to the absence of formwork and welded wire fabric expenses help create a more cost effective structural design.

The values and quantities presented in this section will apply to adjusting the overall schedule of erecting the EEE's structural system. Please note that admixtures were included in the estimate for the 2" topping; this was done to help accelerate the curing time to reduce the overall schedule of the EEE.



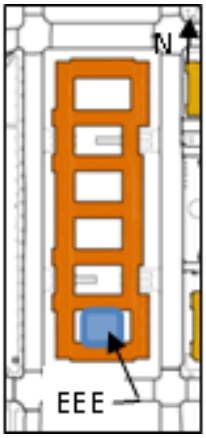


Figure 19: Revit Structures was used for quantity takeoffs and plank coordination for the EEE redesign

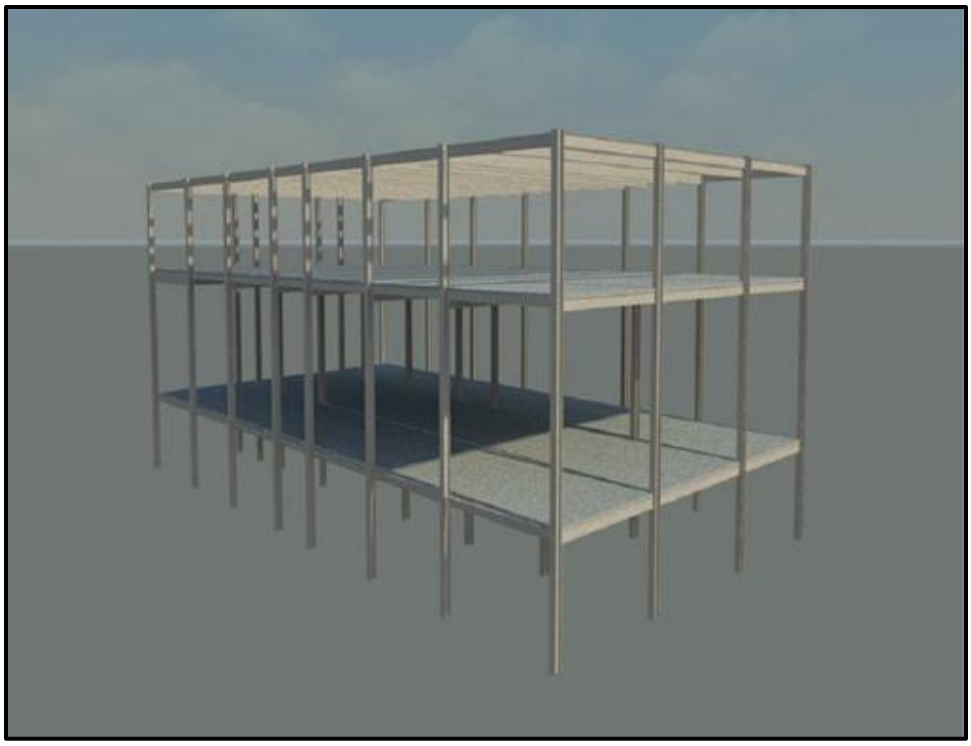


Figure 20: Revit rendering of EEE structural system

6.6 Erection Schedule

The initial goal for implementing a hollow core plank floor system for this analysis was to present an accelerated schedule for the Electrical Equipment Enclosure. As discussed in section 6.3, the originally proposed schedule presented opportunities for acceleration with the allotted curing time for each floor. The durations of major activities for each floor are illustrated again in the table below.

Summary of Major Activities Structural Schedule	
Activity	Duration
Steel Framing	15 Days
Concrete 2nd Floor	7 Days
Concrete to Strength	15 Days
Set/Connect Equipment	22 Days

Table 10: Summary of Major Activities (2nd Floor)

Assumptions

The utilization of precast hollow core planks will allow the project team to minimize the curing time that is listed for the original schedule. It was initially assumed that the prefabricated system would not require a 2" topping to create a rigid diaphragm but minimal case studies were found in regards to this application. To assure the feasibility of this analysis, it was decided to include a 2" topping with accelerating admixtures. Using such admixtures will allow the equipment pads for the equipment in the EEE to be set earlier in the schedule.

Another original assumption for this analysis involved the utilization of precast or prefabricated equipment pads. After contacting Chuck Tomasco of Truland Systems Inc., this assumption proved possible but very impractical. Also confirming the rarity of this application was Ray Sowers of ONCORE Construction, LLC; of whom had no experience with elevated prefabricated pads. It was decided to pour the equipment pads with high early strength concrete to minimize curing time. This would allow the electrical equipment to be set sooner so that erection of the above floors can proceed. Mr. Tomasco noted that equipment could be set on the pads as soon as 1-3 days if high early strength concrete were to be used.

Schedule

The newly revised schedule can be found in Appendix H: Revised EEE Erection Schedule. The following table provides an overview of how specific durations were calculated. Activities that did not change significantly from the original schedule were kept with the same durations. Activities that were added to the new schedule include; Hollow Core Plank Erection, Plank Connections and Grouting, and 2" Topping Placement and Curing. The duration for formwork and equipment pad pouring was also altered due to the application of a high early strength concrete. The separate durations shown in the table below are based off of daily outputs provided by *RS Means Cost Data 2011.*Though these durations were not exactly applied to the schedule, they were used as reference to assure practical production.

Estimated Actvity Durations (RS Means Cost Data 2011)				
Activity	**Unit**	**Daily Output**	**Quantity**	**Duration (Days)**
2nd Floor				
2" Topping- self level dry 3000 psi, pumped	SF	12000	6585	0.548
Topping Cure Time				2.0
Forms in Place for Equipment Pads (4 use)	SFCA	205	109	0.532
Set Equipment Pads- 4" Elevated Pad	SF	2613	1152.9	0.44
Equipment Pad Cure Time				2.0
Stripping of Equipment Pad Formwork	SFCA	205	109	0.532
4th Floor				
2" Topping- self level dry 3000 psi, pumped	SF	12000	6585	0.548
Topping Cure Time				2.0
Forms in Place for Equipment Pads (4 use)	SFCA	205	133	0.648
Set Equipment Pads- 4" Elevated Pad	SF	2613	1114.575	0.42
Equipment Pad Cure Time				2.0
Stripping of Equipment Pad Formwork	SFCA	205	133	0.548

Table 11: Added Activity Durations

Summary of Results

Comparing the Revised EEE Schedule with the Original presents a total time savings of 25 working days. The original schedule lists that the EEE structural schedule will conclude on October 18, 2010; The revised schedule illustrates a structural completion milestone on September 10, 2010. This savings in time is a direct result of eliminating the curing time with the cast in place concrete slabs. It was eliminated by using precast hollow core planks and high early strength concrete for the system's floor system. High early strength concrete was also applied to the equipment pads.

As noted by Mark Taylor, Nitterhouse Concrete Products, Inc. President, each floor would take only one weekend to place its associated planks. The revised schedule allowed a total of 2 weekend days with crane use for this activity. Furthermore, Mr. Taylor explained that another day would be required for plank connections and grouting. The schedule illustrates a total of 5 working days for this activity; this was done to include any curing time or unseen conditions for the plank connections.

The 2" topping for each floor is to be completed by a third party subcontractor. The concrete contractor for the Office Renovation Building is *Southland Concrete*. RS Means data shows that this activity would take less than one working day for each 6585 SF floor area. Research has shown that applying a Type III High Early Strength Concrete with a calcium formate accelerator would allow the topping to cure in approximately 2 days to reach the desired 3000 psi strength. Because of available float in the schedule, a total of 5 days was allotted for setting and curing the 2" topping.

Also illustrated in the schedule is the total time required to form, pour, cure, and strip the equipment pads for each floor. *RS Means* data demonstrates that the required formwork would take approximately ½ working days to perform this activity. Additionally, it would take ½ working days to pour the concrete for each floor's associated pads. Applying the same Type III concrete with appropriate admixtures would require 2 days for the system to reach the desired strength. To compensate for any details missed within this analysis, one whole working week was applied to this series of activities.

Because crane use determined the critical path for the erection schedule, enough time was allotted to each of these activities. Before the equipment is scheduled to be set for each floor, a total of 10 days was included to allow for additional construction sequencing within the EEE's erection.

Also worth noting is the duration listed for the steel framing of each floor. The original schedule allows 15 working days to erect the 2nd floor and 4 working weekends to erect the 4th floor. Though the precast plank design requires significantly less steel per floor, this duration was not changed. This was done to compensate for any time lost due to weather delays or any unseen conditions.

The revised EEE schedule concludes with saving the project team approximately 5 weeks of construction time while allowing enough time to compensate for any unpredictable delays or durations that could not be defined with the researcher's limited construction experience.

6.7 Site Logistics

Part of this analysis is to provide a stage by stage visualization of the site utilization for the Office Renovation Building project. This section will demonstrate how the project team will use site logistics for erecting the 2nd floor steel members, steel and precast plank coordination, and weekday concrete pouring for each floor. These phases of the erection stage will be illustrated using Google Sketchup®.

2nd floor steel members were erected in an unusual fashion. To allow construction of the EEE to continue during the week, subcontractors placed the steel members using hand jacks and industrial dollies. A small crane was used at the southern exterior end of the Office Renovation Building to hoist members onto rollers. Steel members were rolled through the facility into the second floor level of the EEE. Because the newly proposed precast structural system still involves the placement of steel members at the second floor, this logistical plan was not changed. A 3D model was originally created to help illustrate this stage but it was decided construction photos were much more descriptive. Pictured below is a series of photos illustrating how the Gilbane Grunley project team was able to coordinate the delivery of 2nd floor steel members into the EEE.

Figure 21: Delivery trucks back into an area near the building's opened corridor where a small crane is used to hoist the steel members onto rollers

Figure 22: Once set, steel members are rolled through the building into the EEE courtyard. Workers use rollers and hand jacks to place the member in its appropriate place on top of the existing structure

Figure 23: Because the small crane can be used without occupying the adjacent roadway, steel erection can take place throughout the week

The next stage of erecting the newly designed EEE would involve the delivery and placement of the hollow core planks. As previously noted in Appendix E: Occupancy Permit and Crane Plans, crane use for the EEE can only take place over the weekend from Saturday 4:00 AM until Sunday 7:00 PM. This was permitted in an effort to minimize the impact of commuter traffic while being able to accommodate the necessities of the project. Due to the similarity with the delivery of steel, this will be coordinated in the same fashion as the existing steel delivery plan. Once the jib of the large crane is assembled, ample time is still available for an entire floor of hollow core planks to be erected. The following rendering provides a summarized view of how hollow core planks, and all associated steel, will be brought on site and erected by the crane.

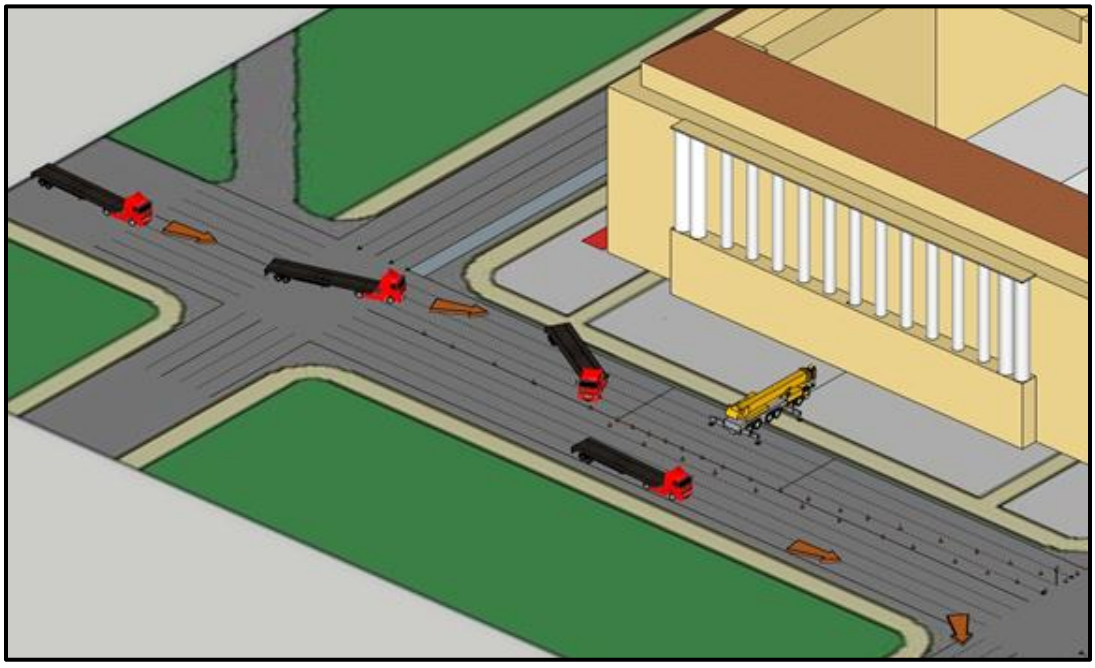


Figure 24: Delivery trucks will stop in the closed of street space denoted in the occupancy permit. Hollow core planks and steel members will be picked directly from the trucks so that the trucks may easily move out of the delivery area and back into the street.

The route chosen for the steel and plank delivery is conveniently coordinated to work with standard traffic flow. The trucks for the hollow core planks will be coming from Chambersburg, Pa in such a route that they will arrive at the site as seen in the figure above. Steel and electrical equipment will be delivered in the same fashion. For each floor of hollow core planks installed, 4 trucks will be used to deliver a total of 84 planks. On a 48' x 8'-6" flatbed, 4 stacks of 8 planks can be delivered, this is a conservative assumption based on the input of Mr. Mark Taylor of Nitterhouse Concrete Products. The first truck is expected to deliver all rigging equipment specific to placing the hollow core planks. This coordination of delivery and staging areas is very similar to what the project team is currently utilizing.

The current structural design for the EEE requires significant concrete work to be performed. The project team utilizes the southern end of the building's property space to host all concrete equipment and deliveries. Gilbane Grunley is able to occupy the parking lane of the adjacent street at all times. Opening up this area to concrete activities allows work to take place throughout the week. Because of the 2" topping and equipment pad activities associated with the newly proposed system, a similar logistics plan will be used. Pictured below is how concrete trucks will drive up to the site where a pump truck will be used to transport concrete through the building into the EEE construction area.

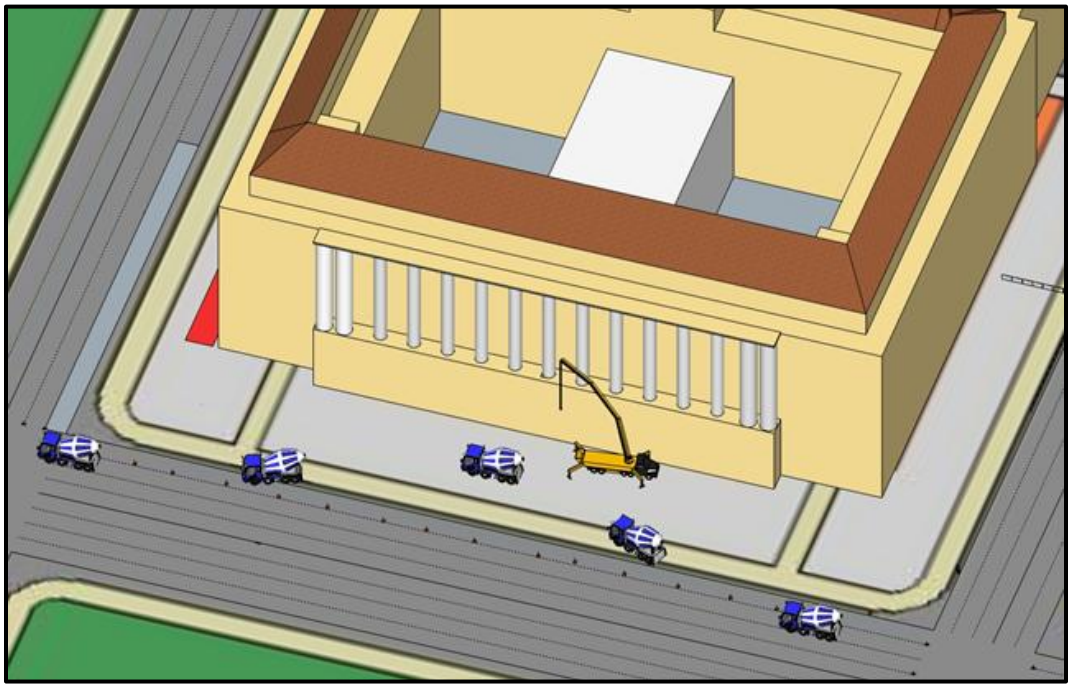


Figure 25: Delivery of concrete and associated concrete activities are permitted to take place during the week because of minimal impact to the area's traffic patterns. A pump truck will be used to transport concrete through the ORB into the EEE construction area

Because the delivery and coordination with the newly proposed structural design of the EEE closely resembles that of the existing logistics plans it is assumed that minimal changes are required. With the limited change in coordination, it can be concluded that the logistics planning of the proposed precast system is feasible.

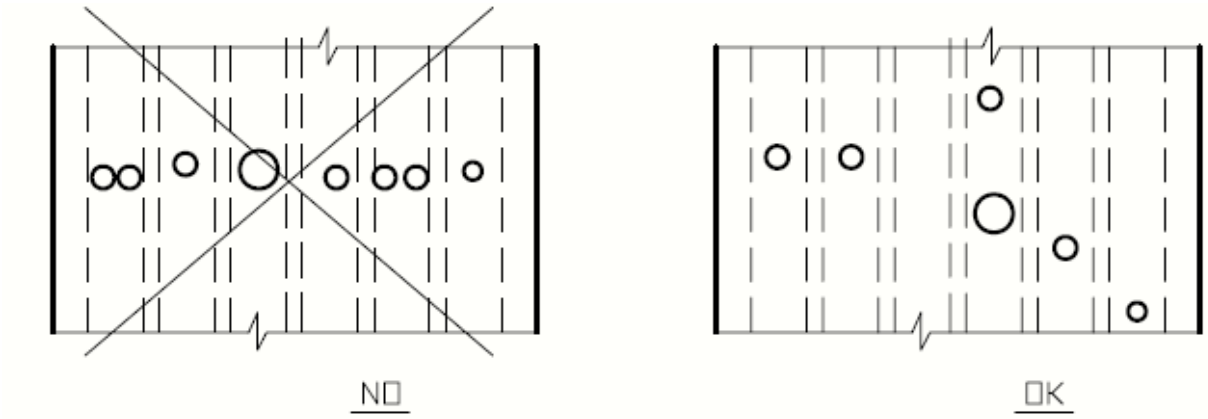
6.8 Connection and Penetration Details

Though the proposed hollow core plank system presents cost and schedule savings for the Electrical Equipment Enclosure, coordinated the layout and penetration details of the floor system is very difficult. Details of how the planks are installed are available in Appendix G: Hollow Core Plank Details.

A major difficulty within this analysis revolved around what floor penetrations are required for the EEE. Because the original floor system was designed to be cast in place concrete on metal decking; the structural drawings did not illustrate where the facility's floor penetrations are located. Input from structural designers state that penetrations are not often shown on such a system because the slabs are not structural elements. Also, the researcher of this analysis was not able to obtain construction drawings of the necessary floor penetrations due to owner restrictions. Floor details and penetrations were not available at the owner's request. Without this crucial bit of information, it was not feasible to coordinate a specific precast plank design.

The details and notes shown below are provided by Nitterhouse Concrete Products. They summarize what types and size penetrations of are permitted through the hollow core planks.

- If needed, holes should be drilled in cores wherever possible while avoided the plank's webs.
- Holes are not to be concreted at one place along the plank



- 'Obviously some cases might involve cutting a web. In general this may be done in planks that meet all of the following:"
  - Only in 4' wide planks
  - Only cut into two webs per plank
  - Planks with no factory cut openings
  - Planks not supporting other planks
  - No closer than every fourth plank
- Most importantly, if any of the conditions previously listed are more critical, a professional engineer or the engineering department at the plank designer should be contacted for consultation.

To best guarantee the structural integrity of the planks, penetrations should be coordinated early and be done in the factory conditions of the manufacturer's plant. Any particularly large penetrations may be integrated with a hollow core plank system by placing two completely separate members around the span of the penetration so that the cutting of webs can be minimized. Also, under extreme conditions, structural steel members can be placed around the large penetration so that the planks may be placed before and after them. This makes is difficult to integrate planks with the system because more internal steel beams are required.

Again, it must be stressed that the impact of floor penetrations is a crucial element of coordinating the design of precast hollow core planks. For the purposes of this analysis, it is unfortunate that specific details on the EEE's floor penetrations could not be provided. This lack of information will severely impact the final recommendation described in the next section.

6.9 Conclusions and Final Thoughts

The results of integrating a precast hollow core plank system with the Electrical Equipment Enclosure of the Office Renovation Building were as expected. The savings from implementing the new system total approximately **$98,600.00**. This saving was calculated by presenting a side by side analysis of the total estimated cost for each system. Directly comparing two estimates performed by the researcher helped minimize any discrepancies or items forgotten in comparison to the actual structural cost.

More importantly, utilizing a precast system helped accelerate the erection schedule for the structure. Hollow core planks and the use of high early strength concrete presented a time saving of **25 working days**. The revised schedule for the EEE was completed with conservative assumptions and less than average daily outputs; this was done to compensate for any detailed items forgotten within the schedule.

Site logistics of the newly proposed system had minimal impact on the current site utilization for the Office Renovation Building. Trucks delivering the precast material were able to be coordinated in a similar manner when being compared to the current steel delivery schedule.

However, the lack of information with the floor penetrations of the EEE provides major uncertainty with the new system's feasibility and accuracy. A major element of successfully executing prefabricated systems within the construction industry include pre planning lead times and precise coordination. Even if details of the facility's floor penetrations were provided, any changes in design or layout would severely impact the planning and coordination of the plank system.

Following the results of the analysis performed, it is recommended that GGJV project team not pursue the utilization of a precast hollow core plank floor system for the EEE. Though schedule acceleration was significant (25 days), similar results could be obtained by using high early strength concrete for the facility's elevated floor slabs and equipment pads. Also, the use of one way slabs on metal decking would make coordination much easier for any floor penetrations. Finally, any changes on the prefabricated system would severely impact any possible cost savings.

7.0 Feasibility Study for Photovoltaic Energy System

7.1 Problem and Background Information

This topic will focus the sustainable application of a photovoltaic energy system on the Office Renovation Building. The 1.8 million square foot office building presents over 180,000 SF of terracotta roof space. This extremely large amount of area presents a worthy opportunity to analyze the feasibility of a solar energy system to contribute to the building's energy consumption. Because the project is currently only in its second phase of construction, this analysis will focus on utilizing a PV array system to help power the building's Electrical Equipment Enclosure.

7.2 Research Goal

The goal of this analysis is to analyze the feasibility of applying a PV array system to help power the structure's Electrical Equipment Enclosure. Due to past research on similar applications, this study will focus specifically on powering the EEE's lighting system. Focusing on this aspect of the structure will present a more direct application of a photovoltaic energy system. With the utilization of a simple 3D model and a life-cycle cost analysis to present that this system should be pursued.

Another reason for analyzing this application relates to the growing popularity of PV systems. Such systems have been growing in popularity in recent years. This is largely due to that fact that the costs associated with PV systems are becoming more affordable. They also offer the opportunity for building's to earn federal credits and tax rebates for installing such systems. A grid- tie in system would be ideal for the Office Renovation Building because it would allow the building owner to make a visual statement that it is trying to contribute towards the building sustainability movement. It will also present the owner with the opportunity to help decrease the expenses associated with increasing energy costs.

7.3 Research and Design

With the growing interest in PV array system technologies, many manufacturers and products are present throughout the industry. Following research of the many available manufacturers, it was decided to pursue Kyocera Solar Energy Products. Kyocera is currently rated as one of the top 10 global manufacturers of solar energy products. Also, Kyocera product information was readily available throughout online sources with extensive information in regards to their performance. The company also provides a well-developed 5 step system to help consumers size, design, and analyze solar power applications.

PV ARRAY PAREMTERS	
Office Renovation Building	
Latitude:	38.892° N
Longitude:	77.032° W
Available Rood Area:	5,760 SF
Slope of Roof	3:5 (31°)
Orientation	Directly South
Optimum Tilt Angle	31 Degrees
Summer	24 Degrees
Fall/Spring	39 Degrees
Winter	54 Degrees
Sun Hours/Day	4.9

Table 12: Preliminary PV Array Parameters

Before following Kyocera's 5 step process for selecting a photovoltaic system, it is required to size the appropriate load that the PV system will power. Presented in the following table, this information summarizes crucial characteristics that help define the parameters of a PV array system. This information includes: the geographic location of the project, the available roof area, the direction the panels will face, the optimal angle for their orientation, and approximated sun hours/day.

The available roof area chosen for this analysis is limited to 5,760 square feet. This area, depicted in **figure 17** was chosen because it is located within an interior bay of the building, its orientation facing directly south and for its proximity to the EEE. This area is also sufficient to bear the required solar panels designed for the system. The sizing for the panels will be presented later within this report.

Furthermore, the angle chosen to orient the solar panels will be 39 degrees. Most research suggests that the optimal angle for solar panels is comparable to the latitude of the project site. This angle is similar to the pitch of the roof, 31 degrees; this will be analyzed later with the panel's connection details.

Finally, the total sun hours per day was derived from appropriate solar isolation maps found online. This is the **first step** of the Kyocera solar panel design process. A map illustrating the area's sun hours per day can be found in **figure 18**. Because of the general location of the Office Renovation building, 4.9 full sun hours per day will be assumed for this analysis

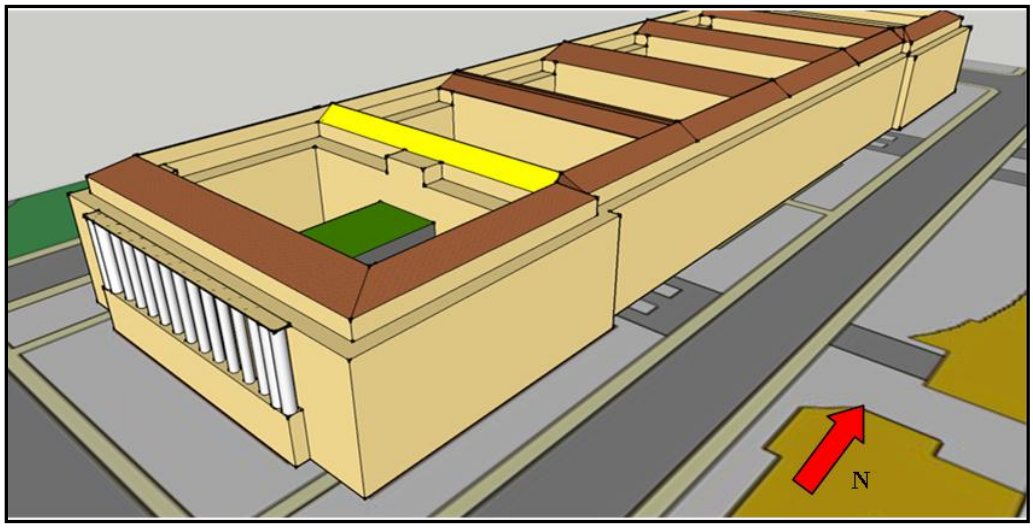


Figure 26: Office Renovation Building with proposed roof space for PV system highlighted in yellow. The roof's angel and orientation makes it an ideal location for PV solar panels.

The **second step** taken to design the appropriate PV system involves calculating the appropriate energy load. Two varieties of fixtures are included to illuminate the Electrical Equipment Enclosure. The second floor consists of 37 2 Lamp 48Watt fluorescent lighting fixtures. The fourth floor presents a total of 40 2 lamp 28 Watt fluorescent lighting fixtures. Additionally, it was assumed that the lights will be in operation, on average, a total of 15 hours per day (5pm-8am). Following the calculations presented in **table 8**, the luminaries in the Electrical Equipment Enclosure consume a total of 91,224 Watt-Hours of energy per day. Within this calculation, a 5 percent waste factor was included to compensate for inefficiencies within the system.

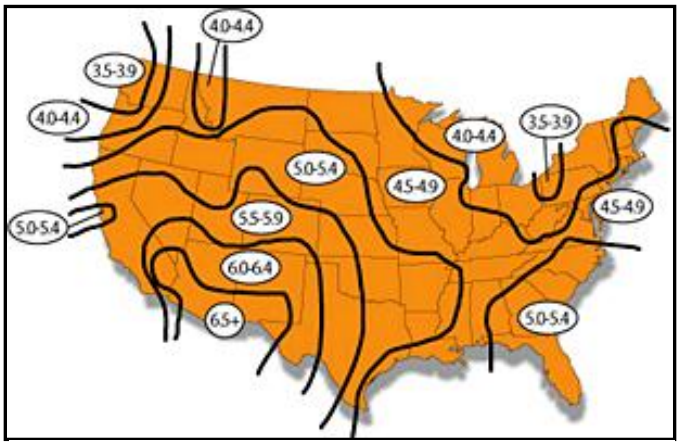


Figure 27: Full Sun Hours/Day Map courtesy of The Innovative Energy Store"

Energy Load Calculations- EEE Lighting				
Component	**Quantity**	**Watts**	**Hrs/ Day**	**kWh**
2nd Floor- 2 Lamp Pendant Mounted Fluorescent Industrial Luminaries	37	48	15	53.28
4th Floor-2 Lamp Pendant Mounted Fluorescent General Purpose Industrial	40	28	15	33.6
			Total kWh	86.88
Total Watt-Hours Energy Load (5% Waste Factor Included)				**91,224**

Table 13: Energy Load Calculations

The **third step** in calculating the structure's PV array system involves finding the appropriate Watts per Hours of Sunlight. This was done by dividing the total energy load (91,224 kWh) by the full solar hours per day (4.9). The total Watts per Hours of Sunlight needed for the system is 18,617.

The **fourth step** requires determining the actual energy produced by the system's selected panel. The Kyocera solar module KD210GX-LP panels were selected. The energy produced by this panel is calculated by multiplying its amperage by its charging voltage. 13 volts was assumed for the charging voltage based on product research and 7.9 amps are specific to this model. The actual produced power for this panel is 102.70.

Finally, the **fifth step** helps to establish the actual number of KD210GX-LP panels required to support the previously calculated load. Taking the total Watts per Hours of sunlight need for the system (18,617 Wh) and dividing it by the energy produced by the selected panel (102.70) results in a total of 181.2 panels to be installed. **Table 14** below summarizes the results of this five step procedure that helped calculate the total number of panels needed to power the system.

KYOCERA - Calculation for the Electrical Equipment Enclosure		
Step	Value	Comment / Description
1	4.9	sun hours per day
2	91224	watt-hours energy load (5% Waste Factor Included)
3	18617	watts/hour of sunlight
4	102.7	amperage x charging voltage for model KD210GX-LP
5	181.3	# of models required
	190	**Units Required**

Table 14: PV System Sizing Calculation Summary

7.4 Photovoltaic System Layout

Now that the total number of panels needed to support the Electrical Equipment Enclosure's lighting system has been calculated, the system lay out must be designed to assure optimum performance. Because of the pitch of the roof at the location, shadow interference is minimal. It was decided to layout the panels in three rows stretching across the majority of the roof's length. This was done to create spacing of approximately 2.5 feet for ease of maintenance access. The 31 degree pitch of the roof should provide a perfect angle for the panels to absorb optimal sunlight throughout the year. The following renderings demonstrate that no shadow interference is present at any time of the year.

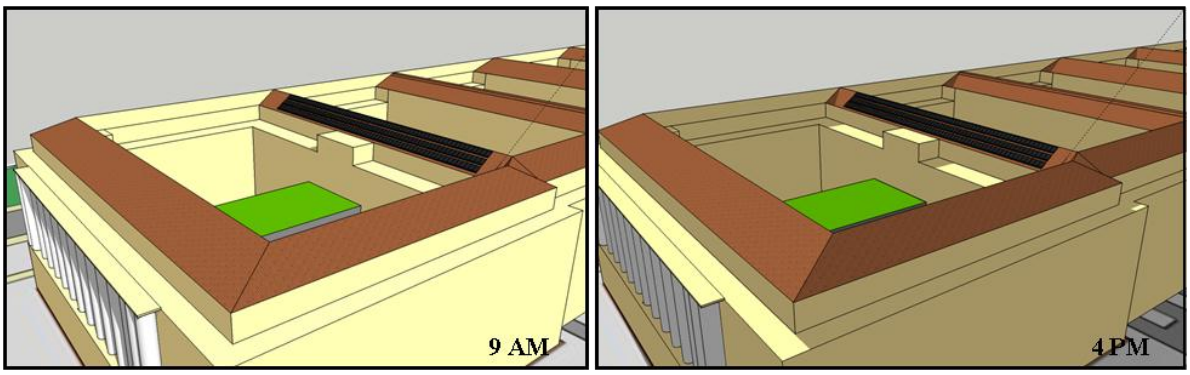


Figure 28: Summer Solstice (June 20)

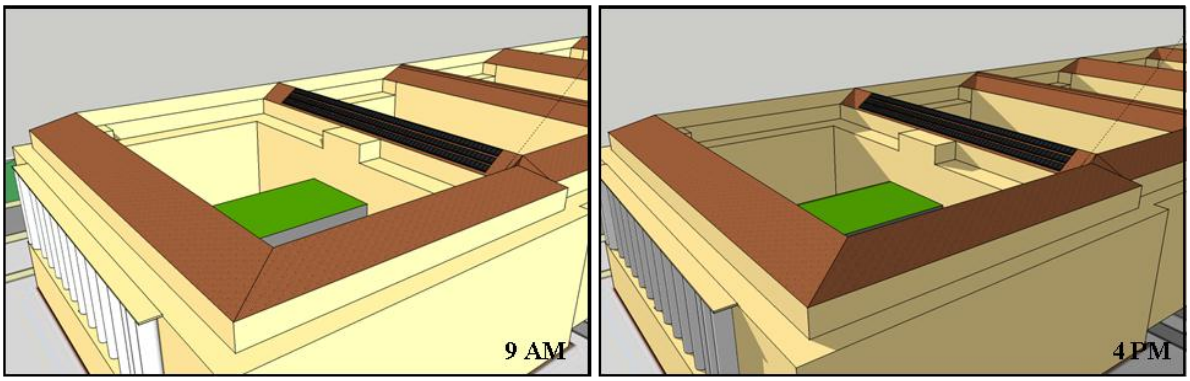


Figure 29: Spring/Fall Equinox (March 20, September 22)

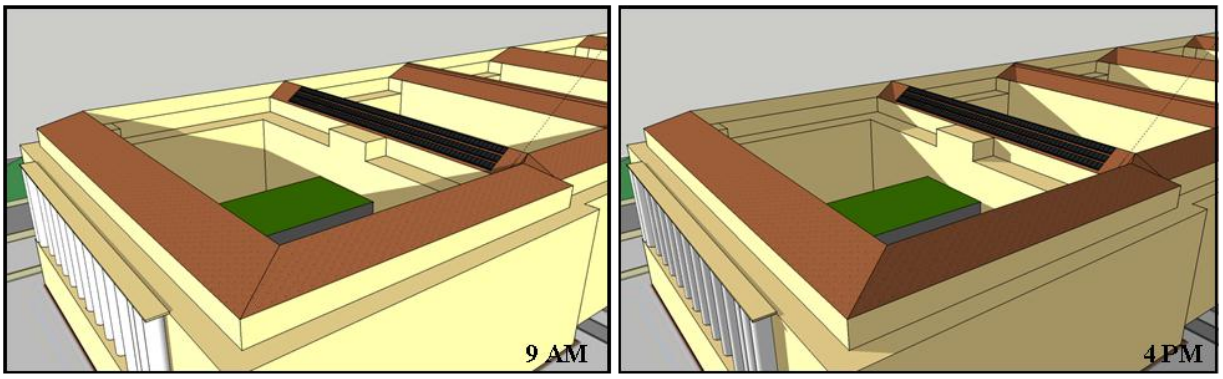


Figure 30: Winter Solstice (December 21)

The final PV layout will be comprised of 192 KD210GX-LP Kyocera panels. As previously stated, they will be organized in three rows of 64 panels. Each panel is 59" x 39" and will be mounted parallel to the roof's pitch of 31 degrees. Also, each row will be separated by 2.5 feet to prevent overcastting shadows from each panel as well as adding space for maintenance services to access each panel. **Figure 21** demonstrates the lay out to be used on the corridor's roof structure

Figure 31: PV Panel Layout, each row contains 64 individual panels

7.5 Structural Impact and Installation

After calculating the number of panels needed and orienting their lay out, it was necessary to determine the structural impacts of the PV system. The current roof structure bears terracotta tiles with underlying filter fabric, rigid insulation, and appropriate water retention lining. The supporting roof structure is cast in place concrete on metal decking which is supported by W14x22 Steel columns located 15' 6" apart with a W24x55 steel beam spanning that distance. Before illustrating the installation process of the photovoltaic panels, the contributing loads of the solar panel system must be determined.

According to Kyocera KD210GX-LP product specifications, each panel weighs a total of 40 lbs. (More information on the KD210GX-LP panels can be found in Appendix I: PV System Details) Additionally, the mounting system selected, SunFrame Shared Rail System, is installed in 16.25' increments; including the system's accessories, the mount weighs 8.86 lbs per linear foot. The **figure32** illustrates how the PV systems contributes to the tributary area of the supporting roof structure

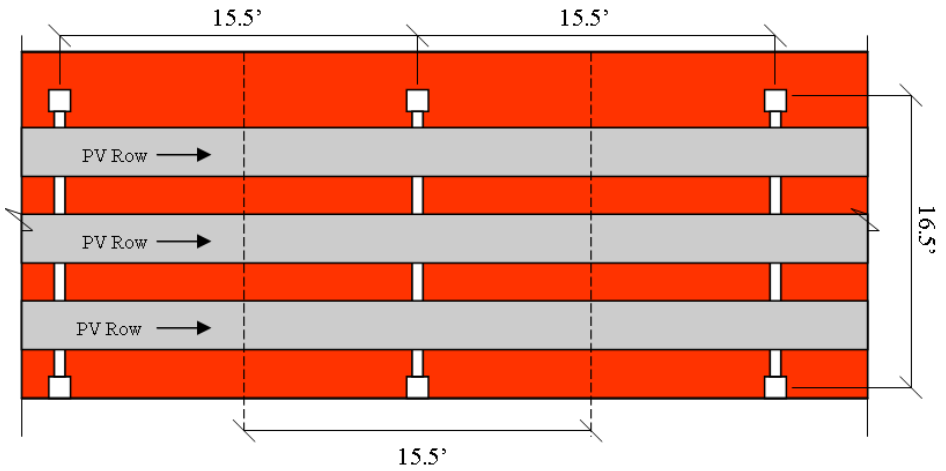


Figure 32: Illustration of how Solar Panels contribute to the structural system supporting the roof

Approximately five solar panels can contribute to the load for each beam's tributary area. After analyzing the total load of the mounting system and the solar panels, 20.01 lbs per linear foot is added to the roof structure. Research and structural engineering input suggests that this load in minimal and does not require the support structure to be changed to compensate for the PV system. A breakdown as to how the total load was determined can be seen in **table 15**.

PV System Contributing Load						
COMPONENT	WEIGHT (LBS.)	TRIB. AREA (FT)	#/TRUSS	LOAD (LBS)	BEAM LENGTH (FT)	LOAD (PLF)
KD210GX-LP	40	15.5	4.8	192	16.5	11.64
Rail System	28.8	15.5	4.8	138.24	16.5	8.38
TOTAL	68.8	15.5	4.8	330.24	16.5	**20.01**

Table 15: Tributary Load Calculations for PV System

Installation

It was difficult to find a practical installation system that can be placed on the existing roof structure for the Office Renovation Building. Most commercial and office structure's that utilize solar panel systems commonly have flat finished concrete roof structures that make is easy to install mounting systems. Fortunately, after referencing many west coast residential buildings, an application for installing the PV system exists. The SunFrame Shared Rail System standing on Standoff attachment accessories is a perfect application for this project. This system is growing in popularity due to the many retrofits of existing structures that contain terracotta tile roofs.

Illustrated in the following series of photographs, installing a PV system on a tile roof structure is not as difficult as most would think. The most efficient way involves removing all of the tiles under where the PV panels will be located. Once the appropriate tiles are removed, the area is re-roofed and resealed with rolled roofing. The Standoff and Rail System are then orientated and installed throughout the entire area followed by attaching the solar panels to the mounting system.

Figure 33: Rolled roofing material replaces the area where the Terracotta tiles are removed

Figure 34: Standoffs are attached to the roof structure with the SunFrame Rail System running the entirety of the PV panel layout

Figure 35: Finished close up of how the PV panels are incorporated with the existing Terracotta roof tile system

7.6 System Tie-In

Following research on PV systems, it has been discovered that a PV system tie-in is most effective when they are interconnected with the corresponding utility grid. Tying in the Office Renovation Building's proposed PV energy system most directly relates to this approach. This is because the photovoltaic panels are sized to compensate the energy consumed for the EEE's lighting load, they will not be directly powering them. The energy produced by the solar panels will be brought into the utility power supply system. Additionally, tying the array into the local utility grid allows the Office Renovation Building to take advantage of a variety of incentives applicable to alternative energy systems. Rebates and Incentives will be discussed in the next section of this analysis

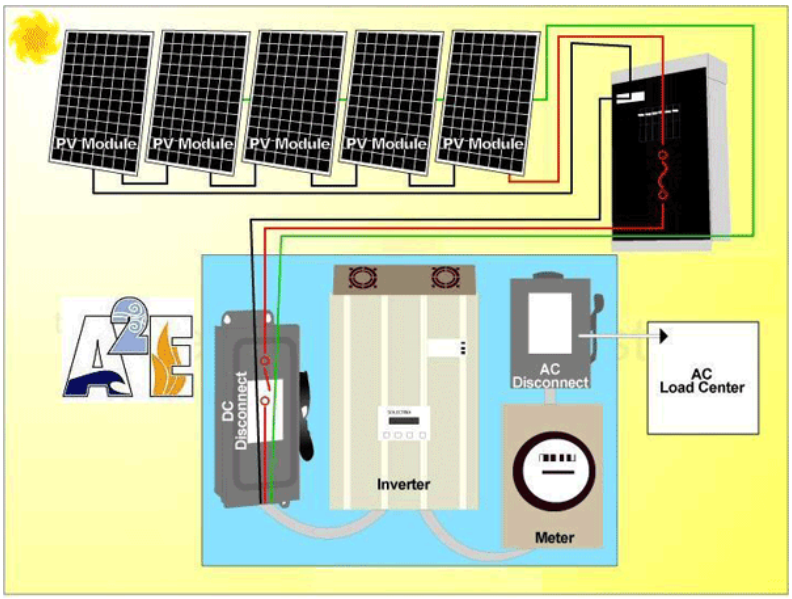


Figure 36: Grid Connection Diagram Courtesy of A2Energy.com

For the system to be tied into the grid, the panels are first connected to a Balance of Systems equipment set (BOS). The series of wires help run energy produced by the PV panels to the electrical system of the facility. Wiring systems included in the BOS are disconnects for the AC and DC sides of the inverter, ground fault protection, and overcurrrent protection for the panels.

The BOS equipment is then connected to the system's inverter. This piece of equipment, commonly located near the PV panels, helps convert the DC power generated by the panels into AC power. The AC power is what the utility company and facility uses for electricity. In reference to Eric Fedder's 2010 Senior Thesis Final Report, the most efficient inverters available for PV systems producing 40.3 kW DC power is a combination of SB 6000-US units mounted on the Sunny Tower-US series by SMA Solar Technologies, LLC. Product information on the SB 6000-US inverters and the Sunny Tower system can be seen in **Appendix I: PV System Details**. A sample combination of six (6) SB 6000-US units are also presented in the appendix. Utilizing this system sizes the inverter to adequately match the requirements of the proposed PV system. This configuration can support 45 kW of DC power produces by solar panels; the system on the Office Renovation Building provides 40.3 kW.

Figure 37 illustrates where the BOS equipment will be connecting to the inverter's proposed location. To prevent voltage drops in DC current running through the wire installation, the Inverter will be located as close as possible to the PV panels. Additionally, this is to minimize the cost of DC wire considering it is much more expensive than the AC variety. The dimensions of the Sunny Tower Unit are 43"x 71"x 39" (W/H/D). Though the system is designed to be installed outside, research suggests that it is highly recommended to house the unit in a ventilated enclosure.

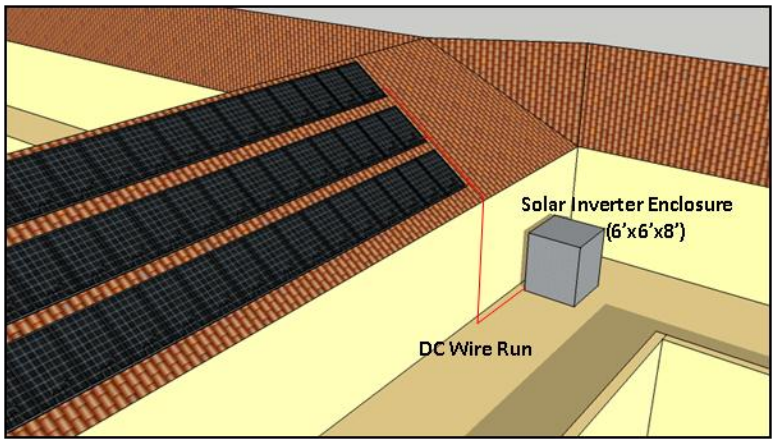


Figure 37: Located of Inverter Enclosure (This location does not obstruct any of the building's windows)

Before being connected to the main service panel, where the generated energy meets the utility company's supplied power, AC disconnects and wire runs will hook up into a meter box. This helps the utility company know how much energy is being produced by the system so that is may award *Net Metering* incentives. Finally, the power generated by the PV system will connect to the main distribution panel where is will be combined with the energy provided by the utility company.

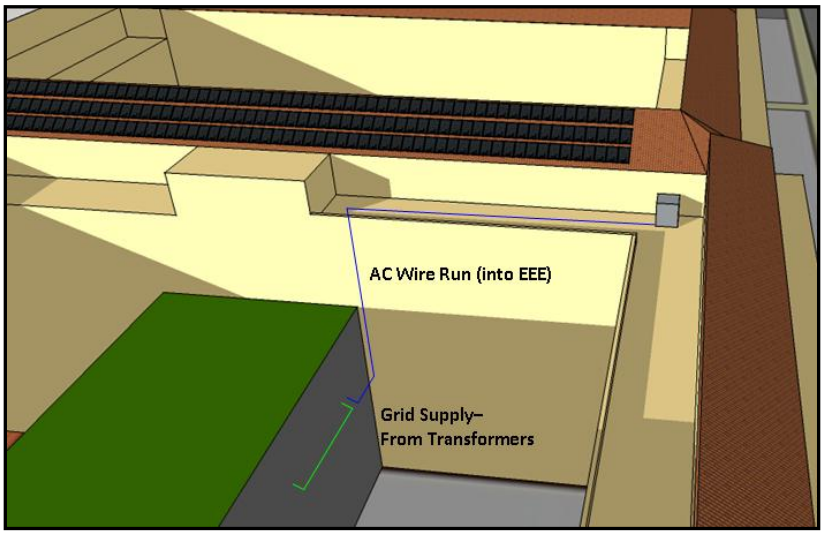


Figure 38: AC Wire Run from Inverter to Grid Connection/Distribution Panel in EEE

7.7 Energy Production and Feasibility Analysis

Energy Production

To determine the efficiency and feasibility of the proposed PV energy system, the total amount of energy produced must be calculated. This is done by taking the watts produced by the product panel (210 Watts) and multiplying it by the total number of panels used (192). This yields system size of 40,320W. This value will help calculate the photovoltaic watts factor for the building's location. It will also determine the amount of alternating current being produced by the system.

The following tables represent AC energy produced over the period of one year for the Office Renovation Building's PV system. This was done with the PVWatts V.1 Calculator. The online calculator works to determine the performance for grid-connected PV systems. In order to find the total number of kilowatt hours produced by the designed system from every kilowatt of DC energy. This is known as the PVWatt factor, it is calculated by taking the total amount of kilowatt hours produced by the system in a year (49,766 kWh) and dividing it by the size of the designed system (40.3 kW). The amount of kilowatt hours produced per kilowatt of energy totals 1,235.

Station Identification	
City:	Mid-Atlantic*
State:	United States*
Latitude:	38.892° N
Longitude:	77.032° W
Elevation:	125 m
PV System Specifications	
DC Rating:	40.3 kW
DC to AC Derate Factc	0.77
AC Rating:	31.0 kW
Array Type:	Fixed Tilt
Array Tilt:	31.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.0 ¢/kWh

Table 17: Information Requirements for PVWatt Calculator

AC Energy Generated			
Month	Solar Radiation (kWh/m^2/da	AC Energy (kWh)	Energy Value ($)
1	3.39	3366	269.28
2	4.13	3614	289.12
3	4.77	4498	359.84
4	5.44	4779	382.32
5	5.53	4781	382.48
6	5.95	4983	398.64
7	5.71	4812	384.96
8	5.52	4734	378.72
9	5.08	4305	344.4
10	4.58	4141	331.28
11	3.38	3063	245.04
12	2.84	2690	215.2
Year	**4.7**	**49766**	**3981.28**

Table 16: Annual AC Energy Output (PVWatt Calculator Results)

System Cost

In order to accurately predict the life-cycle cost and feasibility of applying the designed PV energy system, the cost of the system must be determined. This includes the cost of the solar panels, mounting system, supporting equipment, and the cost for labor and installation. In a study performed by Ryan Wiser titled *Tracking the Sun: The Installed Cost of Photovoltaics* , the author exclaims that the average cost of PV systems has decreased significantly over the past ten years. Data results present that the average cost for a system similar to the one designed for the Office Renovation Building is $7.60 per

watt of energy produced. Because the Renovation Building requires rework for removing the Terracotta tiles on the roof, .20 cents per watt was added to this value. After applying the estimated cost of $7.80 per watt to the 40.3 kW system, a total of $314,340.00 was determined. After researching the direct cost of the Kyocera Solar Panels and UniRac SunFrame Shared Rail System, the average value is higher than expected. This may be a result of including the cost of additional equipment, the system's inverter and wiring for example. This analysis will proceed with using a value of $314,340.00 for the total cost of the sytem.

Rebates and Incentives

Though many tax rebates and grants are available within the Office Renovation Building's region, the project is not applicable for any of them. After interviewing GSA owner representatives, the building's owners do not pay taxes because it is a federal building.

However, the Office Renovation Building would be entitled to any rebates awarded by the area's utility and power provider. At this time, the utility provider offers grants mostly related to building commissioning and controls. According to the *Database of State Incentives for Renewable & Efficiency (www.dsire.org),* the local utility provider is willing to fund up to $500,000.00 for energy efficient systems. Most qualifying applicants are awarded a $40,000.00 grant for installation costs for systems like phovoltaics and solar power. This value will be included used in analyzing the systems life-cycle cost. Additionally, the Office Renovation Building can take advantage of the *Net Metering* principle offered by the provider. This means that the building will receive credit towards its monthly energy bill for the power its PV system supplies. Because the average cost per kWh in the area is $0.13, the Office renovation building is entitled to $130.00/MWh of energy produced.

As previously mentioned, federal buildings are not typically eligible to receiving tax credits or rebates. However, the building's local area offers a program that the project can benefit from. The district's Public Service Commission awards up to $500/MWh produced by alternative energy systems on a building. This *Solar Renewable Energy Certificate* is applicable to federal buildings. This performance based incentive applies to all the energy produced throughout the life of the system. Though the reimbursement rates vary, a conservite assumption of $460/MWh will be used in the following payback analysis. This value was chosen based on the current average rewarded ($370/MWh) and adjusted values projected for the life of the system (projected to exceed $500/MWh over the next 25 years).

Savings and Incentives Applicable to the Office Renovation Building		
Northeast, United States		
Program	Incentive Type	Amount
Utility Company: Existing Buildings Energy Efficient Program	Grant	$20,000.00
Utility Company: *Net Metering*	Performance Incentive	$140/MWh
District Public Service Commision: Solar Renewable Energy Certificates	Performance Incentive	$460/MWh

Table 18: Applicable Incentives

Life Cycle and Payback Period Analysis

To fully understand the benefits of installing a photovoltaic system, a life-cycle analysis had to be performed. The following set of tables and graphs will illustrate the proposed system's payback period. The following photovoltaic rebate and loan calculator is credited to Andrew Mackey, M.S. Construction Management. His work was reapplied to the proposed Photovoltaic system for the Office Renovation Building. All appropriate size factors and appropriate incentives were applied to this analysis. Additionally, consultation was also provided by Matthew Dabrowski of Davis Construction. Mr. Dabrowski had previously analyzed a similar system using Mr. Mackey's loan calculator.

Market			Comments
Retail Cost of Electricity	0.13	$/kWh	-Avg. cost of electricity in Northeast, US (March 2011)
Elec. Rate increase	2.50%		-Projected annual increase electricity cost
Loan			
Percentage Borrowed	100.00%		-Assuming full cost of system is in the GMP
Loan Value	$294,390.00		-Total cost of system less rebates
Interest rate	3.00%	APY	
Period	25	Years	-Assumed life of PV system
CRF	0.004742113		-Capitol Recovery Factor: r(1+r)^n/[(1+r)^n-1]
Rebates / Incentives			
Net Metering Savings	130	$/MWh	-Utility Company Reimbursement (Net Metering)
PSC Certificate	460	$/MWh	-Public Service Commision performance based incentive)
PEPCO Grant	$20,000.00		-Utility provider grant for alternative energy system
System			
Size	40.3	kW DC	-Derived earlier in the PV analysis section
Cost / W	$7.80	$/W	-Assumption explained in *System Cost* section
Total Cost	$314,340.00		-(Size)x(Cost/Watt)
PVWatts Factor	1234		-Location based solar electricity production rate
Annual AC production	49730	kWh	-(Size)x(PVWatts Factor)
Roof Area Needed	5760	sq.ft.	
Value			
Up Front Expense	$0.00		-100% of Cost is placed into the GMP
Loan Cost	$418,738.00		
Total Expense	$418,738.00		
25 yr Value	**$535,609.79**		-Savings accumulated after life of system

Table 19: Rebate and Loan Calculator Results- *Courtesy of Mr. Mackey*

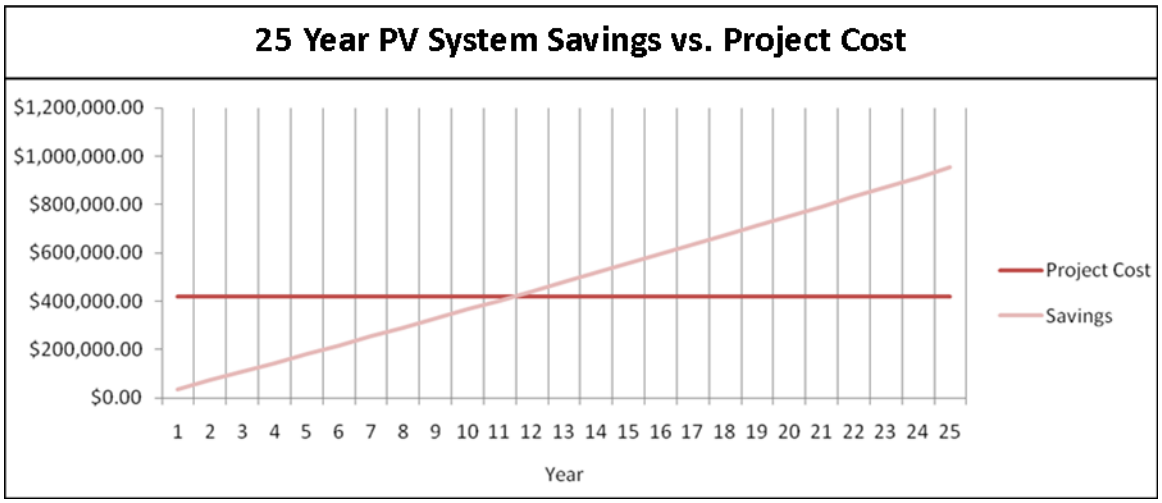


Figure 39: Life-Cycle Savings vs. Cost

The figure above illustrates that if the project owner were to invest in installing the proposed photovoltaic system, the energy savings and incentive applications would pay for itself in approximately 11 years. The calculations summarized on the previous page explain that the results presented are under the circumstances that if the owner preferred to loan the money for installing the system. The analysis is presented in this way to not shift the guaranteed maximum price of the renovation project. Furthermore, a total of $ 535,609.79 in collected savings would be accumulated over the life of the system.

However, a quicker payback period in addition to greater savings would be presented in this analysis if the building owner would prefer to pay directly for the proposed system. The approved change in contract would increase the project's GMP by $314,340.00 (The cost of the system). This decision would present the owner with $660,007.87 in total savings while seeing a payback period approximately 8 years. The graph and table below illustrate the adjusted savings if the GSA would pay the upfront cost for the system.

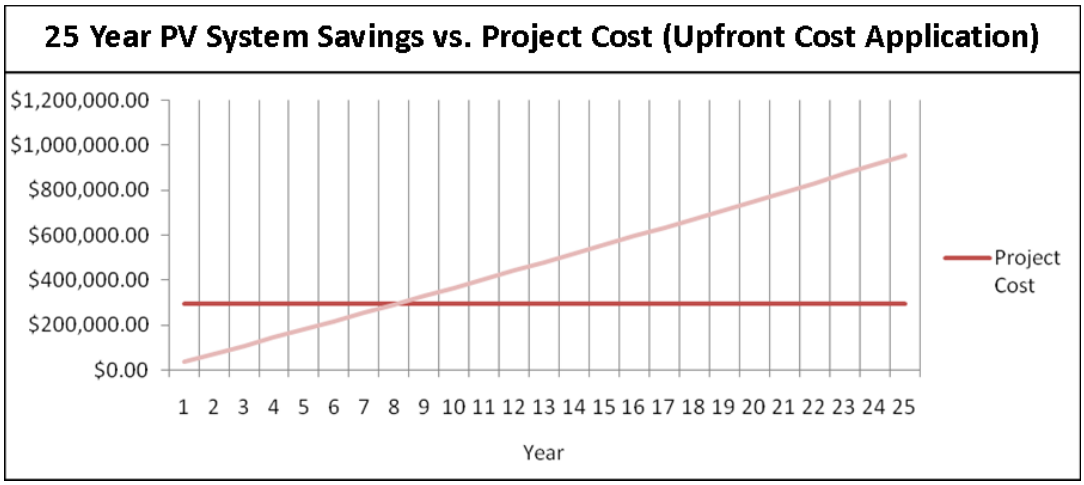


Figure 40: Savings vs. Cost (Paid Upfront)

Summary of Maximized Savings (System paid for Upfront)	
Upfront Expense:	$ 294,390.00
Average Monthly Savings:	$ 2,980.00
Pay Back Period:	8 Years, 2 Months
Total Savings (25 Years):	$ 660,007.89

Table 20: Final Values for PV Application

Though this analysis accurately portrays the savings the system may present, it is worth noting that there is no accurate way to predict the cost of maintenance. Over the course of 25 years, it is expected that some maintenance will be needed on the photovoltaic system but there is no way to implement such cost into the life-cycle calculator used.

7.8 Conclusions and Final Thoughts

After analyzing the criteria previously discussed in this section, it is recommended that the GSA and building owners of the Office Renovation Building invest in the proposed photovoltaic system. The available roof space over the first interior courtyard facing directly south provides an ideal location for the proposed system. In addition to the roof's angle and orientation, the space available is adequate to house a 40.3 kW PV system. The size of this system will provide equivalent energy to power the lighting loads of the Electrical Equipment Enclosure.

Additionally, the proposed system will have minimal impact on the structural design of the roof. Integrating the PV panels with the existing terracotta roof system is possible and easy to implement. Installing the system on an interior corridor roof will have minimal altercations on the architectural aspects of the building.

Furthermore, the location of the PV panels is close in proximity to the Electrical Equipment Enclosure. The system will utilize the parapet to locate the system's inverters while easily being able to integrate the system with the electrical grid system. This minimizes installation costs when tying the PV system into the utility company's grid system.

The main reason the GSA should invest in a photovoltaic array involves the life-cycle savings and minimal payback period associated with the system's initial cost. It is recommended the GSA provide the upfront cost for material and installation; this allows the Office Renovation Building to generate approximately $660,000.00 in net savings over the course of 25 years. The savings generated from the PV system will allow it to pay for itself in just over 8 years. These enticing figures are largely thanks to the rebates and incentives applicable to the project. The Office Renovation Building will be able to benefit from *Net Metering*, a $20,000.00 grant for system installation, and a performance based incentive provided by the Public Service Commission.

7.9 MAE Requirement

The BAE/MAE requirement for this analysis was achieved by including aspects learned in two graduate level courses. The *Feasibility Study for Photovoltaic Energy System* was completed by utilizing aspects learned in AE 597D and AE 572.

AE 597D: Sustainable Building Methods

This graduate level course demonstrated sustainable building practices that can be applied to the AEC industry today. Specific to this analysis, AE 597D contributed to the optimal design of the PV system. This included appropriately sizing the system, utilizing optimal angle requirements, and ideal orientation for photovoltaics. Additionally, learning about the incentives and rebates available for alternative energy systems was a major aspect of the course curriculum. All of these aspects of the class greatly contributed to the analysis and application of this topic.

AE572: Project Development and Delivery Planning

The relevance associated with this course predominately consists of applying life-cycle cost analysis and payback periods for the proposed investment. With the help of Mr. Dabrowski and the utilization of Mr. Mackey's loan and rebate calculator, a cost and feasibility analysis was able to be applied to the Office Renovation Building. Also, learning to present differing cost scenarios to the owner was a large component of the course. This was applied in the analysis by presenting the options of loaning the costs associated with the PV system in contrast to the expense being paid for by the building owner.

8.0 BIM Execution and Utilization/Occupied Phase Planning

8.1 Problem and Background Information

The Gilbane-Grunley team is utilizing building information modeling to help construct a more efficient project. Unfortunately, GGJV has only been using Autodesk Navisworks® to coordinate MEP drawings for the new system. Also, the project team has created a 3D Revit model of the building, but uses it only to provide the owner with a visualization of the construction process. After learning about the opportunities that exist within the utilization of BIM applications, it seems that the project team is not effectively using their resources.

As described in earlier sections of this report, the Office Renovation Building Project is an occupied phased renovation that will be completed in 8 installments. Phase 1 consisted of creating a temporary office space within one of the building's courtyards that will compensate for relocating employees. As each phase of construction begins, employees located within that area will move to the temporary office facility for the duration of that phase's renovation. Mobilization of phase 2 included a tenant relocation duration of approximately 39 days. This move included the relocation of tenants in addition to moving office furniture into storage and other locations. A major focus of this analysis researches the integration of facilities management software applications to current 3D Revit® models to help facilitate tenant relocating. The image below summarizes the phases of construction scheduled to take place during the Office Renovation Building project. Additional information in regards to the scope of work included in each phase can be found in Appendix B: Phase Sequencing. An estimated 570 current employees have been displaced from approximately 245,000 square feet of available office space from the Phase 2 location into the newly constructed office facility.

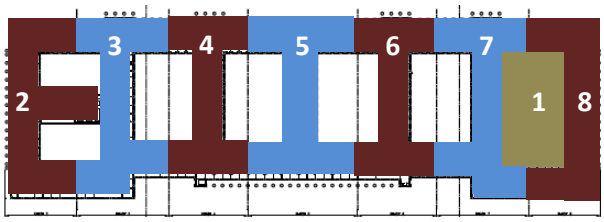


Figure 41: Office Renovation Building Phase Breakdown

8.2 Research Goal

The goal of this technical analysis is to implement *Penn State's BIM Project Execution Planning Guide V2.0* on the Office Renovation Building project. The execution plan is intended to help the project team identify which BIM Uses can directly benefit the project. Implementing these uses will help better utilize the 3D Revit® models already constructed.

Also, BIM applications can also help improve the phase planning of the project. Over the course of the building's 8 renovation phases, all of the building's employees will be impacted by relocation. The transition into phase 2 proved difficult for the project team having used 39 days to relocate current tenants. BIM Research will be focused on utilizing BIM to implement a transition planning and management system to help with future phase planning.

8.3 Penn State BIM Execution Plan Application

With limited BIM execution experience and analytical data; the Penn State BIM Execution Guide will be the primary source for implementing a *start-to-finish* approach for the Office Renovation Building. Using the guide's structured approach to BIM implementation, the applicable BIM Uses will be discussed.

Though a BIM Use analysis will be implemented within this report, only the opportunities to improve space and transition management will be analyzed in depth. The table below, provided by the PSU BIM Execution Plan, summarizes the Uses that are applicable to the Office Renovation Building's existing Revit® model.

Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	**Value added objectives**	
1	Reduce late change orders and field clashes.	3D Coordination
1	Utilizing a 3D model to communicate construction tasks and final spaces to project stakeholders.	Design Reviews
2	Enhance efficiency and accuracy of existing conditions documentation. Visualization purposes	Existing Conditions Modeling
2	Provide documentation of completed project for future uses	Record Modeling
*1	Better understanding of the phasing schedule by the owner and project participants.	Phase Planning (4D Modeling)
*1	Track current use of space and be able to identify and allocate space for appropriate building use.	Space Management and Tracking
*2	Plan maintenance activites proactively and appropri	Building Maintenance Shceduling

Table 21: BIM Uses applicable to the Office Renovation Building

The first four uses listed in the table demonstrate what the project team is currently applying to the 3D Model. Of greatest importance to the building owner is the opportunity to prevent change orders with clash detection modeling of new MEP systems . This Use is specific to the Navisworks® models created for the project; it will not be a major focus of this analysis. The Uses ranked with the (*) symbol represent opportunities for the Gilbane-Grunley project team. Phase Planning and Space Management are uses they can immediately benefit building occupants and subcontractors to improve production. The PSU BIM Execution guide associates Phase Planning predominantly with construction activities and subcontractor communication. Additionally, Building Maintenance Scheduling is applicable to the Revit®

model because of the opportunity to allocate building information on various building materials and maintenance.

BIM Use Descriptions and Project Benefits

3D Coordination:

The BIM application of 3D Coordination primarily deals with clash detection of systems design and organization. Through the use of a 3D Model, the project team, designers, and subcontractors are able to efficiently coordinate systems design to avoid any interferences. Within the scope of the Office Renovation Building, 3D Coordination consists of MEP design in addition to any clashes associated the structure's existing conditions. The project team is using Navisworks® to integrate design drawings to limit the presence of clashes. This is done in an effort to reduce field hindrances; fixing clashes in the model allows for more efficient changes of design.

As previously discussed, the potential value associated with 3D coordination includes the opportunity to visualize construction while significantly reducing RFI's that may delay the project. Properly implementing this use allows the project team to increase field productivity and decrease construction time.

In order to successfully implement this use, the project team must be able to use 3D Modeling technology with a Model Review application (Navisworks®). Team competencies include ability to deal with people and project challenges while being able to manipulate and review 3D models of varying systems.

Design Reviews:

This Use uses the 3D Revit® Model to showcase the design to stakeholders while being able to evaluate project criteria and other details. Virtual mock ups are often a large part of design reviews; they allow stakeholders to experience a space for approval and input. With proper implementation, design reviews can resolve design issues by offering different options. This is the most in depth application to the Office Renovation Building today. Weekly review meetings composed of Grunley's BIM designer and facilities management and GSA representatives to review building design, tenant impacts, and to discuss stakeholder input. Unfortunately, the Revit® model is predominantly used only for this BIM Use.

Potential values within this use include the elimination of costly and timely traditional construction mock ups. Furthermore, it allows different options and design alternatives to be easily visualized. The project team effectively utilizes design reviews to preview space aesthetics and layout scenarios.

Resources required to implement design reviews consist of 3D Model manipulation, interactive review space, and design review software. Project team competencies require the ability to

manipulate the 3D model while being able to effectively model realistic spaces with detailed textures.

Existing Conditions Modeling:

This process has the project team develop a 3D model of the existing conditions for a site. Being that this is a renovation project, it was very important for the team to implement this use. Following the development of this model, project stakeholders can compare the original conditions of the building to the final design intentions. This use's application is very integrated with 3D Modeling and Design Reviews. The Office Renovation Building project uses this model to visually compare the changes in office spaces and other building areas. Facilities Management representatives are able to visually interpret how the newly design spaces will compare to existing space layouts.

Additional values of this use allow stakeholders to document existing building conditions for historical use. This is very important to GSA because of the historic declaration of the Office Renovation Building. On top of the visual benefits, existing conditions modeling aids in future planning for planned renovations while providing location information for the entire structure.

The BIM Execution Guide notes that 3D Laser scanning and point cloud interpretation is a required resource for this application. However, the Gilbane-Grunley project team was able to model the existing structure through original construction documents and the act of physically measuring building plans and layouts. Competencies for the project team include the ability to manipulate the 3D model.

Record Modeling:

This BIM use presents a final model to the owner for future reference. Throughout the design and construction process, the model is used for review and input. Following the project's completion, the model allows the owner to utilize the information it contains. Again, this BIM Use has very similar characteristics to the Design Review and 3D Coordination applications. During construction, design reviews help finalize the model and, of course, the actual structure.

Though the record model helps throughout the construction process; it also will help GSA plan and coordinate any future renovation plans. The record model also presents the opportunity for dispute elimination. If particular construction activities and final deliverable were linked with contract and historical data, the owner will be able to compare and contrast any work in question. As previously mentioned with all of these BIM uses, 3D model manipulation is a required resource for this application. The project team must also know how to use this application to thoroughly understand site processes to ensure correct input in the final product.

The following three BIM Uses identified in the PSU BIM Execution Planning guide are proposed to be added into the project scope for the Office Renovation Building. A focus on these applications has been presented because the Revit® 3D model of the project has already been completed. These uses would be easier to integrate with the project because of the existing model.

Phase Planning (4D Modeling):

This description of this use within the BIM Execution Guide relates directly to the Office Renovation Building; "A process in which a 4D Model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. (BIM Ex 2010)" The concept of 4D helps bring a strong visualization and communication tool that can allow the owner and building occupants to easily understand tenant impacts and construction plans.

The obvious benefit of this use is that it provides a better understanding of the phasing schedule by the owner. Phase Planning presents a visual model to help solve space conflicts often associated with phased occupancy renovations. Potential value is also evident in regards to construction activities; the project team can monitor project status and current progress while supervising contractor interaction and communication.

Competencies and resources required to successfully implement this use revolve around integrating schedule software with 3D and 4D modeling software. This is in addition to being able to manipulate, navigate, and review a 3D model.

Most research done on this use pertained specifically to construction activities. For the purpose of this analysis, it is preferred to be able to use 4D modeling software to help navigate and relocate building tenants to and from the temporary office facility.

Space Management and Tracking:

Space Management and Tracking will be the BIM Use most directly applied to the Office Renovation Building in this report. Similar to the potential of Phase Planning, space management and tracking allows particular facility management software to be integrated with the 3D Model or existing conditions model. This integration creates an interactive interface that allows facilities management to better plan and track the building's resources. This use particularly relates to space allocation and coordination for building employees and tenants. This Use will be explained in great detail in the following section.

Building Maintenance Scheduling:

Preventative maintenance scheduling is a process in which the building structure and equipment are maintained throughout the operational life of the facility (BIM Ex 2010). Data from the building's walls, roof, mechanical equipment, etc. is available through an interactive

record model. Properly being able to track information on equipment and building details will improve building performance, reduce repairs, and reduce overall maintenance costs.

Similar to Space Management and Tracking, this BIM use allows facility management to properly allocate people in the building. Maintenance Scheduling helps to efficiently coordinate maintenance staff when issues arise. This Use also allows continuous maintenance tracking throughout the life cycle of the building. Throughout the construction process, building information is integrated with the record model to allow operations and maintenance staff to easily identify information on varying building structure and equipment.

Resources required for the proper application of Maintenance Scheduling include design review software, Building Automation System (BAS) linked to the record model, and a Computerized Maintenance Management System (CMMS) linked to the Record Model. The project team mush know how to integrate these programs with the record model while being able to understand typical equipment operation and maintenance practices.

After evaluating the BIM Uses described above, it is evident that many uses have interchangeable benefits with each other. The uses analyzed require the creation and constant manipulation of a 3D model. For the Office Renovation Project, this directly relates to the already completed Revit® Model created by the Grunley Construction BIM team. It is worth noting that Revit Models have been created for both the existing conditions of the building and for the building layout following the renovation. Other BIM applications may also be incorporated with the underutilized 3D Model. These uses include: *Asset Management, Construction System Design (Virtual Mockup), Site Analysis, and Cost Estimation*. Because the project team and building owner are fairly new to BIM applications and utilization, a focus in this research pertains only to the Uses described in detail.

8.4 Space Management and Phase Planning

Specific Problem

As previously identified, the Gilbane-Grunley project team is under utilizing the 3D Revit® Model created for the Office Renovation Building. Section 8.3 helped identify which BIM Uses can easily be applied to the existing model. Within the use of Space Management and Tracking lies a great solution to the phased planning of the occupied space. Transitioning building occupants from the Phase 2 work area into the temporary office facility took a total of 39 days. This amount of time was longer than expected and could have been planned more proficiently. This section will discuss how the transition planning between phases of occupied space can be done more efficiently. Additionally, this section will analyze how the Gilbane-Grunley project team can offer additional services that will help assure contracted work for future phases of the renovation.

Proposed Solution

The proposed solution to minimize occupant moving time involves the application of FM:Systems' FM:Interact Workplace Management Suite. This software will help facility management personnel better track and organize the building's occupants and resources. A major component of applying FM:Interact requires a 3D Model of the structure to be completed. This has already been done for the existing conditions and new construction of the Office Renovation Building. Having already completed the existing, demolition, and new construction model filters there is minimal effort required to implement this software. The image below demonstrates different stages of the Phase 2 renovation; this is done through the phase filtering ability in Revit Architecture. The benefits and implementation of this application will be explained later in this section.

Figure 42: FM Systems Logo

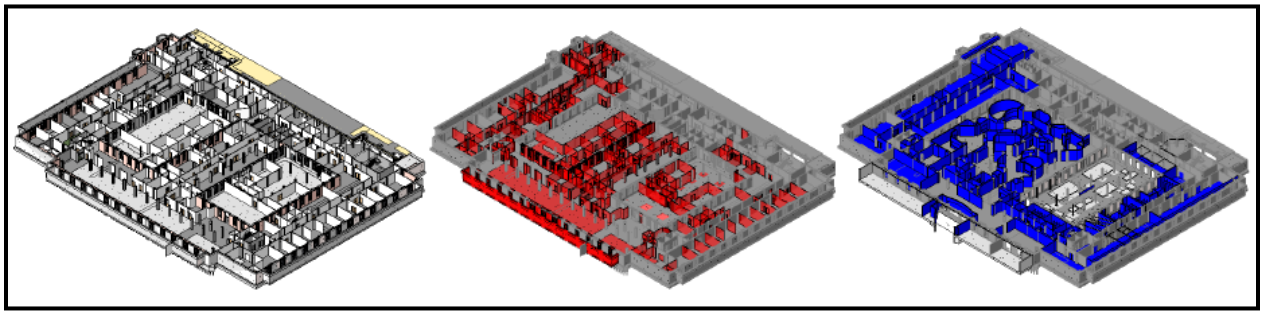


Figure 43: Model Views of Phase 2 4th Floor area. From left to right are the Existing, Demolition, and New Construction layouts of the Office Renovation Building

General Contractor Benefit and Potential Value

There are multiple reasons as to why the Gilbane-Grunley project team should pursue the implementation of this BIM Use. The following paragraphs explain why the focus of this analysis is in the best interest of the Gilbane-Grunley Project team.

Before phase 2 had commenced, it took 570 employees a total of 39 days to relocate to the other end of the building. If this transition period were to be reduced, more time could be spent on renovating the actual structure. Though research has proved that quantitative data for space management is very difficult to come by, it is expected that the implementation of FM:Interact Workplace Management Suite would drastically decrease the moving time. Fortunately, Gilbane-Grunley is also under contract to perform phase 3 of the Office Renovation Building. Once permission to begin Phase 3 is received, an estimated 1000 employees will need to be relocated; this includes moving employees from phase 2 back to their original locations in addition to moving phase 3 occupants to the temporary office facility. If the project team were to properly implement the BIM use of space management and tracking, the transition time is sure to be less significant than that of phase 2. This will allow the Gilbane-Grunley project team to get an ever important head start on the phase 3 renovation.

Another reason for GGJV to invest in FM:Interact, and most importantly, is that the contracts for phases 4-8 of the renovation have not been awarded. Within these last 5 phases of the renovation project, approximately $400 million in performed work is available. Within the current competitive economic market, it would be in the best interest of GGJV to invest in this technology to become an industry leader in phased occupied renovation project. Following the demonstration that would be performed in the phase 3 tenant relocation, GGJV can offer definitive numbers of how FM:Interact improved the moving process. Additionally, GGJV would be able to offer these services for future phases while delivering an end product of a complete facility management database for space management and occupant/resource tracking.

Gilbane-Grunley Joint Venture will be able to benefit from the immediate advantages of this BIM use during the phase 3 tenant move. Additionally, the project team could present this application as a competitive advantage when bidding for the remaining five phases of the renovation project.

8.5 Implementation Process

This section will analyze how the Gilbane-Grunley project team can implement FM:Systems' FM:Interact to the Office Renovation Building. The walkthrough will discuss what elements are needed, the process flow required to create a complete database, and a general time frame for implementation. Following this section, it is intended that the reader realizes the simplicity and value of incorporating space management and tracking software with an already existing 3D Model.

What's Already There?

There are two primary forms of input information needed to effectively apply FM:Interact to transition planning and management. First, archived building information or Room Data Sheets need to be completed for each corresponding space. Room Data Sheets present summarized data of a room or office by listing its appropriate attributes. Though the information supplied is at the discretion of the owner and facility manager, details often include room finishes, mechanical and electrical equipment, fixtures, and fittings. Building occupants and employee information is also often included in room data sheets. Facility Management at the Office Renovation Building currently utilizes Microsoft® Access to organize the building's Room Data Sheets. Microsoft Access is a "Relational Database Management System," which means it is able to store, filter, and report data in the form of tables and graphs. An example of a Room Data Sheet similar to those used within the Office Renovation Building can be found in Appendix J: Room Data Sheet Example. Having this information available for the existing building conditions is crucial to help more efficiently move employees into the new office facility and the newly renovated office spaces. It is fortunate that facility management has such information for the building's current spaces.

The other primary information needed to utilize space management and tracking software are building drawings and plans. The information provided in a Revit model and bounded areas often include; room name/number, square footage, etc. Fortunately, the 3D Model created by the Gilbane-Grunley project team was completed with Autodesk® Revit Architecture. With the advancements of Revit Architecture and property attributes, specific room or asset data can be added straight into the Revit model. Revit

has the ability to apply area boundaries around each desired space allowing it to be archived with its own respective room number. Revit Architecture is regarded as a leading BIM application that integrates elements, views, and annotations into a single, coordinated building information model. For the matter of space management and tracking, it is an application that recognizes room data as actual design attributes in opposition to previously utilized annotations.

Integration

This subsection will describe what steps are needed to create an integrated, bi-directional information database that contributes to the needs of facility management and transition planning. It will also focus on the benefits of FM:Interact and why it was chosen as the facility management application.

The process map below shows how other FM applications and space management software applied to construction documents and floor plans. Please note the figure's *Firewall,* it represents the barrier of information between operations and construction. Once the model or drawings are handed over to facility management, the information within them is used to create the building's information database. However, because the applications are not bi-directional, there is no direct way to update the model if any changes are made to the building or facility. This includes future renovations or alterations in space or office layout.

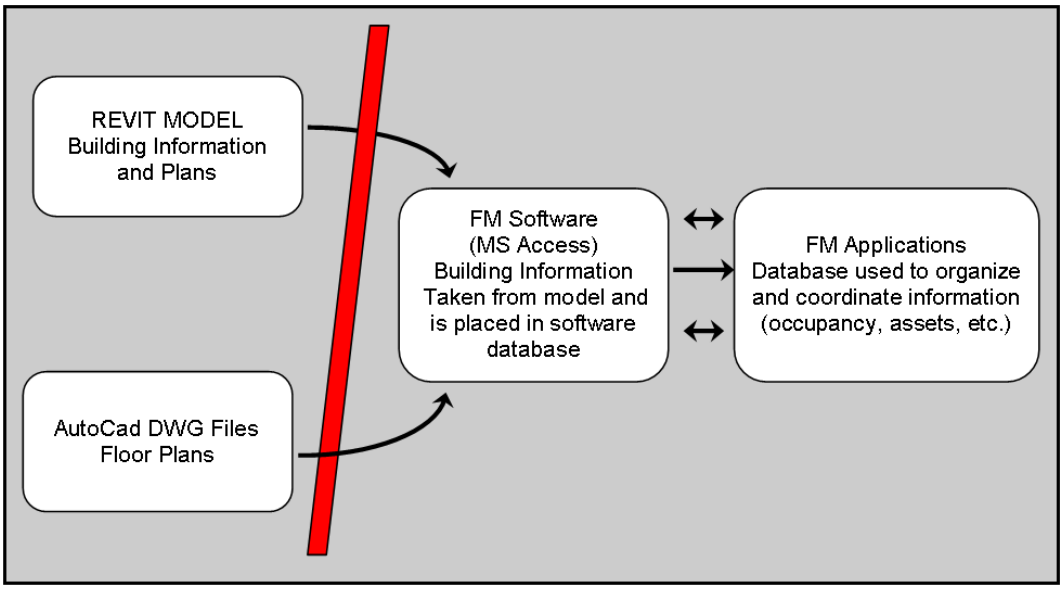


Figure 44: Typical FM Software Process Map- Because the FM Database is not linked with the construction model, there is no way to translate information back into the Revit model or CAD drawings

The next figure demonstrates the process flow when FM:Interact is used as the building's facility management system. Because of its bi-directional capabilities, building information can be updated in either the Revit Model or FM Database; updating the information in one application automatically revises the other. This reintroduces the model in an ongoing platform that can be properly maintained throughout the lifecycle of the building.

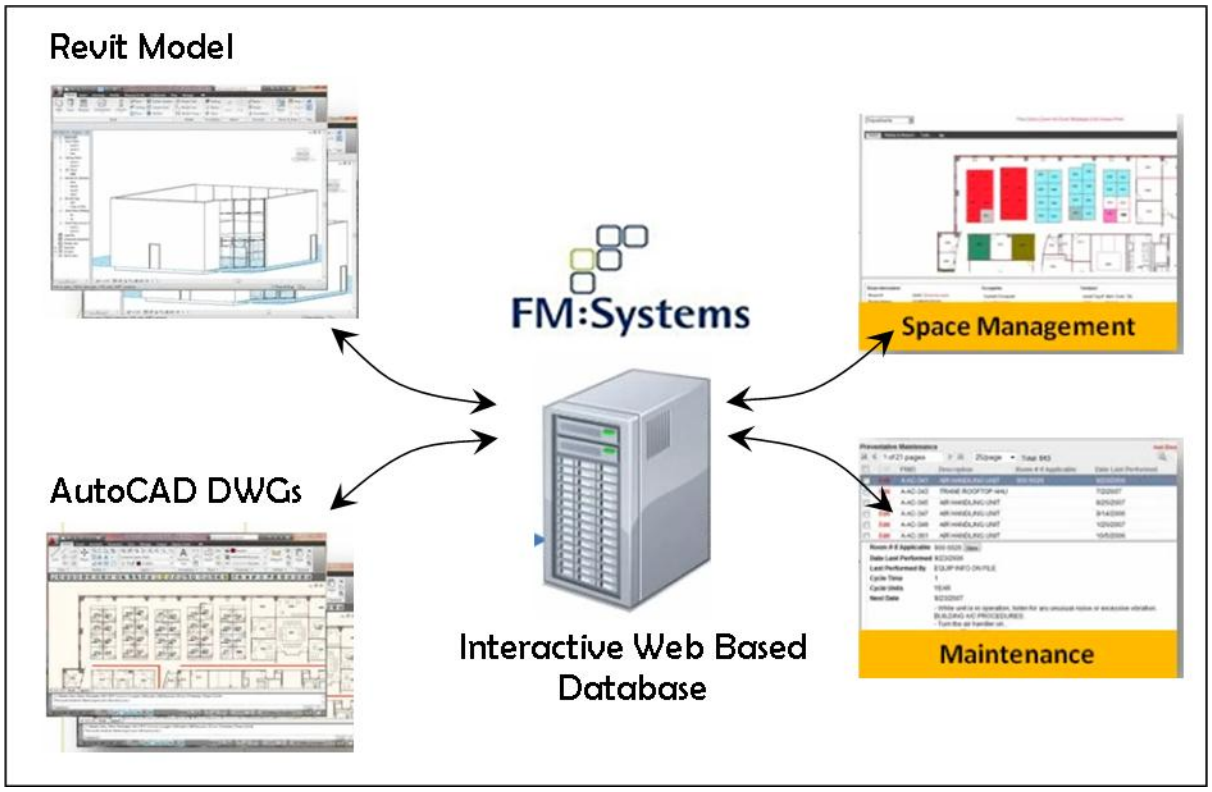


Figure 45: With FM:Interact as the database, information can be viewed, altered, and updated through a bi-directional format in the database and in the original Revit files

This level of integration is made possible through the direct DWF publishing of Revit files that is recognizable by FM:Interact. Furthermore, the interface in the program allows information changes to automatically update the Revit or CAD files. This allows easy translation of asset properties constructed in the original model to be placed in the information database. This application was chosen because FM:Interact eliminates the barrier, or *firewall*, that is present in other FM software.

Implementation

For implementing FM:Interact, the first step involves defining areas and spaces within the Revit model. Within the model, areas much be tagged with boundary lines so that it may be identified as an individual room. Often referred to as polylining, this process can be done to an extremely specific level of detail. For example, specific cubicle spaces can be bounded as their own areas; this allows facility management to allocate occupant and equipment information specifically to that area. Other applications often only identify open floor plans as one entire space; they are incapable of breaking down the area into greater detail. Research shows that this is the most time consuming part of the FM:Interact application; best

practices suggest that polyining should be done as the project is being constructed. Being that the Revit model for the Office Renovation Building was already designed to include room numbers, coordinating the area tags for FM:Interact should be unproblematic .

The next step for the Office Renovation Building involves the facility manager providing data from the existing room data sheets into the existing conditions Revit model. If facility management preferred to input the data, they can utilize the easy to use interface of FM:Interact. As mentioned earlier, FM:Interact utilizes a unique and direct integration between its information database and the Revit model. This significant feature prevents constant file format exports and imports often associated with other data types (i.e. COBie). As facility management uploads information for the existing building layout; Gilbane-Grunley can progressively catalog all the information associated with the renovated office spaces. This includes new room numbers, square footages, finishes, and equipment.

The following set of screen shots represent the overall process and interface associated with creating an effective space and management application using FM:Interact. Please note that these screen shots are referenced from research articles and journals and do not reflect the plans or spaces of the Office Renovation Building. For the purposes of this research assignment, it is at the request of the owner that no interior spaces of the Office Renovation be replicated or redesigned in anyway.

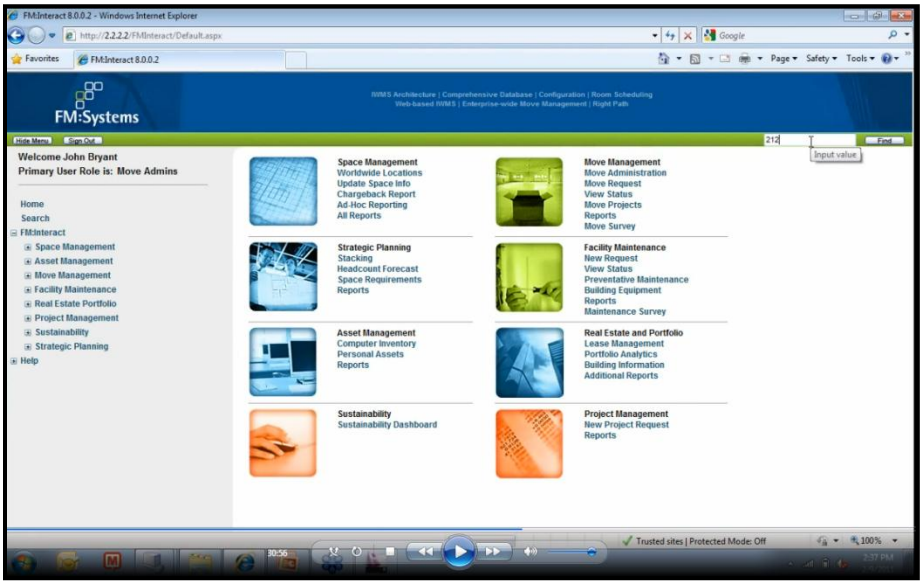


Figure 46: Web-based log in and interface of FM:Interact

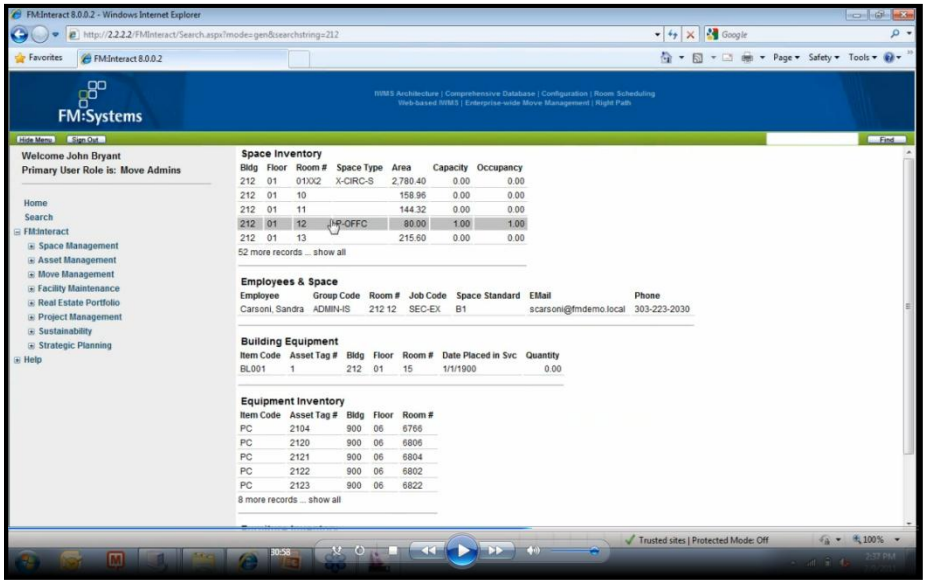
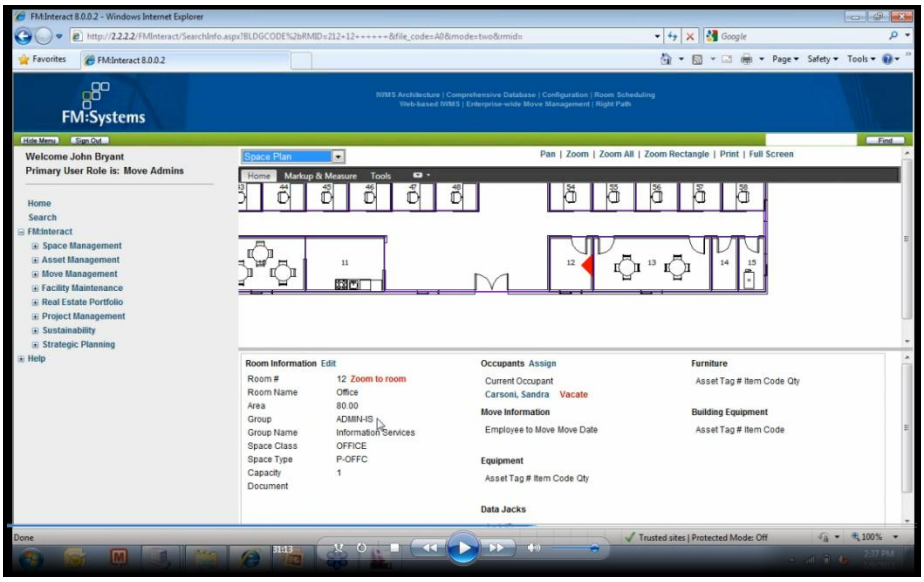


Figure 47: The application's search option makes it easy to find rooms and spaces based on any of the area's associated information.



Selecting a room (red arrow shown) brings up a space plan of the specific area and all the information associated with it. In the image above, the selected area is listed as an Office space with an area of 80 SQ, associated furniture, and the name of the current occupant. This information is customizable by any permitted individuals. By clicking on any of the categories, the room's information can be changed or updated directly in the web based application. The next screen shot shows the Revit Model with instantley updated room information.

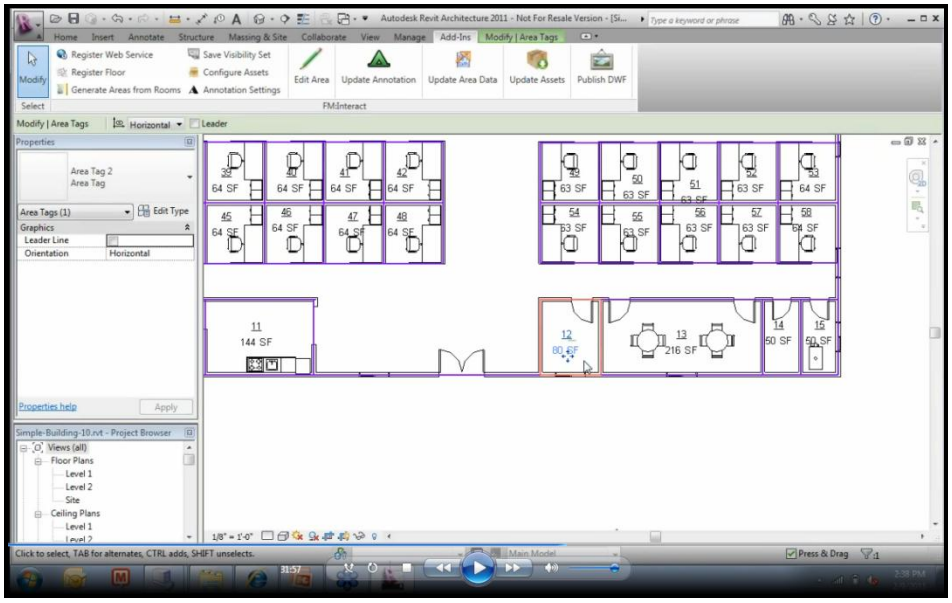


Figure 48: Revit file with updated information connected to FM:Interact through its Revit Add-In

The figure below shows a close up of the Revit Add-In from FM:Interact. This add in allows building information to be updated within the Revit model; once the model is published as a DWF, the FM:Interact database will automatically recognize and update and changes. This makes is easy to apply any physical changes that may alter the area or square footage of a room.

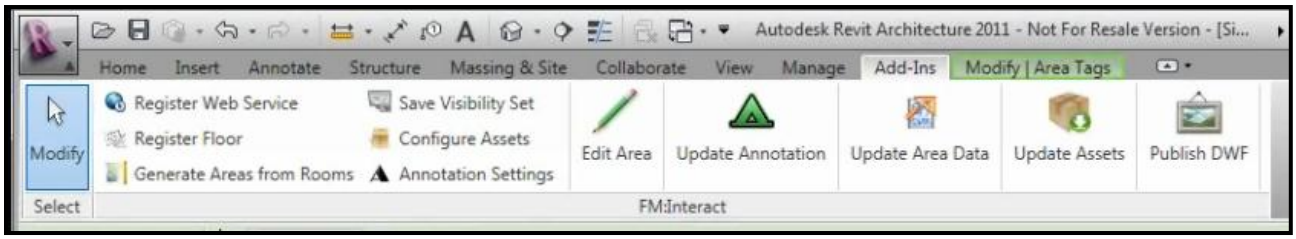


Figure 49: Close up of FM:Interact add-in within Revit

Once all the facility drawings and associated information is uploaded into the database, AEC Bytes editor and building technology researcher Lachmi Khemlani best describes the application's potential: "Facility managers can retrieve and edit selected data from any drawing or from multiple drawings, run queries to get needed information, generate on-the-fly graphical or data-based reports, identify asset relationships, dynamically initiate work orders, and export required information to a spreadsheet, a text document, or a database. Since the space plans are object-based, it is easy to generate color-coded drawings based on specified criteria, such as vacancy, occupancy by department, project schedules, cost centers, and so on." See screen shot on the next page for a sample view.

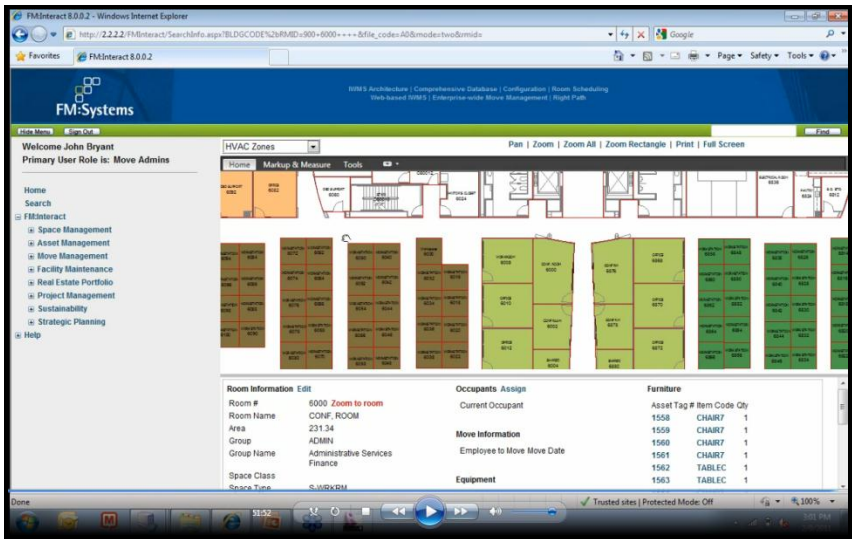


Figure 50: Object-Based rooms make it easy to classify or color code each space. The Office Renovation Building would most likely classify Departments, Janitorial, Bathrooms, and various facilities as different spaces

Maintenance Scheduling

The image below illustrates a general process map that identifies the flows of information exchanges comprised within the application. The additional applications available within the FM:Interact Suite include the *Facility Maintenance* add in which is also a web-based application. This allows building occupants to submit work requests to facility management and maintenance service for a specific location. Though a focus of this analysis is to illustrate the benefits for space management and phase planning, Facility Request demonstrates how the BIM Use of Maintenance Scheduling can be incorporated into space management and tracking. This application helps facility management better coordinate and schedule the times and locations of various maintenance activities.

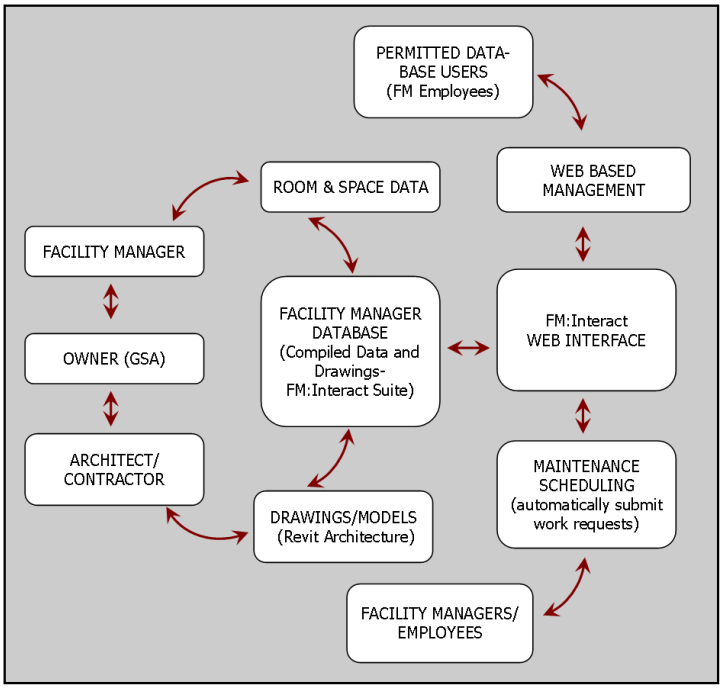


Figure 51:Total FM Process Map Overview

The final portion of the process map is labeled "Web Based Management' which allows the entire database created in FM:Interact to be published online. This enables remote access to whoever facility management would like to grant access. Web users can view facility drawings, data, and any reports that involve upcoming changes. If space plans for plan views need to be updated (following an office renovation for example), the physical dimensions must be edited in a Revit Model. Most research presents that trained staff or third party organizations with AutoCAD and REVIT experience perform these updates. Fortunately, with the sensitivity involved with the Office Renovation Building and its federal associated, facility management would have the ability to restrict access to specific individuals. The major benefit of the Facility web access is that is allows users to create and share drawing markups to communicate information. This is a great way to communicate moving dates to tenants during phase transitions.

8.6 Step By Step Overview

The following table offers a summarized overview on how FM:Systems would implement FM:Interact Workplace Management Suite with the Office Renovation Building and Gilbane-Grunley.

NEEDS ANALYSIS	•Identify project goals and users •Review FM processes •Establish standards and procedures
SYSTEM CONFIGURATION	•Configure views and reports •Set up Web Views •Set up Data Links
CAD AND DATA IMPORTS	•Drawing verification and room tags •Import data and routines
TRAINING	•System Administrator •FM Users •End Users (Building Employees)
ROLLOUT	•Testing •Final Installation
ON-GOING LIFE USE	•Data Maintenance •Maintain Work order requests •Evaluate and Enhance

Table 22: Implementation Overview courtesy of FM:Systems

The first step for implementing a successful FM management system involves defining the goals of the database. This is where facility management decides what information they would like to track and include in the Revit model and FM:Interact database. Because this BIM use application focuses on the phase planning and move management of the Office Renovation Building, it is recommended that only basic building elements be included in this model:

FM Application Goals:

- To successfully track to amount of office space available for building departments and employees
- To drastically decrease the move time associated with relocating tenants between construction phases

FM Database Information to Include:

- Room spaces and numbers (to help easily allocate building office space)
- Building occupants and department employees (to determine how much office space is available for each phase tranisition)
- Cataloged inventory of office furniture (chairs, desks, etc.)
- office equipment including light fixtures, outlets, fax machines, printers

Using Existing and New Renovation Models

A major obstacle with applying a space management to a renovation project is that the occupied space is always varied. The current area of construction will present a different room and office layout while the rest of the existing structure will have its original plans. The conditions of the model would be consistently changing with each phase's completion. Fortunately, Grunley Construction has already created extensive phase filter of the building's existing conditions and new renovation layout. The ability to manipulate and activate these filters prevents a lot of rework that would be involved with integrating models of each stage of the building's progress.

Luckily, the bi-directional functions of FM:Interact make this issue easy to adjust throughout the entire renovation process. As explained by Gerad Johnson of FM:Systems, Inc., "with the presence of phase filters, the FM:Interact database would only link itself to the current state of occupied spaces within the building." This means that data links within the database would only be interconnected with certain parts of each model. For example, at its current state in Phase 2, only the new office spaces associated with Phase 2 and the Temporary Office Facility in the New Renovation Filter will be linked with FM:Interact. Additionally, the remaining six phases of space will be linked to the database using the Existing Conditions Filter. This is able to be done because FM:Interact can assign permissions to varying Revit models or phase filters through its Add In component. Only the rooms polylined within each filter will be recognized by the database as occupant areas for the Office Renovation Building. The series of images on the next page summarize how the two different phase filters will contribute data to the FM:Interact database.

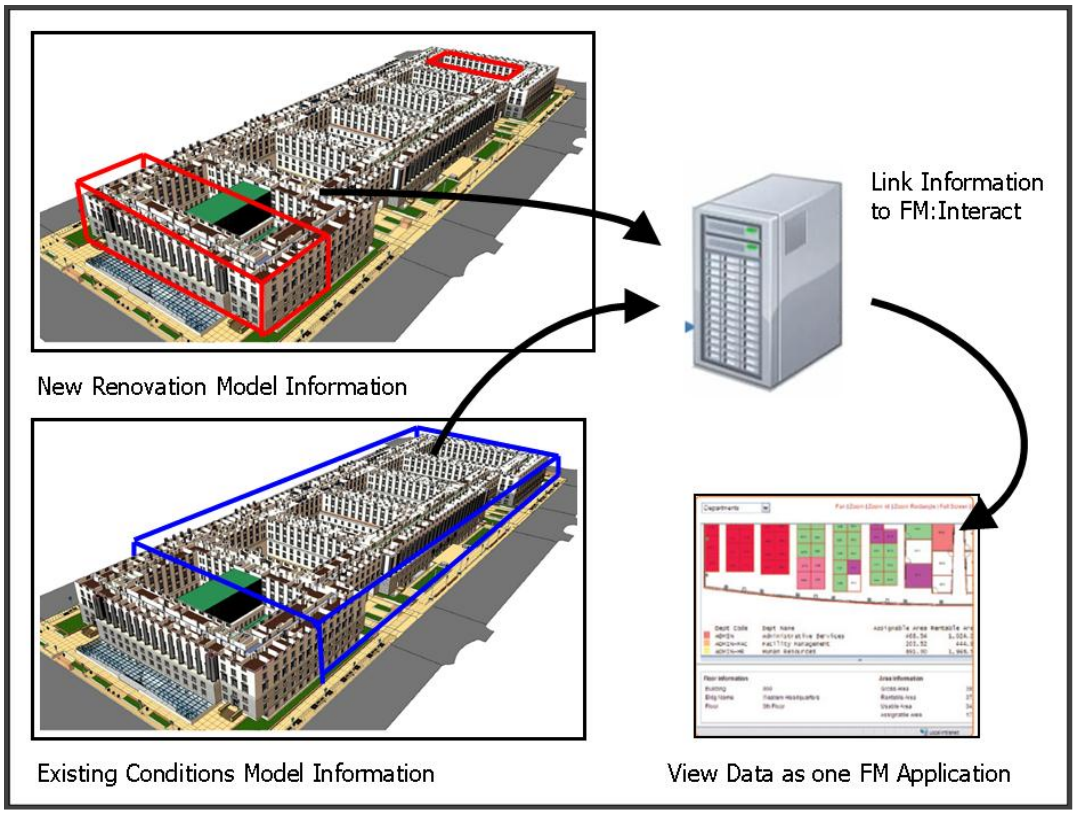


Figure 53: Linked information from the New Renovation and Existing Conditions Filters for Phase 2 will be used to present a complete database of current building information

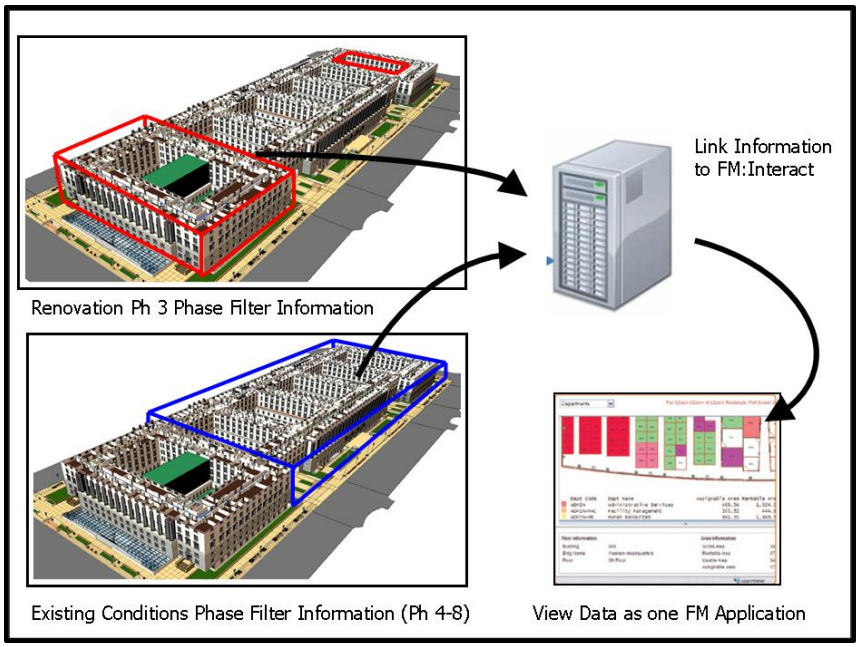


Figure 52: Information for Phase 3 will be updated with the new layouts and occupant information from each phase filter

Comparative Timeline for Implementation

As mentioned earlier in the report, it is very difficult to present the cost saving and production benefits of this BIM Use without quantitative data. This application is very new to the AEC and FM industries and comparable case studies are limited. FM:Systems advertises that their *Right Path* method will have any facility up and running with FM:Interact Workplace Management Suite in 3 to 6 months. This timeframe includes all of the steps associated with *Implementation Overview Table* seen in **Table 22.** Research has shown that most case studies from a variety of market sectors demonstrate a similar schedule for implementation.

However, in a case study summarized by FM Systems, an office facility of similar size and scope was able to move over 500 employees with zero errors in two weekends. The move was management by only two facility professionals. This is a drastic improvement compared to the 39 days taken to move approximately 500 employees in the Office Renovation Building. Furthermore, the company utilizing the FM software was able to implement the application in less than a month; this included preparation of technical and needs analysis, software installation and configuration, and on-site training. The Space Planning Manager associated with the facility reflects on the application that: "The bottom line is that productivity has been greatly increased since implementing this technology. The ratio of time saved in 10-1, for every ten minutes we spent prior to FM Desktop we now spend only one minute. I think that speaks for itself!"

8.7 Criticisms for Improvement

Compared to other FM applications, FM:Interact seems to be more user friendly and interactive with current common modeling software, but it does have its limitations. Though FM:Interact allows efficient space polylining with are boundary lines, it is not entirely without its share of additional work. Revit drawings still require that all spaces within the facility to be identified. The application is still far from presenting the instantaneous ability to import information-rich spatial data already created by designers. Importing space properties from Revit Architecture and data entry are still required but best practices suggest that this should be done at the project's earliest stages.

Additionally, though FM Software can import building details like doors, wall geometry, and windows; it does not yet have the ability to import the property attributes associated with these objects. Adding schedules with these items presents another stage of tedious and repetitive work. Also, FM:Interact is limited in applying itself to the use of tracking detailed equipment information. MEP drawings can be imported into Facility Manager, but the user will have to manually create the appropriate equipment records and specification details for all of the spaces and equipment. Additionally, maintenance scheduling and detailed asset management is not completely implemented with this software. To date, FM:Interact is working with a third party provider, *Quick Scan,* to integrate barcoding technologies with the software. The option for facility management to physically interact with a building asset and update the information while standing there is not yet practical with this software.

Research has shown that Autodesk® and FM:Systems, Inc. are heavily investing in applications that integrate intelligent building data that can be imported into FM:Interact more seamlessly from BIM applications more efficiently.

> In time, a complete and up to date FM database will eventually evolve to a *live* model of the facility that can be used to control all activities of a building (Khemlani).

8.8 Conclusions and Final Thoughts

After analyzing the criteria previously discussed, it is recommended that GSA and the Gilbane-Grunley project team invest in the implementation of FM:Interact Workplace Management Suite to the Office Renovation Building. This implies that GGJV should expand its approach in BIM utilization.

Applying the concepts of Space Management and Tracking, FM Desktop can help the facility manager better track and allocate space for the life of the building. Though no definite quantitative information is available for portraying the results of this application, research suggests that productivity of facility management is significantly increased.

Gilbane Grunley Joint Venture should invest in applying this technology to streamline the transition time between phases 2 and 3. After comparing the results of a similar project, it is estimated that GGJV and facility management will be able to relocate 1000 employees in approximately 4 weekends. In phase 2, it took a total of 39 days to displace 570 employees. The timed save will help the general contractor get a head start on the phase 3 renovation.

Additionally, Gilbane-Grunley should invest in this BIM application in an effort to ensure future work with the Office Renovation Building. The general contractor is only under contract to complete the first 3 phases of the renovation project. The remaining five phases of the renovation accumulate to approximately $400 million worth of work. Presenting GSA with the opportunity to create a complete database of the 3,500 employee 1.8 million square foot Office Renovation Building would differentiate GGJV from other general contractors. With increased competition for managing government projects, offering the technology of Space Management and Tracking for such a large facility would benefit Gilbane Grunley Joint Venture in future bids.

It is recommended that GGJV first negotiate and apply FM Desktop and its phase planning incentive as a complementary service to GSA. This is only to be provided for the transition from phase 2 to phase 3. Following the move, GGJV could present definite quantitative values as to how the effective FM Desktop proved to be. The results could be compared directly to the 39 day move that took place during the early stages of phase 2. Approaching the scenario in this matter would allow GGJV to learn the application while making a strong argument for future work on the upcoming phases.

8.9 MAE Requirements

The BAE/MAE requirement for this analysis was achieved by including aspects learned in a graduate level course. The BIM Use Analysis and Process Map were completed by utilizing aspects learned in AE 597G.

AE 597G: BIM Execution and Planning

This graduate level course provided a valuable educational experience in Building Information Modeling. Utilizing the works of the PSU BIM Execution Guide, the class demonstrated that BIM technology is more than just 3D Modeling and Clash Detection. Additionally, research methods learned in this class were used to fin credible sources of information in regards to the AEC industry.

Special Thanks

Special thanks is owed to Lachmi Khemlani, founder and editor of AECbytes. Her writing, research, and reflection on the application of FM software was heavily referenced throughout this analysis. She has a Ph.D. in Architecture from UC Berkeley, specializing in intelligent building modeling, and consults and writes on AEC technology.

Thanks is also owed to Jeremy Thibodeau of Grunley Construction. His position as BIM Implementation Manager helped specifically apply this analysis to the Office Renovation Building; his experience with a technology consulting company also helped contribute valuable insight.

Also credited to this analysis is Gerad Johnson of FM:Systems, Inc. With his contributions, the screen shots and images specific to FM:Interact are present in this report. He also provided valuable access to software webinars and case studies. Without his help, this analysis would not have been completed.

9.0 Final Recommendations

The purpose of this Senior Thesis Final Report was to research and analyze some of the many aspects within the AEC industry. The Office Renovation Building was used as a caste study to evaluate and enhance specific areas associated with the project. Over the course of the 2010-2011 academic year, a focus was placed on the project's electrical equipment enclosure schedule, the feasibility of alternative energy systems, and the ever growing applications of building information technologies. The findings of these analyses are not to be perceived as criticisms to the project team and are strictly presented for education experience.

The first analysis attempted to accelerate the structure schedule of the building's electrical equipment enclosure by implementing a precast hollow core plank floor design. Under the requirements of the AE program's breadth analysis, structural calculations were performed to ensure the new system would meet the necessary criteria. Following a detailed cost comparison between the new and original designs, the prefabricated planks presented $98,000 in total savings. Furthermore, the re-design was able to effectively eliminate the structural inefficiencies of the original design by minimizing the cure time associated with each floor. With the utilization of admixtures, the proposed system reduced the total schedule duration by 25 working days. However, due to limited building information, the structure's exact floor penetrations are unknown. This presents a major coordination issue with precast hollow core planks. Because of this issue, it is recommended that the Office Renovation project continue to pursue its existing structural design for the electrical equipment enclosure. Accelerating admixtures should be utilized on the floors elevated slabs and associated equipment pads to minimize cure time while accelerating the facility's overall schedule.

The second analysis involved the preliminary design of a PV array to be connected to the building's electrical system. Meeting the proposed electrical breadth calculations, the system was sized to provide enough power to satisfy the needs of the EEE's lighting design. After researching the area's rebates and incentives for implementing an alternative energy system, a life-cycle cost analysis was performed. It is recommended the GSA provide the upfront cost for material and installation; allowing the Office Renovation Building to generate approximately $660,000.00 in net savings over the course of 25 years. The savings generated from the PV system will allow it to pay for itself in just over 8 years. Furthermore, it is encouraged that the GSA invest in this system to help promote the sustainability movement within the building industry. GSA should see itself as an industry leader in energy efficiency and sustainable building practices.

The final analysis revolved around better utilizing the project's detailed 3D Revit Model. By applying Penn State's BIM Execution and Planning Guide, it was discovered that the GGJV could use the model for much more than 3D coordination. Presenting the opportunity to increase phase transition efficiency and allowing facility management to use the model throughout the life cycle of the building, it is recommended that the GGJV work to implement FM:System's FM:Interact Workplace Management Suite. It is encouraged that the project team implement this software during the transition from phase 2

to phase 3 of the renovation project. Integrating this FM software would help the project team relocate approximately 1000 building employees in 4 weekends. If properly implemented, GGJV could use the existing model to help ensure future work on the Office Renovation Building. Utilizing this BIM use presents the opportunity for the project team to become an industry leader in phased occupied renovations while being awarded 5 additional phases of the renovation totaling over $400 million worth of work.

Following the research performed on each of the described analyses, valuable insight was gained on the construction industry and its investment in new technologies. Experience was gained in working with prefabricated systems while learning more about site logistics and project coordination. Performing a life-cycle cost analysis on a building integrated PV system reiterated that alternative energy is becoming more feasible and cost effective. Finally, researching BIM Uses and its applications to benefit end users of a building provided valuable insight on the growing value building information technologies. BIM is much more than 3D coordination and clash detection. In conclusion, each topic analized throughout the course of the semester provided a satisfying educational experience that will soon be brought into the AEC industry as a working professional.

10.0 Breadth and MAE Requirements

The following breadths involve research and investigation within other technical disciplines within the Architectural Engineering major. Each topic pertains to the analyses previously discussed within this report.

Structural Breadth: Contributes to section 6.0: Schedule Acceleration with Prefabrication

The erection of the Office Renovation Building's Electrical Equipment Enclosure is the only new construction to take place during phase 2. The structure is currently designated to be composed of steel columns and beams and will include three levels of elevated concrete slabs on composite metal decking.

Substituting cast in place floor slabs as described in *section 6.4 had significant* structural impacts on the facility's current design. The structural steel design and connection details originally applied to the structure's design were impacted with the proposed alternate system. Calculations equivalent to the educational knowledge gained in AE 308 and AE 404 are presented in Appendix F.

Renewable Energy/Electrical Breadth: Contributes to section 7.0: PV Feasibility Study

Section 7.0 presented a renewable energy study to implement a PV energy system sized appropriately to power the lighting loads of the electrical equipment enclosure. Research was be done in regards to how the new renewable energy system will alter the existing design and how it will be connected to the facility's energy provider. The Photovoltaic system will be designed to provide enough energy to power the Electrical Equipment Enclosure's lighting system. Lighting and energy loads were calculated based on the knowledge gained in AE 311.

MAE Requirements

The knowledge gained from an array of 500 level MAE courses was applied to each of the technical analyses discussed. Research and references from *AE 597G: BIM Execution and Planning* were applied to the implementation of *BIM Project Planning and Execution*. Furthermore, the conceptual foundation and methodologies of *AE 570: Production Management* will be applied to effectively accelerate construction of the Electrical Equipment Enclosure and its *Prefabricated* components. Also, the topics discussed in *AE 598C: Sustainable Building Methods* will be used to optimize the design and implementation of a *Photovoltaic Energy System.*Additionally, the knowledge obtained from AE 572: Project Delivery and Planning was used to perform a life cycle cost analysis for the PV system.

- AE 597G: BIM Execution and Planning
- AE 570: Production Management
- AE 598C: Sustainable Building Methods
- AE 572: Project Delivery and Planning

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Appendix A:

Overall Site Plan and Existing Conditions

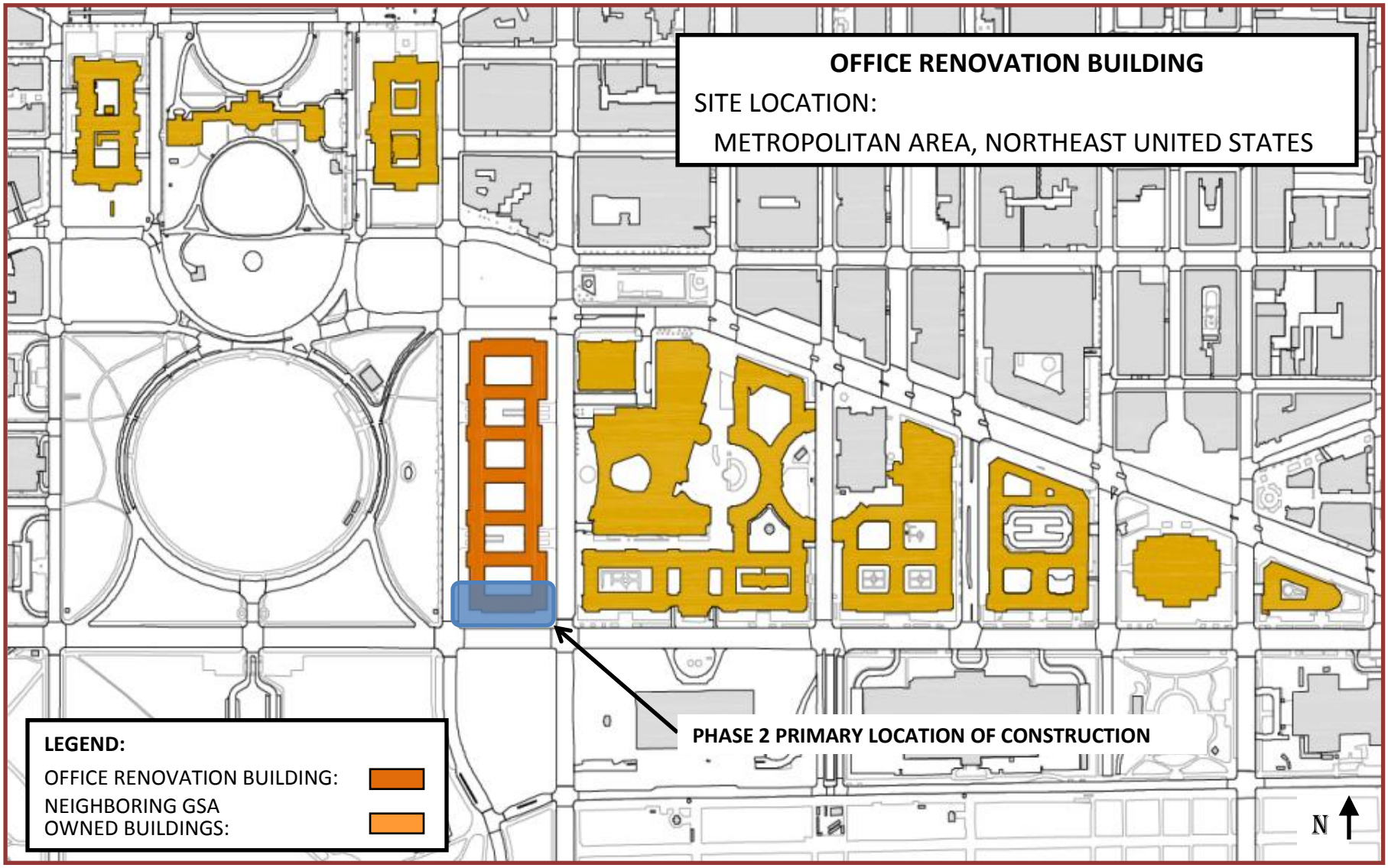
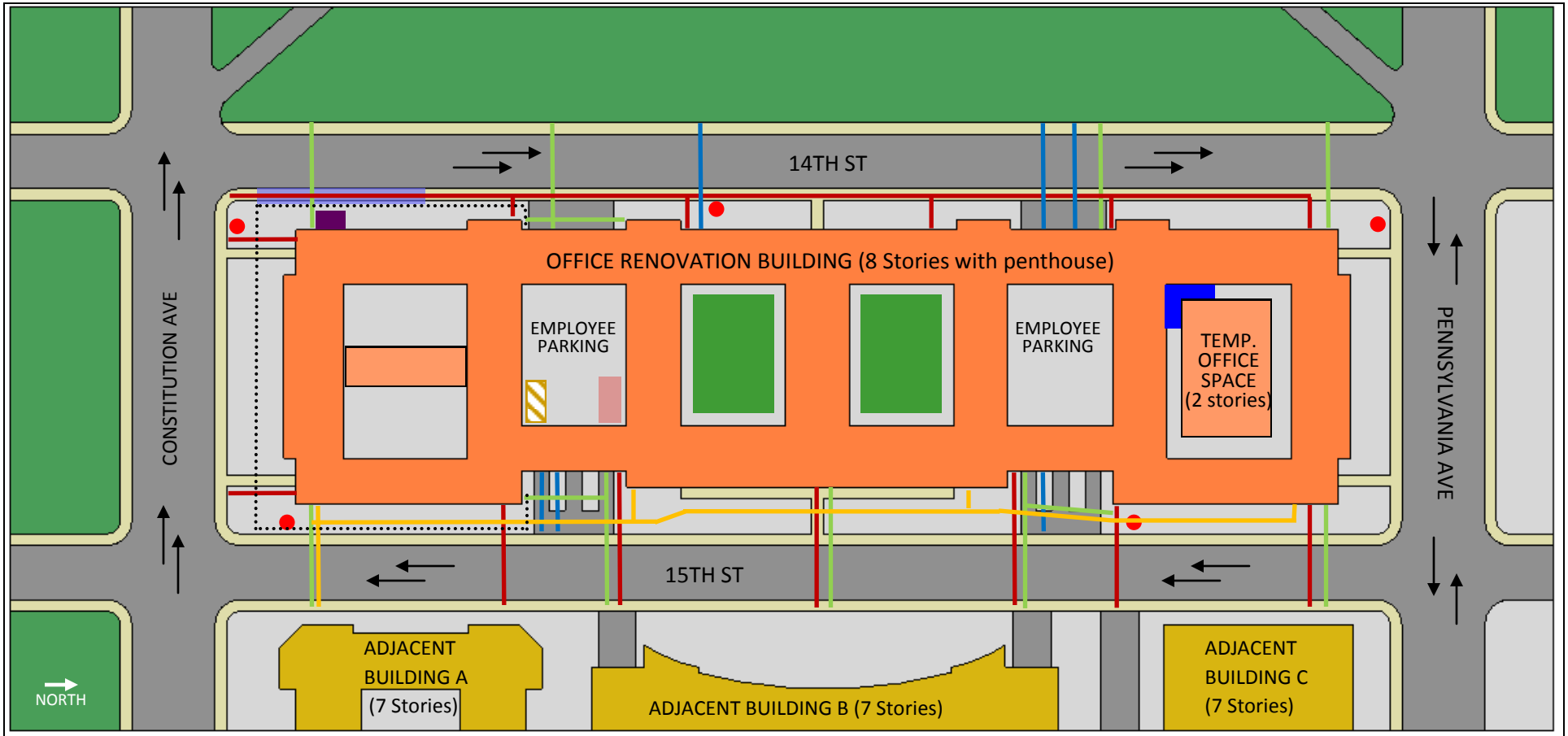


Figure C-1: Site Plan and Building Location

Please note that the specific region and location of the Office Renovation Building is not listed as per the request of the owner



EXISTING UTILITIES:

- STORM
- SANITARY
- WATER
- POWER

SYMBOLS:

- PEDESTRIAN WALKWAY
- VEHICULAR TRAFFIC
- CONSTRUCTION FENCE
- FIRE HYDRANT
- GC OFFICE
- SUPERINTENDENT PARKING
- MATERIAL HOIST
- COVERED WALKWAY
- MATERIAL WAIST CONTAINERS (BASEMENT LEVEL)

ADJACENT BUILDING NAMES HAVE BEEN RENAMED AT THE REQUEST OF THE OWNER
PHASE 2 OF CONTSTRUCTION CAN BE SPECIIFIED IN FIGURE X ON PAGE Y

OFFICE BUILDING RENOVATION

EXISTING CONDITIONS SITE PLAN

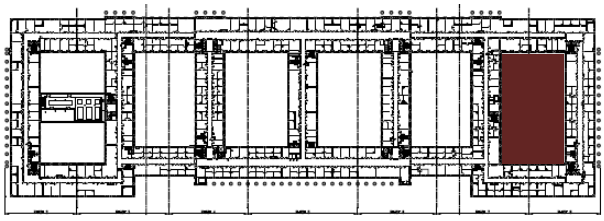
OCTOBER 4, 2010

ANTHONY JURJEVIC– CM

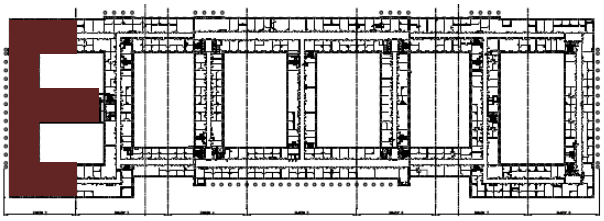
Appendix B:

Phase Sequencing

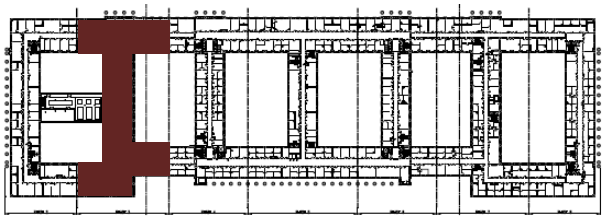
The images below illustrate the phase sequencing of construction. Phase 1 consisted of an office space for building occupants to relocate to when their building sections are under construction.



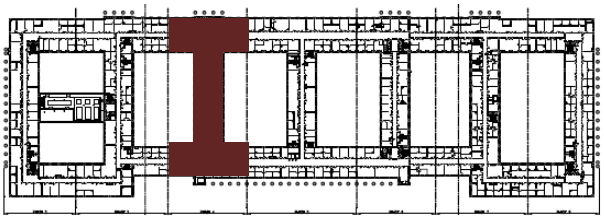
Phase 1: Construction of new temporary office space in courtyard 6 to house relocated occupants



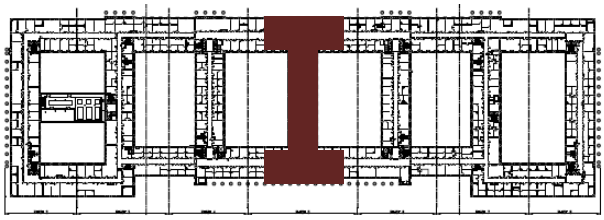
Phase 2: New MEP Infrastructure including chiller plant and new Electrical Equipment Enclosure in courtyard 1. Complete façade restoration and office renovations on 7 floors



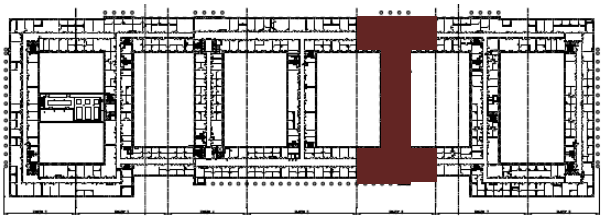
Phase 3: System replacement on all floors and repaving of courtyard 2



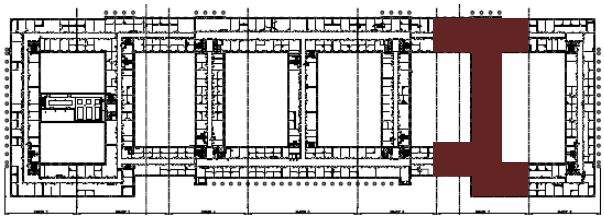
Phase 4: System replacement on all floors



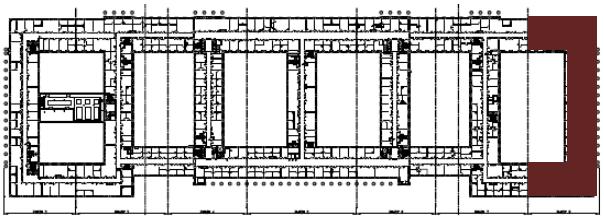
Phase 5: System replacement on all floors including auditorium, main entrance lobby, and mass transit tunnel



Phase 6: System replacement on all floors and courtyard 5 loading dock part 1



Phase 7: System replacement on all floors and courtyard 5 loading dock part 2



Phase 8: System replacement on all floors and tourist visitor center upgrades

N

Appendix C:

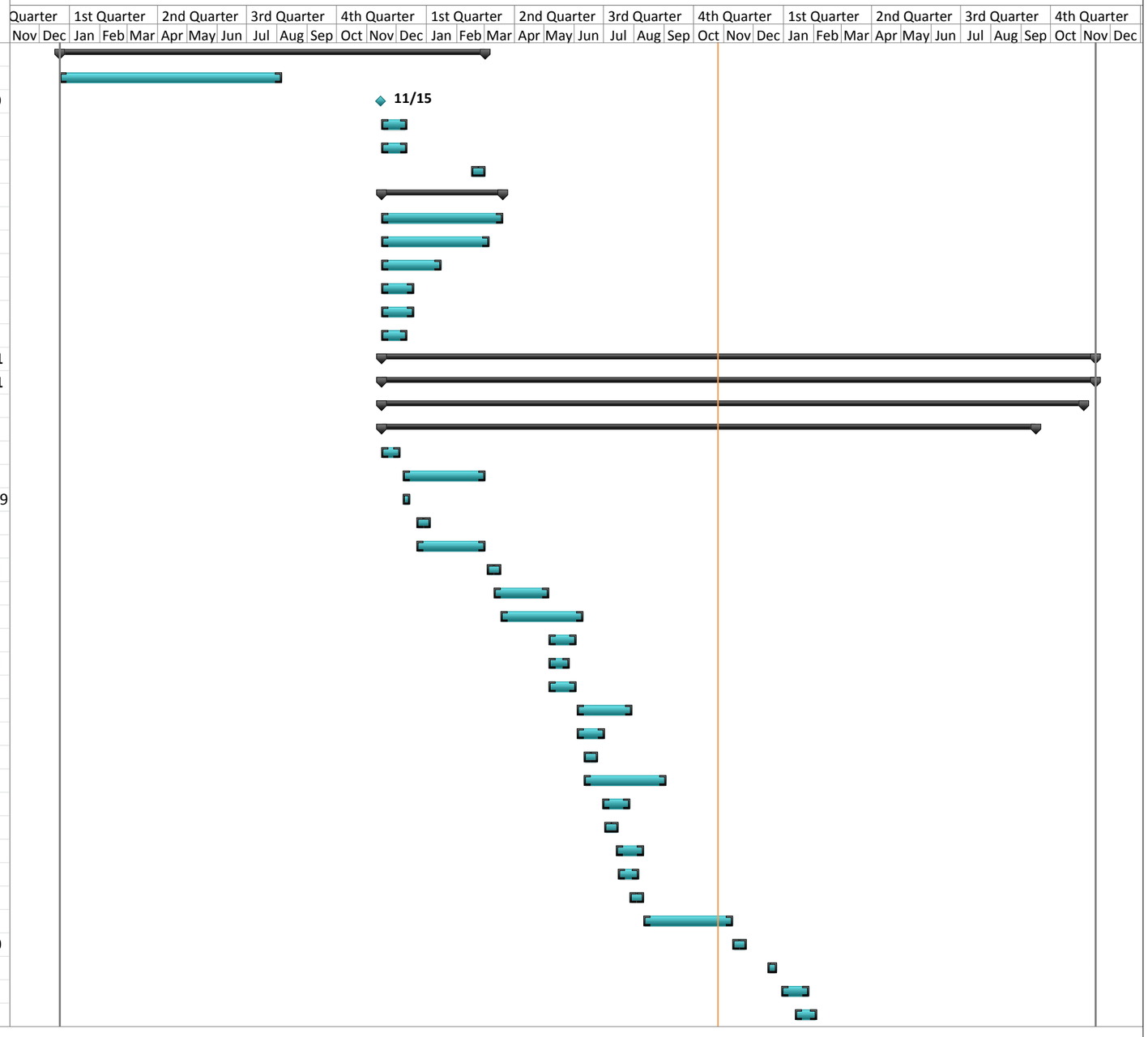
Detailed Project Schedule

Office Renovation Building
Phase II Schedule

Anthony Jurjevic
Construction Management

Detailed Project Schedule- Tech Two
October 25, 2010

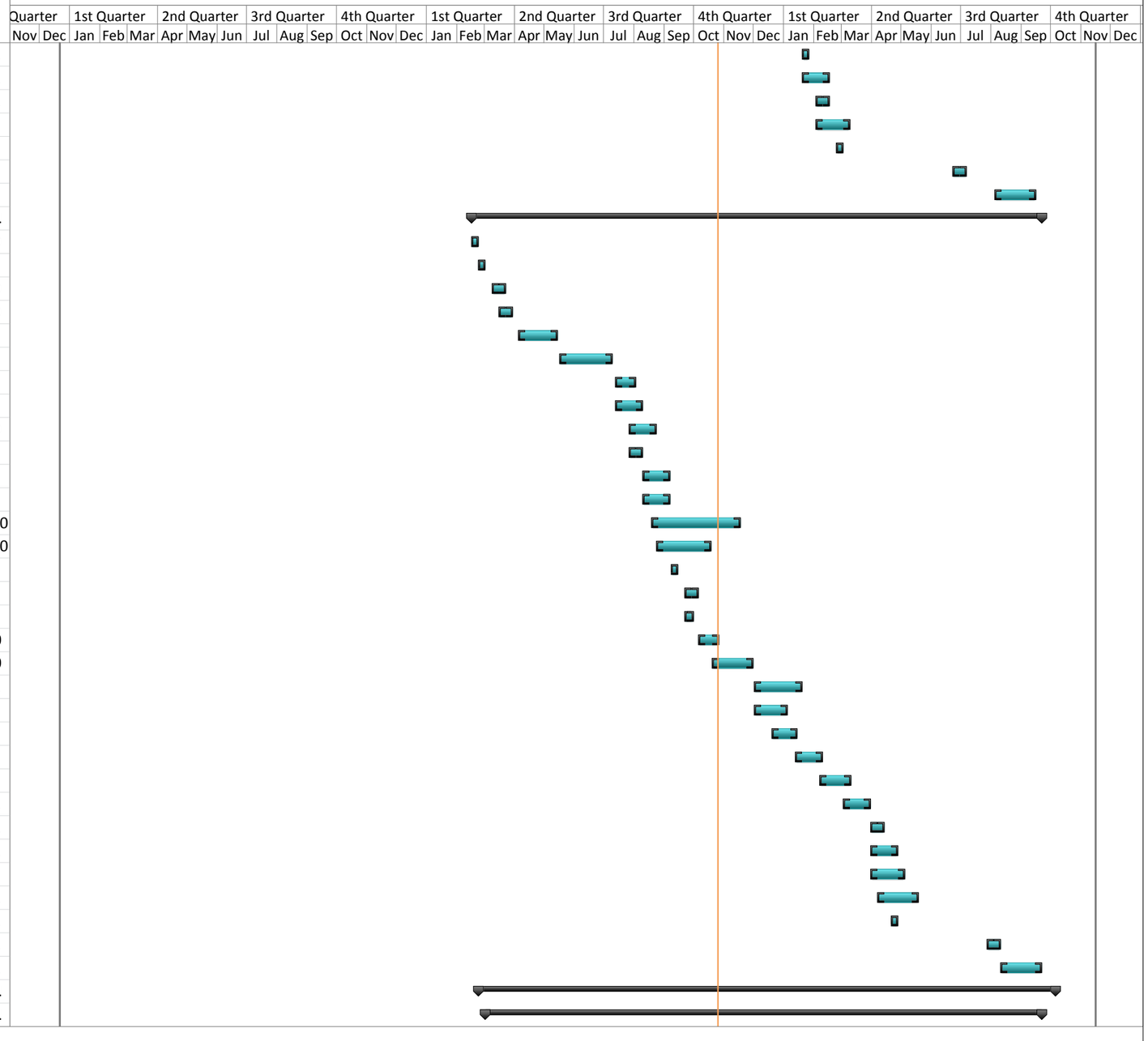
ID	Task Mode	Task Name	Duration	Start	Finish
1		**PRECONSTRUCTION/PROCUREMENT**	**311 days**	**Mon 12/22/08**	**Mon 3/1/10**
2		Estimating & Procurement	163 days	Mon 12/22/08	Wed 8/5/09
3		Phase II Notice To Proceed	0 days	Sun 11/15/09	Sun 11/15/09
4		Prepare BIM Model	20 days	Mon 11/16/09	Fri 12/11/09
5		Exterior Permits	20 days	Mon 11/16/09	Fri 12/11/09
6		Interior Existing Conditions Survey	10 days	Tue 2/16/10	Mon 3/1/10
7		**SUBMITTALS/FABRICATION/DELIVERY**	**90 days**	**Mon 11/16/09**	**Fri 3/19/10**
8		Structural Steel	90 days	Mon 11/16/09	Fri 3/19/10
9		Coordination Dwgs EEE	80 days	Mon 11/16/09	Fri 3/5/10
10		Electrical Equipment	45 days	Mon 11/16/09	Fri 1/15/10
11		Concrete	25 days	Mon 11/16/09	Fri 12/18/09
12		Abatement	25 days	Mon 11/16/09	Fri 12/18/09
13		Masonry Restoration	20 days	Mon 11/16/09	Fri 12/11/09
14		**CONSTRUCTION**	**522 days?**	**Mon 11/16/09**	**Tue 11/15/11**
15		**INTERIOR**	**522 days?**	**Mon 11/16/09**	**Tue 11/15/11**
16		**Basement & Chiller Plant**	**514 days**	**Mon 11/16/09**	**Thu 11/3/11**
48		**8th Floor**	**479 days**	**Mon 11/16/09**	**Thu 9/15/11**
49		Dust Partitions & Construction Line	15 days	Mon 11/16/09	Fri 12/4/09
50		Demo CW Piping (8th)	60 days	Tue 12/8/09	Mon 3/1/10
51		Temporary Power & Lighting	5 days	Tue 12/8/09	Mon 12/14/09
52		Selective Demo & Salvage	10 days	Tue 12/22/09	Mon 1/4/10
53		Abatement, Abate Fittings Cut N Cap	50 days	Tue 12/22/09	Mon 3/1/10
54		Install Hangers	10 days	Thu 3/4/10	Wed 3/17/10
55		Demo	40 days	Thu 3/11/10	Wed 5/5/10
56		Install new CW Piping	60 days	Thu 3/18/10	Wed 6/9/10
57		Mechanical Rough In	20 days	Thu 5/6/10	Wed 6/2/10
58		Strip, Refurb & Prime Paint Int Windows	15 days	Thu 5/6/10	Wed 5/26/10
59		Core Drill	20 days	Thu 5/6/10	Wed 6/2/10
60		Sprinkler Rough In	40 days	Fri 6/4/10	Thu 7/29/10
61		Install FCU Riser 8th Floor	20 days	Fri 6/4/10	Thu 7/1/10
62		Pipe Steam Condensate Pumps	10 days	Fri 6/11/10	Thu 6/24/10
63		Install HW Piping (8th)	60 days	Fri 6/11/10	Thu 9/2/10
64		Install HVAC Pipe	20 days	Wed 6/30/10	Tue 7/27/10
65		FCU Run Outs	10 days	Fri 7/2/10	Thu 7/15/10
66		Install Remote Chillers	20 days	Wed 7/14/10	Tue 8/10/10
67		Controls Rough In	15 days	Fri 7/16/10	Thu 8/5/10
68		Install Packaged AHU's	10 days	Wed 7/28/10	Tue 8/10/10
69		Ductwork and Insulation	65 days	Wed 8/11/10	Tue 11/9/10
70		Install Busduct Risers	10 days	Wed 11/10/10	Tue 11/23/10
71		Connect Mech Equipment	7 days	Thu 12/16/10	Fri 12/24/10
72		Drywall Framing & Hanging	20 days	Thu 12/30/10	Wed 1/26/11
73		Drywall Finish & Paint	16 days	Thu 1/13/11	Thu 2/3/11



Project: Detailed Project Schedule
Date: Tue 10/26/10

Task — Milestone — Inactive Summary — Manual Summary — Finish-only — Progress
Split — Summary — Manual Task — Start-only — Deadline

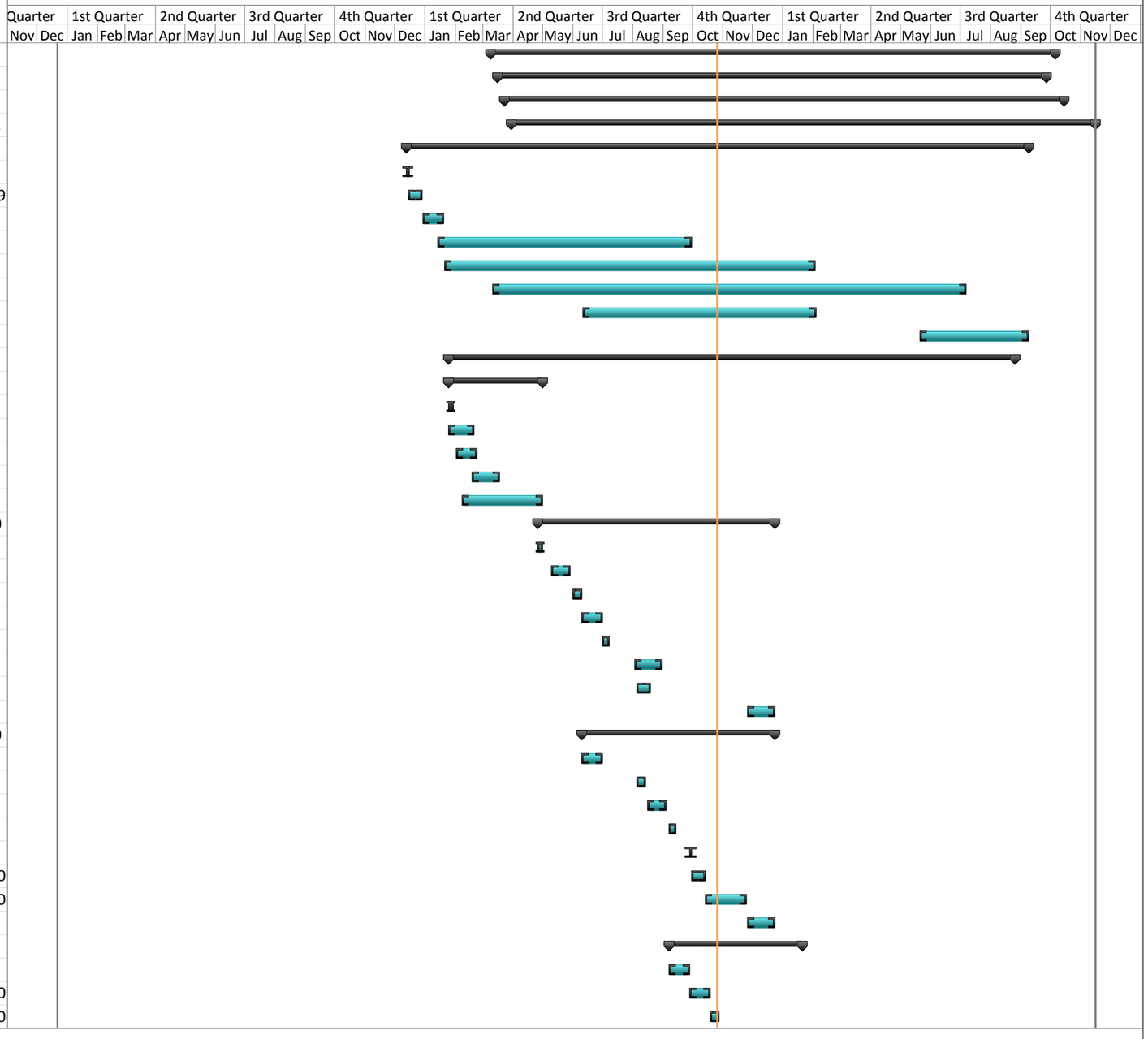
ID	Task Mode	Task Name	Duration	Start	Finish
74		Doors & Hardware	5 days	Thu 1/20/11	Wed 1/26/11
75		Paint Exterior Corridors	20 days	Thu 1/20/11	Wed 2/16/11
76		Sprinkler Drops & Heads	10 days	Thu 2/3/11	Wed 2/16/11
77		Install Light Fixtures & Controls	25 days	Thu 2/3/11	Wed 3/9/11
78		Test & Balance	5 days	Thu 2/24/11	Wed 3/2/11
79		Commissioning	10 days	Thu 6/23/11	Wed 7/6/11
80		Punch & Correct 8th Floor	30 days	Fri 8/5/11	Thu 9/15/11
81		**7th Floor**	**417 days**	**Tue 2/16/10**	**Wed 9/21/11**
82		Dust Partitions & Construction Line	5 days	Tue 2/16/10	Mon 2/22/10
83		Temporary Power & Lighting	5 days	Tue 2/23/10	Mon 3/1/10
84		Abate Fittings, Cut N Cap	10 days	Tue 3/9/10	Mon 3/22/10
85		Selective Demo & Salvage	10 days	Tue 3/16/10	Mon 3/29/10
86		Abatement	30 days	Mon 4/5/10	Fri 5/14/10
87		Demo	40 days	Mon 5/17/10	Fri 7/9/10
88		Strip, Refurb & Prime Paint Int Windows	15 days	Tue 7/13/10	Mon 8/2/10
89		Core Drill	20 days	Tue 7/13/10	Mon 8/9/10
90		Mechanical Rough In	20 days	Tue 7/27/10	Mon 8/23/10
91		Plumbing Rough In	10 days	Tue 7/27/10	Mon 8/9/10
92		Install HVAC Riser Pipe	20 days	Tue 8/10/10	Mon 9/6/10
93		Install FCU Riser 7th Floor	20 days	Tue 8/10/10	Mon 9/6/10
94		Ductwork and Insulation	65 days	Thu 8/19/10	Wed 11/17/10
95		Sprinkler Rough In	40 days	Tue 8/24/10	Mon 10/18/10
96		Install CRAC units	5 days	Wed 9/8/10	Tue 9/14/10
97		FCU Run Outs	10 days	Wed 9/22/10	Tue 10/5/10
98		Connect Mech Equipment	7 days	Wed 9/22/10	Thu 9/30/10
99		Controls Rough In	15 days	Wed 10/6/10	Tue 10/26/10
100		Drywall Framing & Hanging	30 days	Wed 10/20/10	Tue 11/30/10
101		Elevator Lobby Restoration	35 days	Thu 12/2/10	Wed 1/19/11
102		Drywall Finish & Paint	24 days	Thu 12/2/10	Tue 1/4/11
103		Doors and Hardware	20 days	Mon 12/20/10	Fri 1/14/11
104		Paint Exterior Corridors	20 days	Thu 1/13/11	Wed 2/9/11
105		Install Bathroom Fixtures & Accessories	24 days	Mon 2/7/11	Thu 3/10/11
106		Ceiling Grid	20 days	Thu 3/3/11	Wed 3/30/11
107		Sprinkler Drops & Heads	10 days	Thu 3/31/11	Wed 4/13/11
108		Flooring	20 days	Thu 3/31/11	Wed 4/27/11
109		Install Light Fixtures & Controls	25 days	Thu 3/31/11	Wed 5/4/11
110		Terrazzo Restoration	30 days	Thu 4/7/11	Wed 5/18/11
111		Test & Balance	5 days	Thu 4/21/11	Wed 4/27/11
112		Commissioning	10 days	Thu 7/28/11	Wed 8/10/11
113		Punch & Correct 7th Floor	30 days	Thu 8/11/11	Wed 9/21/11
114		**6th Floor**	**422 days**	**Tue 2/23/10**	**Wed 10/5/11**
148		**5th Floor**	**407 days**	**Tue 3/2/10**	**Wed 9/21/11**



Project: Detailed Project Schedule
Date: Tue 10/26/10

Task | Milestone | Inactive Summary | Manual Summary | Finish-only | Progress
Split | Summary | Manual Task | Start-only | Deadline

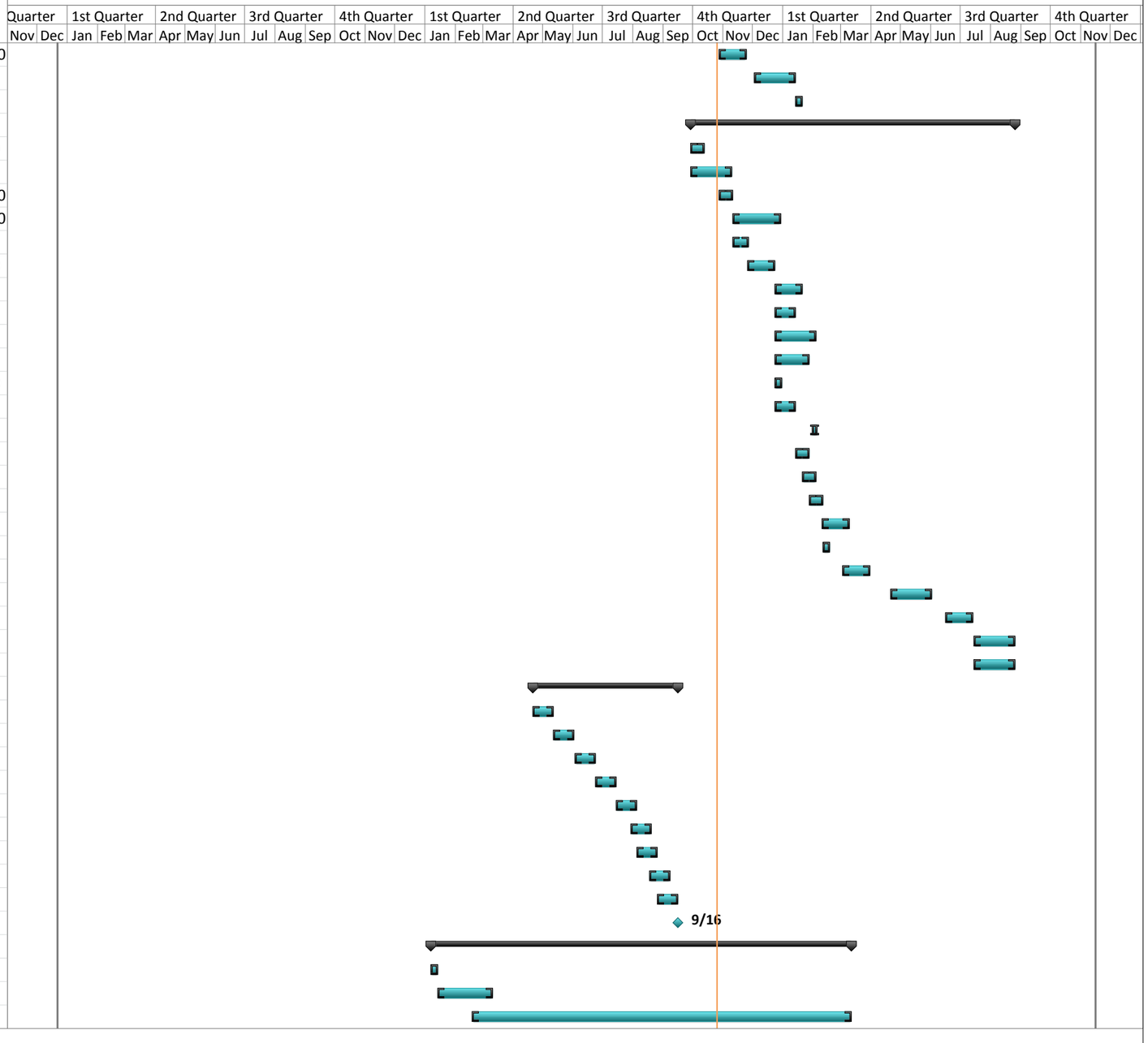
ID	Task Mode	Task Name	Duration	Start	Finish
181		**4th Floor**	**412 days**	**Tue 3/9/10**	**Wed 10/5/11**
215		**3rd Floor**	**400 days**	**Tue 3/16/10**	**Mon 9/26/11**
249		**2nd Floor**	**409 days**	**Tue 3/23/10**	**Fri 10/14/11**
283		**1st Floor**	**426 days?**	**Tue 3/30/10**	**Tue 11/15/11**
318		**Sitework and Utilities**	**454 days**	**Sun 12/13/09**	**Thu 9/8/11**
319		Mobilization	3 days	Sun 12/13/09	Tue 12/15/09
320		Fence Staging/Dumpster/Hoise Area	10 days	Tue 12/15/09	Mon 12/28/09
321		Tree Protection and Relocation of Magnolia Trees	15 days	Wed 12/30/09	Tue 1/19/10
322		Storm & Sewer	185 days	Thu 1/14/10	Wed 9/29/10
323		General Site Demolition (Phased)	270 days	Thu 1/21/10	Wed 2/2/11
324		Site Improvements & Hardscape	345 days	Thu 3/11/10	Wed 7/6/11
325		Ductbank Reconstruction	170 days	Fri 6/11/10	Thu 2/3/11
326		Landscaping	80 days	Sat 5/21/11	Thu 9/8/11
327		**EEE**	**414 days**	**Mon 1/25/10**	**Thu 8/25/11**
328		**Basement (Existing)**	**70 days**	**Mon 1/25/10**	**Fri 4/30/10**
329		Dust Partitions (Basement)	5 days	Mon 1/25/10	Fri 1/29/10
330		Emplty Basement Storage Area	20 days	Mon 1/25/10	Fri 2/19/10
331		Cut & Cap EEE	15 days	Tue 2/2/10	Mon 2/22/10
332		Demo AHU EEE	20 days	Thu 2/18/10	Wed 3/17/10
333		Demo EEE (Basement Existing)	60 days	Mon 2/8/10	Fri 4/30/10
334		**2nd Floor**	**174 days**	**Mon 4/26/10**	**Thu 12/23/10**
335		Salvage Roof Pavers for Reuse	5 days	Mon 4/26/10	Fri 4/30/10
336		Steel Framing 2nd Floor EEE	15 days	Mon 5/10/10	Fri 5/28/10
337		Concrete 2nd Floor EEE	7 days	Tue 6/1/10	Wed 6/9/10
338		Concrete up to Strength	15 days	Thu 6/10/10	Wed 6/30/10
339		Set Equipment Pads	5 days	Thu 7/1/10	Wed 7/7/10
340		Set/Connect Switchgear	20 days	Tue 8/3/10	Mon 8/30/10
341		Assemble & Protect Switchgear	10 days	Thu 8/5/10	Wed 8/18/10
342		Set/Connect 5KV Chiller SWGR NW	20 days	Fri 11/26/10	Thu 12/23/10
343		**4th Floor**	**141 days**	**Thu 6/10/10**	**Thu 12/23/10**
344		Steel Framing 4th Floor EEE	15 days	Thu 6/10/10	Wed 6/30/10
345		Concrete 4th Floor EEE	7 days	Thu 8/5/10	Fri 8/13/10
346		Concrete up to Strength	15 days	Mon 8/16/10	Fri 9/3/10
347		Set Equipment Pads	5 days	Tue 9/7/10	Mon 9/13/10
348		Rigg Generator & Switchgear	2 days	Tue 9/28/10	Wed 9/29/10
349		Assemble & Protect Generator	10 days	Thu 9/30/10	Wed 10/13/10
350		Set/Connect Generators 1,2,3	30 days	Thu 10/14/10	Wed 11/24/10
351		Set/Connect Switchgear & Transformers	20 days	Fri 11/26/10	Thu 12/23/10
352		**Roof**	**98 days**	**Tue 9/7/10**	**Thu 1/20/11**
353		Steel Framing Roof EEE	15 days	Tue 9/7/10	Mon 9/27/10
354		Install Louver Framing EEE	15 days	Tue 9/28/10	Mon 10/18/10
355		Concrete Roof EEE	7 days	Tue 10/19/10	Wed 10/27/10



Project: Detailed Project Schedule
Date: Tue 10/26/10

Task | Milestone | Inactive Summary | Manual Summary | Finish-only | Progress
Split | Summary | Manual Task | Start-only | Deadline

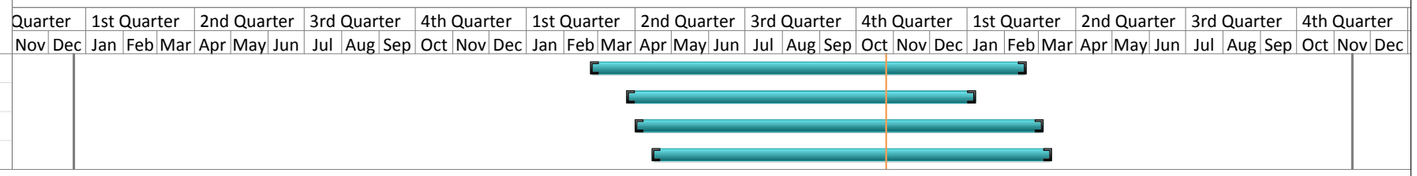
ID	Task Mode	Task Name	Duration	Start	Finish
356		Spray Fireproofing EEE	20 days	Thu 10/28/10	Wed 11/24/10
357		Install Membrane & GR Components EEE	30 days	Fri 12/3/10	Thu 1/13/11
358		Install Roof Plantings EEE	5 days	Fri 1/14/11	Thu 1/20/11
359		**All Floors (Interiors & Finishes)**	**237 days**	**Wed 9/29/10**	**Thu 8/25/11**
360		Install Stairs EEE	10 days	Wed 9/29/10	Tue 10/12/10
361		Masonry EEE	30 days	Wed 9/29/10	Tue 11/9/10
362		Storm Piping	10 days	Thu 10/28/10	Wed 11/10/10
363		Conduit & Cable Generator EEE	35 days	Thu 11/11/10	Wed 12/29/10
364		Fuel Oil Piping	12 days	Thu 11/11/10	Fri 11/26/10
365		Ductwork EEE	20 days	Fri 11/26/10	Thu 12/23/10
366		Sprinkler Rough In	20 days	Fri 12/24/10	Thu 1/20/11
367		Conduit & Cable Transformers EEE	15 days	Fri 12/24/10	Thu 1/13/11
368		Fire Alarm EEE	30 days	Fri 12/24/10	Thu 2/3/11
369		Conduit & Cable Switchgear EEE	25 days	Fri 12/24/10	Thu 1/27/11
370		Pepco Ductbank Tie-In	5 days	Fri 12/24/10	Thu 12/30/10
371		Rough-In 5kv/15kv Feeders	15 days	Fri 12/24/10	Thu 1/13/11
372		Pepco Pull Main Cables to Ductbank EEE	5 days	Mon 1/31/11	Fri 2/4/11
373		Unit heaters 2nd & 4th Floors	10 days	Fri 1/14/11	Thu 1/27/11
374		Sprinkler Drops & Heads	10 days	Fri 1/21/11	Thu 2/3/11
375		Hot Water Piping	10 days	Fri 1/28/11	Thu 2/10/11
376		Frame, Hang & Finish Drywall EEE	20 days	Thu 2/10/11	Wed 3/9/11
377		Insulation Mechanical	5 days	Fri 2/11/11	Thu 2/17/11
378		Startup & Test Electrical EEE	20 days	Thu 3/3/11	Wed 3/30/11
379		Exterior Louvers EEE	30 days	Thu 4/21/11	Wed 6/1/11
380		Test & Balance Mechanical EEE	20 days	Thu 6/16/11	Wed 7/13/11
381		Commissioning EEE	30 days	Fri 7/15/11	Thu 8/25/11
382		Punch & Correct EEE	30 days	Fri 7/15/11	Thu 8/25/11
383		**ROOF**	**106 days**	**Wed 4/21/10**	**Thu 9/16/10**
384		Remove/Salvage terrace roof paver	15 days	Wed 4/21/10	Tue 5/11/10
385		Demo Built up roofing on terraces	15 days	Wed 5/12/10	Tue 6/1/10
386		Install built up roofing on terraces	15 days	Thu 6/3/10	Wed 6/23/10
387		Reinstall pavers on terraces	15 days	Thu 6/24/10	Wed 7/14/10
388		Demo existing penthouse roofs	15 days	Thu 7/15/10	Wed 8/4/10
389		Repairs to South colonnade roof (S2)	15 days	Fri 7/30/10	Thu 8/19/10
390		Install new penthouse roofs	15 days	Thu 8/5/10	Wed 8/25/10
391		Repairs to East colonnade roof (E1)	15 days	Wed 8/18/10	Tue 9/7/10
392		Install new pavers at penthouse roofs	15 days	Thu 8/26/10	Wed 9/15/10
393		Roof work complete	0 days	Thu 9/16/10	Thu 9/16/10
394		**EXTERIOR/ FAÇADE RESTORATION**	**307 days**	**Thu 1/7/10**	**Fri 3/11/11**
395		Scaffold/swing stage Training	5 days	Thu 1/7/10	Wed 1/13/10
396		Perform Cleaning and Repointing Mockips (Phased)	40 days	Thu 1/14/10	Wed 3/10/10
397		Perimeter Fencing For Restoration Areas (Phased)	277 days	Thu 2/18/10	Fri 3/11/11



Project: Detailed Project Schedule
Date: Tue 10/26/10

Task | Milestone | Inactive Summary | Manual Summary | Finish-only | Progress
Split | Summary | Manual Task | Start-only | Deadline

ID	Task Mode	Task Name	Duration	Start	Finish
398		Abate/strip/prime Windows (Phased)	259 days	Tue 2/23/10	Fri 2/18/11
399		Clean Façade	207 days	Thu 3/25/10	Fri 1/7/11
400		Masonry Repairs	242 days	Thu 4/1/10	Fri 3/4/11
401		Final Paint Exterior Windows	237 days	Thu 4/15/10	Fri 3/11/11

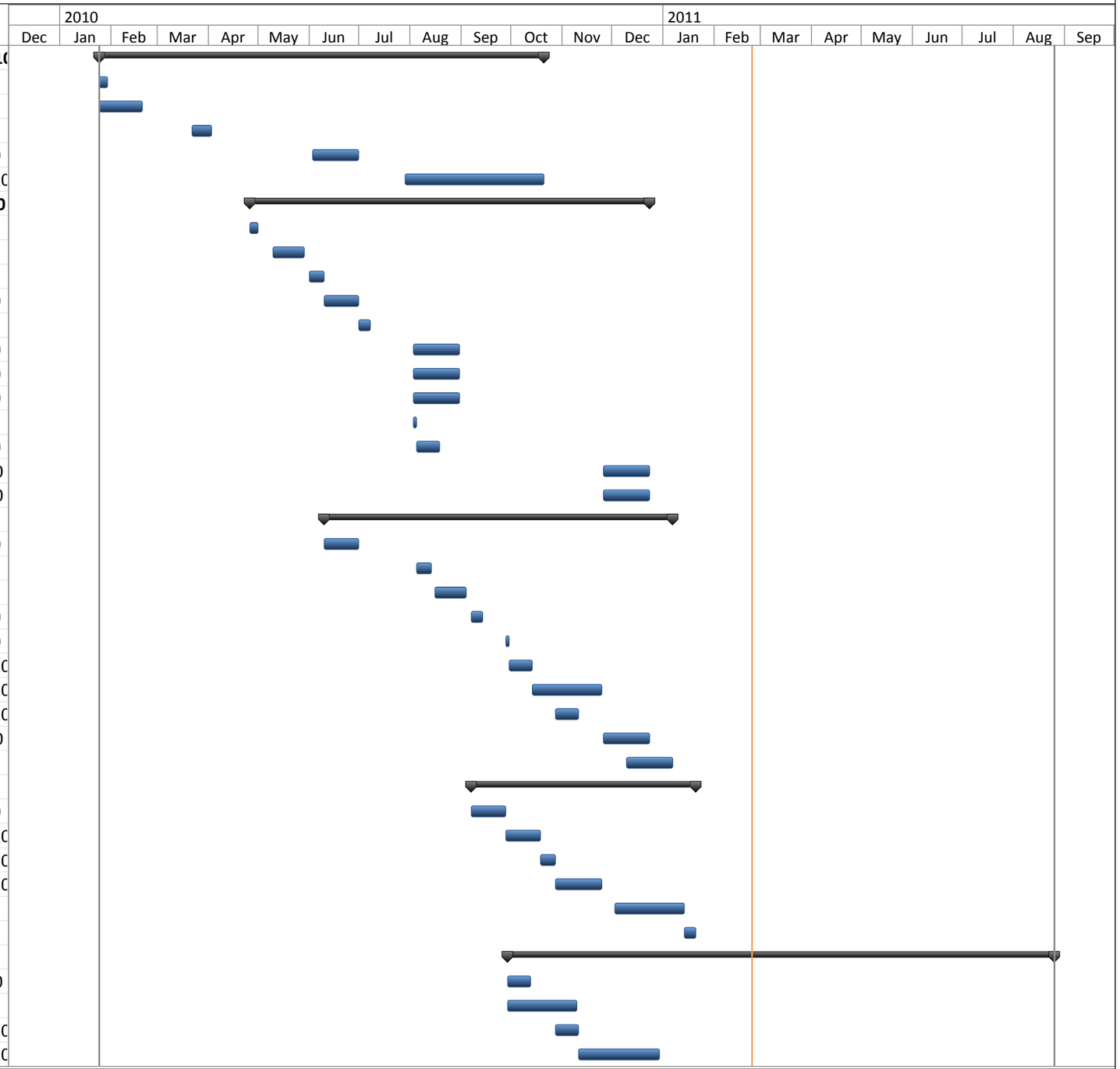


Appendix D:

Detailed EEE Schedule

EEE Original Construction Schedule

ID	Task Mode	Task Name	Duration	Start	Finish
1		**Basement**	**193 days**	**Mon 1/25/10**	**Wed 10/20/10**
2		Dust Partitions (Basement)	5 days	Mon 1/25/10	Fri 1/29/10
3		Emplty Basement Storage Area	20 days	Mon 1/25/10	Fri 2/19/10
4		Cut & Cap EEE	10 days	Mon 3/22/10	Fri 4/2/10
5		Demo AHU EEE	20 days	Thu 6/3/10	Wed 6/30/10
6		Demo EEE (Basement Existing)	60 days	Thu 7/29/10	Wed 10/20/10
7		**2nd Floor**	**174 days**	**Mon 4/26/10**	**Thu 12/23/10**
8		Salvage Roof Pavers for Reuse	5 days	Mon 4/26/10	Fri 4/30/10
9		Steel Framing 2nd Floor EEE	15 days	Mon 5/10/10	Fri 5/28/10
10		Concrete 2nd Floor EEE	7 days	Tue 6/1/10	Wed 6/9/10
11		Concrete up to Strength	15 days	Thu 6/10/10	Wed 6/30/10
12		Set Equipment Pads	5 days	Thu 7/1/10	Wed 7/7/10
13		Set/Connect Parl Switchgear	20 days	Tue 8/3/10	Mon 8/30/10
14		Set/Connect MV Switchgear North	20 days	Tue 8/3/10	Mon 8/30/10
15		Set/Connect MV Switchgear South	20 days	Tue 8/3/10	Mon 8/30/10
16		Rigg Switchgear & Transformers	2 days	Tue 8/3/10	Wed 8/4/10
17		Assemble & Protect Switchgear	10 days	Thu 8/5/10	Wed 8/18/10
18		Set/Connect 5KV Chiller SWGR NW	20 days	Fri 11/26/10	Thu 12/23/10
19		Set/Connect 5KV Chiller SWGR NW	20 days	Fri 11/26/10	Thu 12/23/10
20		**4th Floor**	**151 days**	**Thu 6/10/10**	**Thu 1/6/11**
21		Steel Framing 4th Floor EEE	15 days	Thu 6/10/10	Wed 6/30/10
22		Concrete 4th Floor EEE	7 days	Thu 8/5/10	Fri 8/13/10
23		Concrete up to Strength	15 days	Mon 8/16/10	Fri 9/3/10
24		Set Equipment Pads	5 days	Tue 9/7/10	Mon 9/13/10
25		Rigg Generator & Switchgear	2 days	Tue 9/28/10	Wed 9/29/10
26		Assemble & Protect Generator	10 days	Thu 9/30/10	Wed 10/13/10
27		Set/Connect Generators 1,2,3	30 days	Thu 10/14/10	Wed 11/24/10
28		Set Generator EEE	10 days	Thu 10/28/10	Wed 11/10/10
29		Set/Connect SWGR#1 NW Transf	20 days	Fri 11/26/10	Thu 12/23/10
30		Set/Connect LVDO SWGR#1	20 days	Fri 12/10/10	Thu 1/6/11
31		**Roof**	**98 days**	**Tue 9/7/10**	**Thu 1/20/11**
32		Steel Framing Roof EEE	15 days	Tue 9/7/10	Mon 9/27/10
33		Install Louver Framing EEE	15 days	Tue 9/28/10	Mon 10/18/10
34		Concrete Roof EEE	7 days	Tue 10/19/10	Wed 10/27/10
35		Spray Fireproofing EEE	20 days	Thu 10/28/10	Wed 11/24/10
36		Install Membrane & GR Components EEE	30 days	Fri 12/3/10	Thu 1/13/11
37		Install Roof Plantings EEE	5 days	Fri 1/14/11	Thu 1/20/11
38		**All Floors**	**237 days**	**Wed 9/29/10**	**Thu 8/25/11**
39		Install Stairs EEE	10 days	Wed 9/29/10	Tue 10/12/10
40		Masonry EEE	30 days	Wed 9/29/10	Tue 11/9/10
41		Storm Piping	10 days	Thu 10/28/10	Wed 11/10/10
42		Conduit & Cable Generator EEE	35 days	Thu 11/11/10	Wed 12/29/10

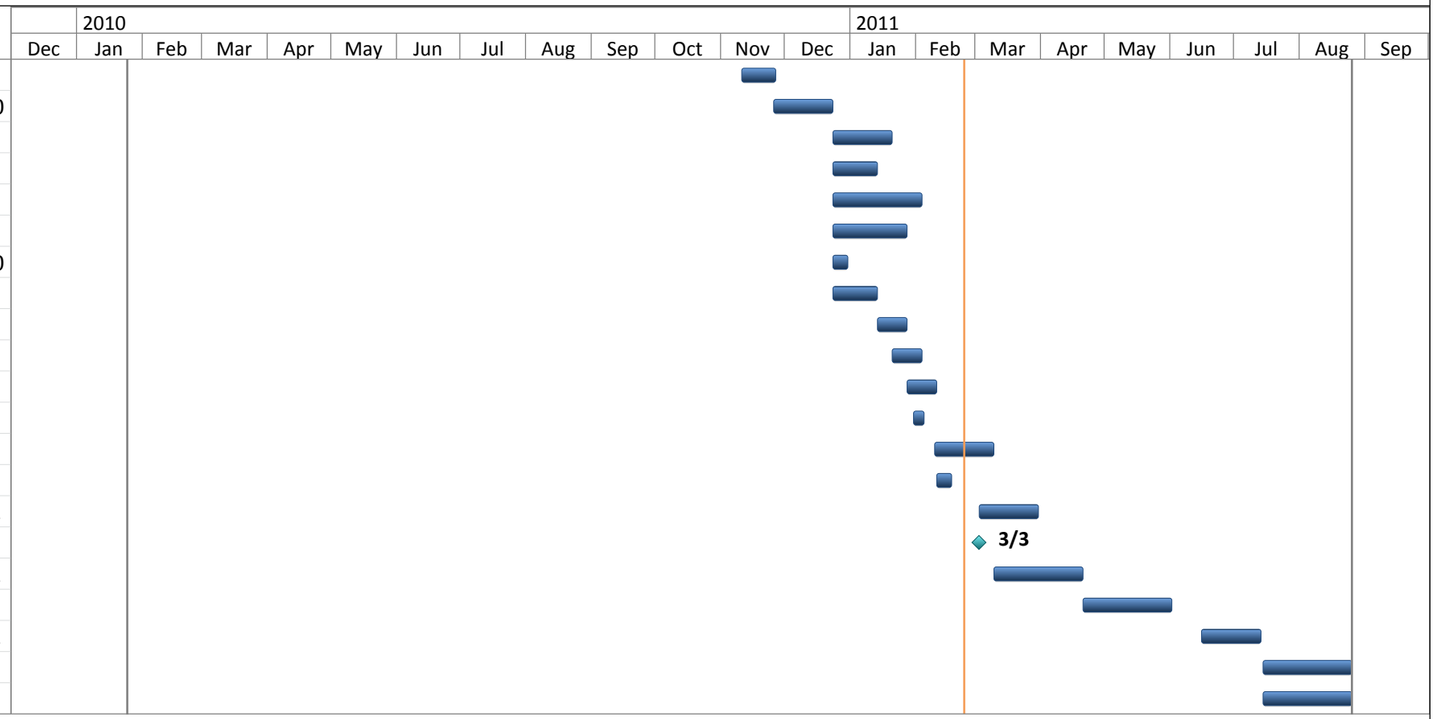


Project: EEE Original Schedule
Date: Thu 2/24/11

Task | Milestone | Project Summary | Manual Task | Manual Summary
8Split | Summary | External Tasks | Manual Summary Rollup | Finish-only

EEE Original Construction Schedule

ID	Task Mode	Task Name	Duration	Start	Finish
43		Fuel Oil Piping	12 days	Thu 11/11/10	Fri 11/26/10
44		Ductwork EEE	20 days	Fri 11/26/10	Thu 12/23/10
45		Sprinkler Rough In	20 days	Fri 12/24/10	Thu 1/20/11
46		Conduit & Cable Transformers EEE	15 days	Fri 12/24/10	Thu 1/13/11
47		Fire Alarm EEE	30 days	Fri 12/24/10	Thu 2/3/11
48		Conduit & Cable Switchgear EEE	25 days	Fri 12/24/10	Thu 1/27/11
49		Pepco Ductbank Tie-In	5 days	Fri 12/24/10	Thu 12/30/10
50		Rough-In 5kv/15kv Feeders	15 days	Fri 12/24/10	Thu 1/13/11
52		Unit heaters 2nd & 4th Floors	10 days	Fri 1/14/11	Thu 1/27/11
53		Sprinkler Drops & Heads	10 days	Fri 1/21/11	Thu 2/3/11
54		Hot Water Piping	10 days	Fri 1/28/11	Thu 2/10/11
51		Pepco Pull Main Cables to Ductbank EEE	5 days	Mon 1/31/11	Fri 2/4/11
55		Frame, Hang & Finish Drywall EEE	20 days	Thu 2/10/11	Wed 3/9/11
56		Insulation Mechanical	5 days	Fri 2/11/11	Thu 2/17/11
57		Startup & Test Electrical EEE	20 days	Thu 3/3/11	Wed 3/30/11
58		Permanent Power	0 days	Thu 3/3/11	Thu 3/3/11
59		Paint EEE	30 days	Thu 3/10/11	Wed 4/20/11
60		Exterior Louvers EEE	30 days	Thu 4/21/11	Wed 6/1/11
61		Test & Balance Mechanical EEE	20 days	Thu 6/16/11	Wed 7/13/11
62		Commissioning EEE	30 days	Fri 7/15/11	Thu 8/25/11
63		Punch & Correct EEE	30 days	Fri 7/15/11	Thu 8/25/11



Project: EEE Original Schedule
Date: Thu 2/24/11

Task
8Split
Milestone
Summary
Project Summary
External Tasks
Manual Task
Manual Summary Rollup
Manual Summary
Finish-only

Appendix E:

Public Occupancy Permit & Crane Plans

GOVERNMENT OF DISTRICT OF COLUMBIA
DEPARTMENT OF TRANSPORTATION
1100 4TH STREET SW / 2ND FLOOR, WASHINGTON, DC 20024

PUBLIC SPACE OCCUPANCY/PARKING PERMIT

Issue Date:	01/12/2011	**PERMIT NO:**	PA10019278
		Source Permit:	
Location:	1401 CONSTITUTION AVENUE NW		
Permission Granted To:	Crane Service Company		
Permit Fee No:	300029350	**Permit Fee Amount:**	$27.50
Meter Fee No:		**Meter Fee Amount:**	$0.00
Deposit No:		**Deposit Amount:**	$0.00
Public Inconvenience Fee No:		**Public Inconvenience Fee Amount:**	$0.00

Permission is hereby granted to the entity named above to perform the work described herein at the address shown above in strict accordance with all conditions stated on all pages of this permit as well as on the application submitted.

Event: Mobile Crane Work Zone

Spaces Occupied: 10 **Start Time:** 4:00 AM **End Time:** 7:00 PM

Meter Numbers: *(If applicable)*

Location Description:

To temp occupy Constitution Ave.,NW between 14th Street ad 15th Street, NW to place a 300 ton crane to hoist materials Saturday 4am thru Sunday 7pm

Conditions:

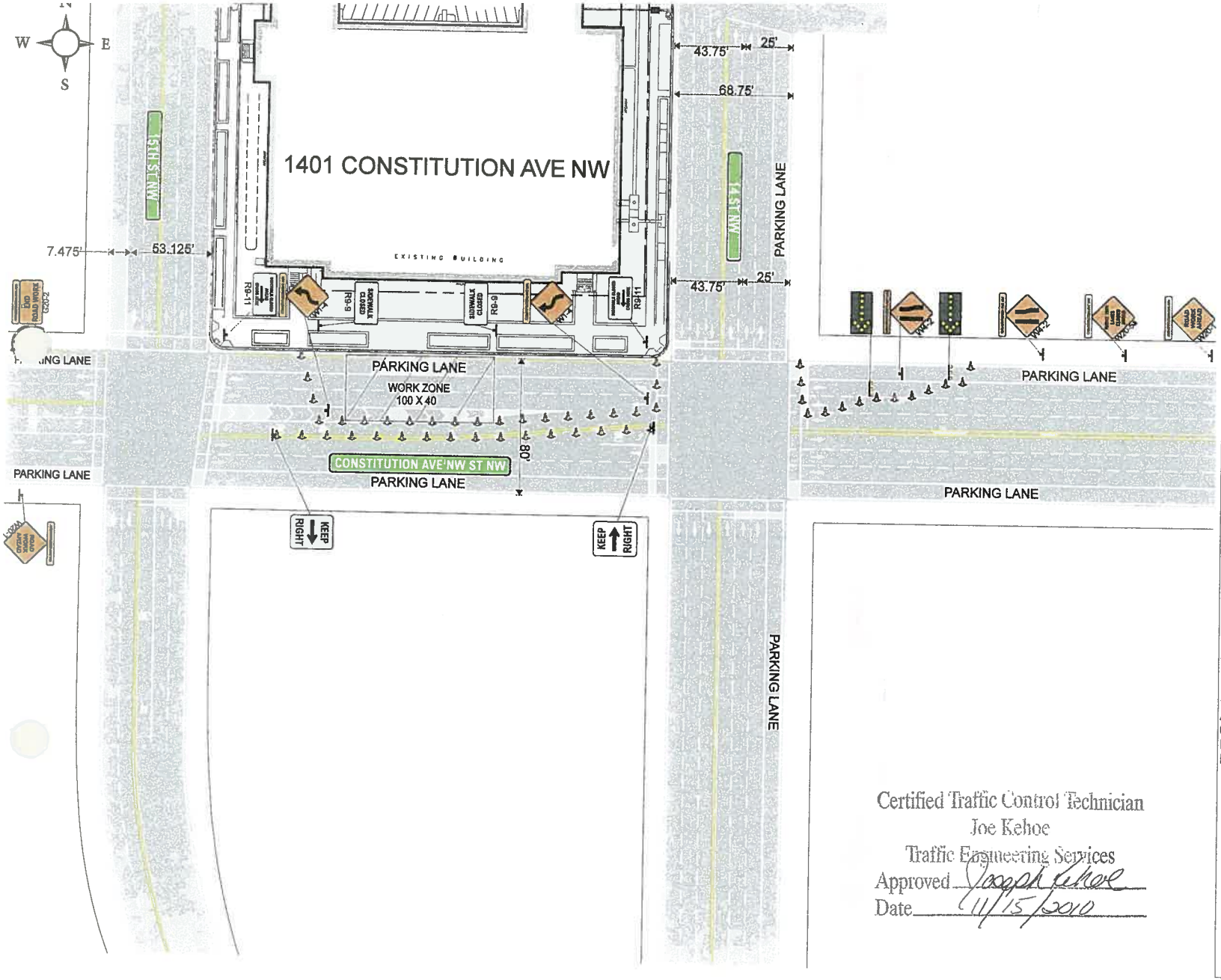
*"Emergency No Parking" and "Reserved Parking" signs must be posted no less than 72 hours in residential zones and 24 hours in business zones prior to occupancy. Signs must be immediately removed upon completion of work.
*All work and occupancy must comply with all District regulations and statutes. Violation may result in revocation of this permit.
*If street, alley or sidewalk closures are involved, approved Traffic Control Plan (TCP) is a part of this permit and must be on site at all times and visible from public space.
*Must not block any Metro Transit bus stops or Metro entrances without the permission of WMATA and DDOT.
*Must not block Fire Hydrants or any important utility structures (e.g. manholes, vault grates, ventilation, traffic signal box, etc...)
*Must not occupy Loading Zones and driveways.
*No crossing of sidewalk with trucks unless permission is granted and noted on TCP by DDOT.
*Only registered commercial vehicles directly needed for construction are permitted to be parked in the area defined by this Permit when applicable.
*Permit holder is responsible for all damage to public space as a result of work done under this permit.
*Permit holder is responsible for obtaining any additional permits required by statute or regulation including DOH, WASA, FEMS, MPDC, DDOT and DCRA permits.
*Prior to street, alley and sidewalk closures Permittee must immediately notify FEMS, MPDC and MPTD.
*Renewals require all prior public space permits be on premise.
*This permit is revocable at any time at the discretion of FEMS, MPD and/or DDOT.
*This permit must be on site at all times and visible from public space.
* Person(s) who posts an unauthorized sign or removes an authorized sign is subject to a fine of $100 per day.
* All street trees located within the construction work zone shall have a 4' high orange snow fence placed around the tree space (4' x 10'). The fence shall be install prior to work starting and removed after work has been completed.
* Trash containers and Moving Containers are to be placed in curb lane at the front of this property unless specified elsewhere on the Permit.
*No work or construction in public space is authorized by this permit.
*No work is permitted before 7am or after 7pm Mon. thru Sat. or all day Sun.. Work before 7am or after 7pm Mon. thru Sat. or all day Sun. requires permit from DCRA.
*Permit holder is responsible for contacting DDOT at 202-671-2020 to request the reinstallation of parking meters.

Permit Effective: 01/29/2011 **Permit Expires:** 01/30/2011

Curtis Pearson
Civil Engineering Technician

Terry Bellamy
Director

Copy



TRAFFIC ENGINEERING SERVICES

ROAD CLOSED

LET US HANDLE ALL OF YOUR TRAFFIC CONTROL NEEDS FROM BEGINNING TO END

4700 SANDY SPRING RD	FX: 301-549-1951
BURTONSVILLE, MD 20866	PH: 301-549-1950

1401 CONSTITUTION AVE NW

NOTES:
TO TEMP OCCUPY CONSTITUTION AVE NW BETWEEN 14TH ST NW AND 15TH ST NW TO PLACE A 300 TON CRANE TO HOIST STEEL FROM **4AM SATURDAY TO 7PM SUNDAY**

SPEED (MPH)	MINIMUM SIGN SPACING (FT)
25	150
30	200
35	250
40	350
45	550
50	600
55	700

STANDARD NOTES

1. PARKING IS TO BE RESTRICTED 72 HOURS IN ADVANCE UNLESS THERE IS AN EMERGENCY.
2. ALL SIGNS MUST BE 48X48 AND ON SPRING LOADED STAND S AND MUST BE FHWA APPROVED / NCHRP-350 RATED
3. IF SIGNALED INTERSECTIONS, TRAFFIC CONTROL DIVISION MUST BE NOTIFIED 48 HOURS PRIOR.
4. CONTRACTOR MUST FOLLOW ALL DDOT GUIDELINES
5. TES ASSUMES NO RESPONSIBILITY FOR CONTRACTORS WHO FAIL TO FOLLOW ABOVE CONDITIONS.
6. CONTRACTOR SHALL INSTALL "STEEL PLATE AHEAD" SIGNS WHEREVER STEEL PLATES HAVE BEEN INSTALL.

KEY

- ILLUMINATED ARROW PANEL
- SPRING LOADED STAND
- 36 INCH CONES WITH RETROREFLECTIVE STRIPES
- 48 X 48 INCH RETROREFLECTIVE SIGN
- TYPE III BARRICADE WITH RETROREFLECTIVE STRIPES

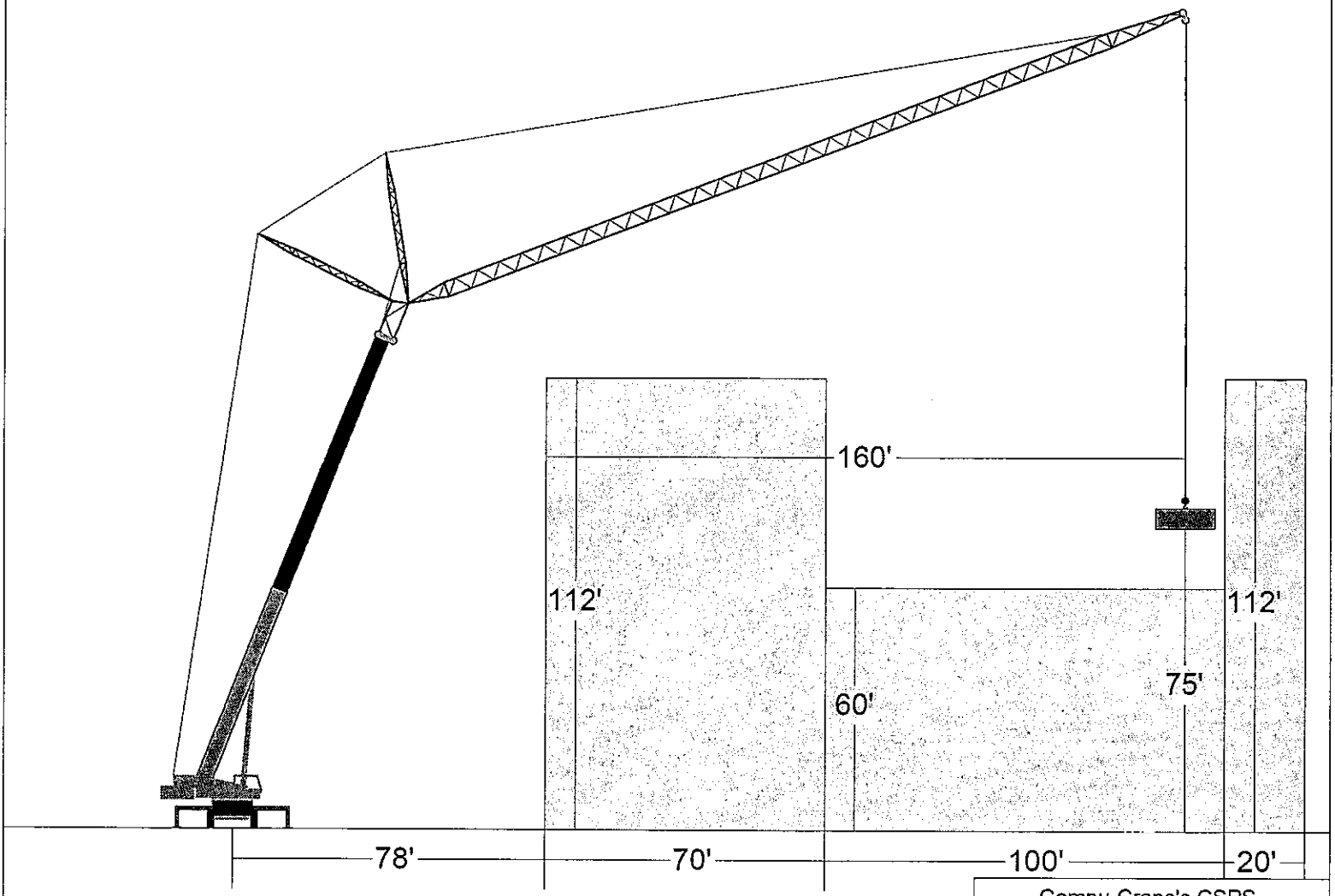
Certified Traffic Control Technician
Joe Kehoe
Traffic Engineering Services
Approved Joseph Kehoe
Date 11/15/2010

16626

Crane Service Company
10-14-2010
Scale: 39.5 (ft/in)
Elevation View: Liebherr LTM1250/1
Hook Height: 80.0 (ft)
Counterweight: 187,400#
Tip Height: 203.7 (ft)
Attached Jib Capacity Deduction: 0.0 (lb)
% of Chart Capacity: 42% (100% Limit)
Original Load Weight: 5,000.0 (lb)
Superior Iron
Hoover Building
14th.& Constitution Ave. N.W.
2nd / 4th floor

	Load Radius (ft)	Boom Length (ft)	Luffing Jib Length (ft)	Luffing Jib Offset (°)		
Crane:	238.0	119.0	207.0	47.3	Load Weight:	5,000
Chart:	240.0	119.0	207.0	58.0	Capacity (lb):	11,800

Liebherr LTM1250/1 - 51' - 119' Main Boom + 207' Luffing Jib, On 29' x 27' Outriggers, 187,400# Cwt, 360 Deg, 85% Cap, [ ]



Crane Service Company

ESTABLISHED 1926

CRANE LIFT PLAN ©

LOCATION Hoover Building DATE OF LIFT T. B. D. Tentatively 1/29/11 – 1/30/11

DESCRIPTION OF LOAD Steel Beams

LIFT DESCRIPTION Hoist steel beams to courtyard

A. WEIGHT

1	Equipment Condition	New [X] Used [ ]	
2	Weight Empty	4,000	lbs
3	Weight of Headache Ball		lbs
4	Weight of Block	n/a	lbs
5	Weight of Lifting Bar	n/a	lbs
6	Weight of Slings & Shackles	159	lbs
7	Weight of Jib [X] Erect [ ] Stored		lbs
8	Weight of Headache Ball on JIB	1,100	lbs
9	Weight of Cable (Load Fall)		lbs
10	Allowance for Unaccountable Material in Equipment		lbs
11	Other		lbs
	Total Weight	5,259	lbs

Source of Load Weight:

Superior Iron

Weights Verified By:

LMI

B. JIB

Erected x Stored

1 If Jib to be used: Yes

2 Length of Jib: 207'

3 Angle of Jib:

4 Rated Capacity of Jib (from chart): 11,800

C. SIZE OF SLINGS

1 Sling Selection

a. Type of Arrangement: 2 point pick

b. Number of Slings in Hook-up: 2

c. Sling Size: 4-Mar

d. Sling Length: 20'

e. Rated Capacity of Sling: 4.9 ton per

2 Shackle Selection

a. Pin Diameter (inches): 3/4"

b. Capacity (tons): 4 3/4 tons ea.

c. Shackle Attached to Load By: Lifting Lug

d. Number of Shackles: 2

D. CRANE

1 Type of Crane: Liebherr 1250

2 Crane Capacity: 300 Tons

3 Lifting Arrangement

a. Max. Distance-center of load to center of pin of crane: 238 ft

b. Length of Boom: 119.0 ft

c. Angle boom at pick-up: 66 degrees

d. Angle of boom at set: 35 degrees

e. Rated capacity of crane under severest lifting conditions. (from chart)

1 Over Rear: 11,800 lbs

2 Over Front: 11,800 lbs

3 Over Side: 11,800 lbs

4 From Chart - Rated Capacity for this lift: 11,800

5 Max. Load on Crane: 5,259

6 Lift is 45% of Crane's rated capacity.

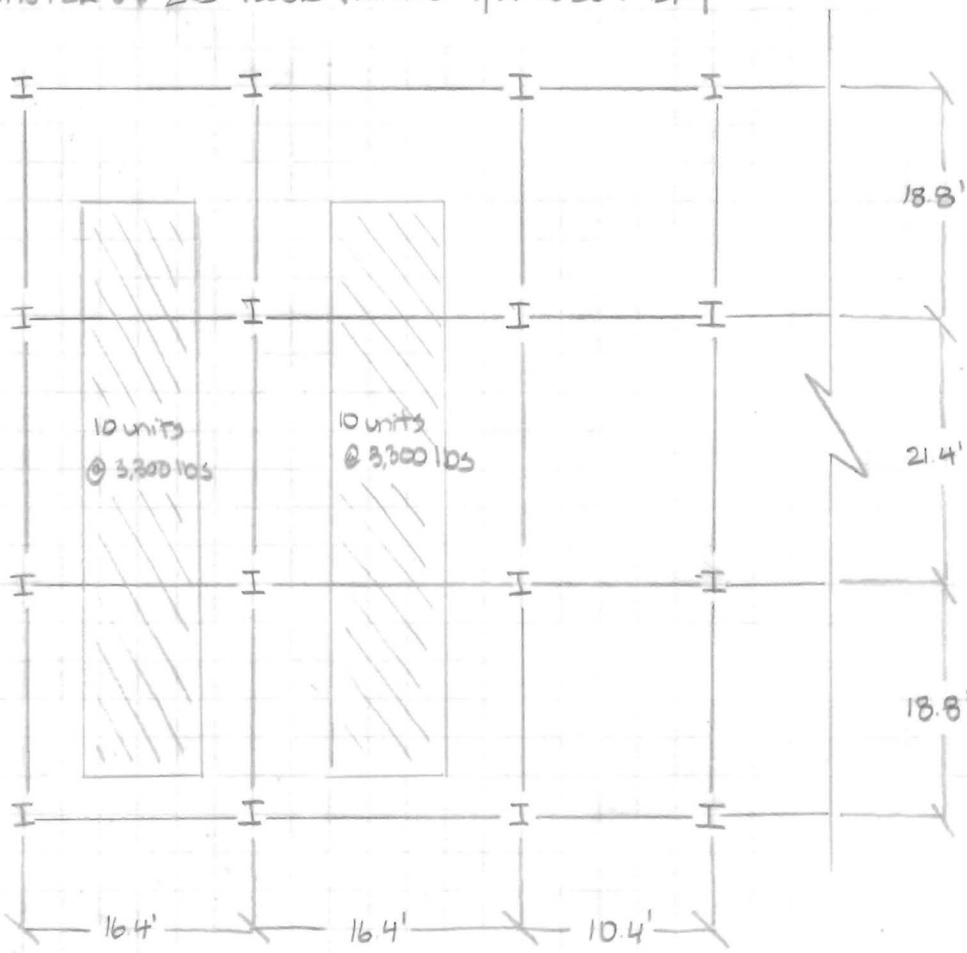
4 Max Operating Wind Speed for above boom configuration: 16.68 mph

Appendix F:

Structural Breadth Calculations

2ND FLOOR LOAD CALCULATIONS

SKETCH OF 2ND FLOOR HEAVIEST/LARGEST BAY:



EQUIPMENT AREA: $6' \times (8'\text{long} \times 5\text{ units}) = 240$ SF

$(10)(3{,}300\ \text{lbs/unit}) = 33{,}000$ lbs } 137.5 PSF

4"/12" EQUIP PAD + (9'×42' AREA) = $126\ FT^3 \left(115 \frac{lb}{ft^3}\ \text{Wt Concrete}\right) = 14{,}490$ lbs

$115\ lb/ft^3\ (0.33\ ft) =$ = 38.33 PSF

---

for hollow core NEED to add weight for 2" concrete topping:

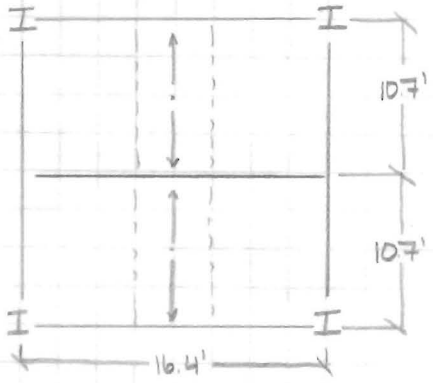
$\left(2" \cdot \frac{1\ ft}{12"}\right)\left(115 \frac{lb}{ft^3}\right) =$ = 19.166 PSF

SIZING OF HOLLOW CORE PLANK

SUPERIMPOSED : 25 psf
LIVE LOAD: 40 psf
DEAD LOAD: 13.75 (equip) + 38.33 (pcd) + 19.166 (topp) + 48.75 (plnk)
= 243.7746

$1.2(268.74) + 1.6(40) = 386.48$ PSF → LOAD TABLES

6"x4'-0" HOLLOW CORE PLANK (2 HR RATED w/ 2" TOPPING)
CLEAR SPAN LOAD 10.7' = 524 PSF ✓ 6-1/2" Ø STRANDS.



$(386.48 psf)(4') = 1545.92$ plf
$= 1.545.92$ klf

$E = 33 W_c^{1.5} \sqrt{f'c} = 33(150^{1.5})(77.5)$
$= 4,685,982.325$ psi

$I = 757$ in^4

CHECK FOR DEFLECTION:

$\Delta_{\text{ACTUAL TOTAL}} = \frac{5wl^4}{384EI} = \frac{5(1.545)(10.74)(1728)}{384(4696)(757)} = 0.128"$

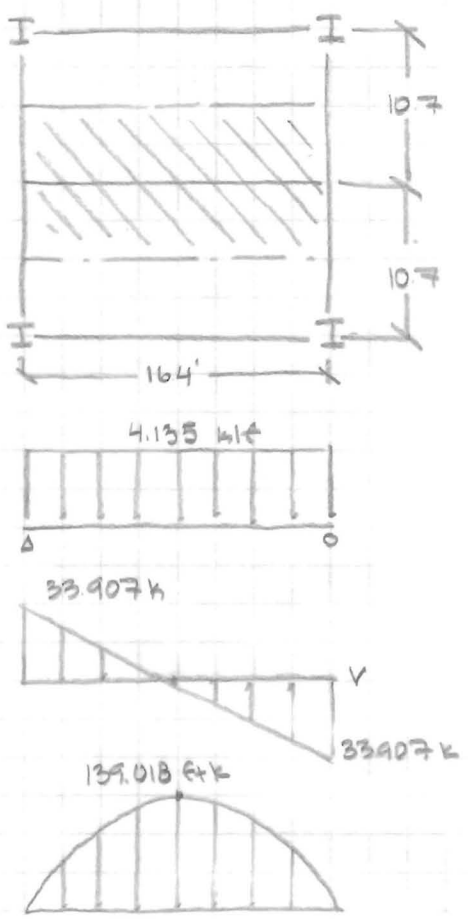
$\Delta_{ALLOW} = L/240 = 10.7(12)/240 = 0.535" > 0.128"$ ✓

$\Delta_{LL} = \frac{5(0.16)(10.74)(1728)}{1365070848} = 0.010"$

$\Delta_{LL\ ALLOW} = L/360 = 0.356" > 0.010"$ ✓

SELECTED PLANKS ARE ACCEPTABLE ✓

SIZING OF INTERIOR BEAMS



$(386.48\ PSF)(10.7') = 4135.336\ plf$
$= 4.135\ klf$

$\phi_b M_{px} = W12\times16\ (Exist) = 75.4\ kf$ X

W12x26 = 140 ft-k > 139 ft-k
DOESN'T PASS DEFLECTION

W12x30 = 162 ft-k > 139 ft-k
DOESN'T PASS DEFLECTION

W12x35 = 192 ft-k > 139 ft-k ✓

check beam self weight: 4.135 + 35 psf = 4.17 k

$M = w_u l^2/8 = 140 < 192$ ✓

DEFLECTION (TOTAL LOAD)

$$\Delta_{ACT} = \frac{5wl^4}{384EI} = \frac{5(4{,}135)(16.4^4)(1728)}{384(29{,}000{,}000)(238)} = \frac{258E12}{2.6503E12} = 0.97"$$

$\Delta_{ALLOW} = L/240 = 16.4(12)/240 = 0.82"$ X

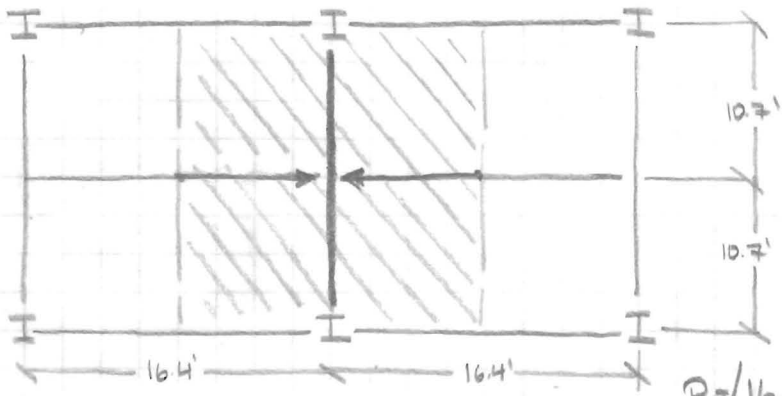
$W_{12\times35} \rightarrow I = 285 \Rightarrow \frac{258E12}{3.17E12} = 0.810" < 0.82$ ✓

$$\Delta_{LL\,ACT} = \frac{5(64)(16.4^4)(1728)}{3.17E12} = \frac{4.00E10}{3.17E12} = 0.012"$$

$\Delta_{ALLOW\,LL} = L/360 = 16.4(12)/360 = 0.546"$ ✓

W12x35 will be used

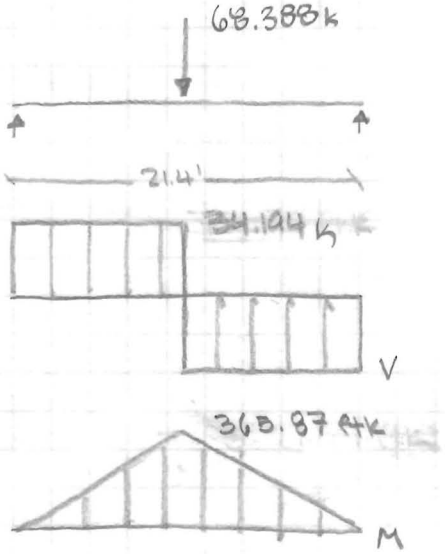
SIZING OF GIRDERS



4.135 KIF (loads)
.035 KIF (beams)
4.17 KIF
convert to POINT LOAD

$$P = \left(\frac{16.4'(4.17\ \text{KIF})}{2}\right) 2$$

$P = 68.388$ kips



ϕM_{px} (W24x84 original) = 840 KFt ✓

more efficient option = W21 x 48
398 FTK > 368 ✓

DEFLECTION (TOTAL ACTUAL)

$$\Delta_{MAX} = PL^3/48EI = \frac{(68,388.00)(21.4^3)(1728)}{48(29,000,000)(959)} = \frac{1.15}{1.33} = 0.86"$$

$\Delta_{ALLOW} = L/240 = 1.07$ ✓

$$\Delta_{MAX\,LL} = \frac{(140384)(21.4^3)(1728)}{1.33E12} = 0.178$$

$\Delta_{ALLOW} = L/360 = 0.7133$ ✓

check girder self weight = $68.3 + \left(\frac{48^{lb}/ft^2\,(21.4)}{1000}\right) = 69.415$ kips

$\frac{PL}{4} = 371.37$ FTK < 398 FTK ✓ GOOD.

W21x48

Appendix G:

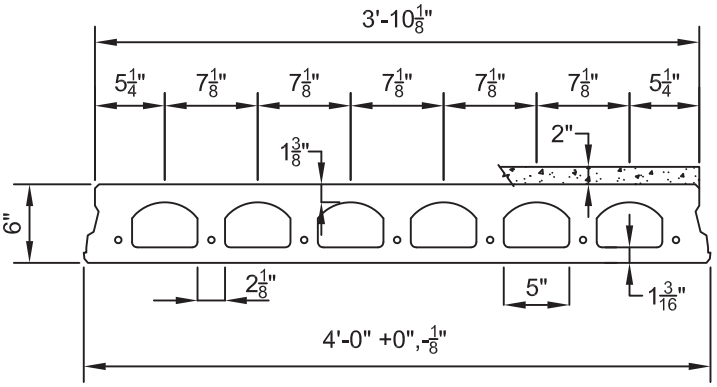
Hollow Core Plank Details and Notes

Prestressed Concrete
6"x4'-0" Hollow Core Plank

2 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES Composite Section	
A_c = 253 in.^{2}	Precast b_w = 16.13 in.
I_c = 1519 in.^{4}	Precast S_{bcp} = 370 in.^{3}
Y_{bcp} = 4.10 in.	Topping S_{tct} = 551 in.^{3}
Y_{tcp} = 1.90 in.	Precast S_{tcp} = 799 in.^{3}
Y_{tct} = 3.90 in.	Precast Wt. = 195 PLF
	Precast Wt. = 48.75 PSF

DESIGN DATA



1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI
3. Precast Density = 150 PCF
4. Strand = 1/2"Ø 270K Lo-Relaxation.
5. Strand Height = 1.75 in.
6. Ultimate moment capacity (when fully developed)...
   - 4-1/2"Ø, 270K = 67.4 k-ft at 60% jacking force
   - 6-1/2"Ø, 270K = 92.6 k-ft at 60% jacking force
   - 7-1/2"Ø, 270K = 95.3 k-ft at 60% jacking force
7. Maximum bottom tensile stress is $10\sqrt{f'c}$ = 775 PSI
8. All superimposed load is treated as live load in the strength analysis of flexure and shear.
9. Flexural strength capacity is based on stress/strain strand relationships.
10. Deflection limits were not considered when determining allowable loads in this table.
11. Topping Strength @ 28 days = 3000 PSI. Topping Weight = 25 PSF.
12. These tables are based upon the topping having a uniform 2" thickness over the entire span. A lesser thickness might occur if camber is not taken into account during design, thus reducing the load capacity.
13. Load values to the left of the solid line are controlled by ultimate shear strength.
14. Load values to the right are controlled by ultimate flexural strength or fire endurance limits.
15. Load values may be different for IBC 2000 & ACI 318-99. Load tables are available upon request.
16. Camber is inherent in all prestressed hollow core slabs and is a function of the amount of eccentric prestressing force needed to carry the superimposed design loads along with a number of other variables. Because prediction of camber is based on empirical formulas it is at best an estimate, with the actual camber usually higher than calculated values.

SAFE SUPERIMPOSED SERVICE LOADS — IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)

Strand Pattern		SPAN (FEET)																		
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
4 - 1/2"ø	LOAD (PSF)	349	317	290	258	227	197	174	149	127	108	92	78	66	55					
6- 1/2"ø	LOAD (PSF)	524	478	437	377	334	292	269	237	215	188	165	142	122	104	88	73	61	49	39
7 - 1/2"ø	LOAD (PSF)	541	492	451	416	364	331	293	274	242	214	190	167	144	124	107	91	77	64	53

NITTERHOUSE CONCRETE PRODUCTS

2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17202-9203
717-267-4505 Fax 717-267-4518

This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths. The allowable loads shown in this table reflect a 2 Hour & 0 Minute fire resistance rating.

11/03/08

6F2.0T

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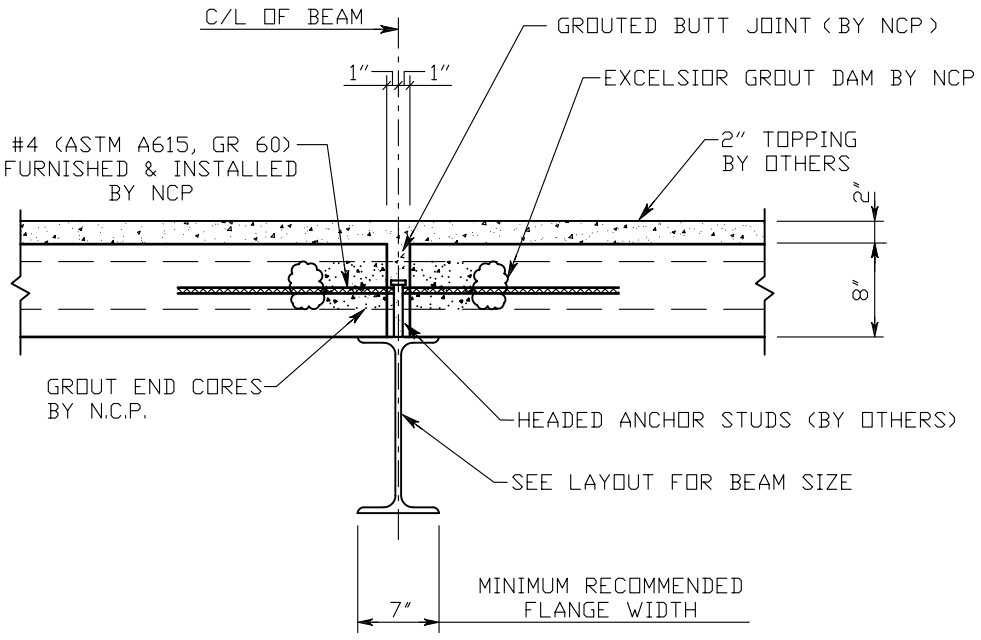
NITTERHOUSE CONCRETE PRODUCTS

HOLLOW CORE PLANK CONNECTION

DETAIL OF BEARING ON STEEL BEAM



NOTES:

1. N.C.P. WILL PROVIDE A BROOMED FINISH IN ORDER TO CREATE A COMPOSITE TOPPING. C.I.P. TOPPING BY OTHERS IS TO BE 3,000 PSI. (NORMAL WEIGHT CONCRETE).
2. THE DESIGN OF CONNECTIONS FOR HOLLOW CORE PLANK TO OTHER BUILDING COMPONENTS IS THE RESPONSIBILITY OF THE ENGINEER OF RECORD, SINCE THEY ARE PART OF THE GLOBAL DESIGN OF THE STRUCTURE.
3. N.C.P. WILL PROVIDE A SMOOTH FINISH FOR INSTALLATION OF ROOFING MATERIALS BY OTHERS.
4. WELD PLATES ARE FOR BRACING THE COMPRESSION FLANGE OF THE STEEL BEAM AND FOR TRANSFERRING DIAPHRAGM FORCES. THEY ARE NOT TO HOLD THE PLANKS ON THE STEEL BEAMS. THE CONTRACT DRAWINGS SHALL INDICATE THE REQUIRED SPACING IN 4'-0" INCREMENTS.

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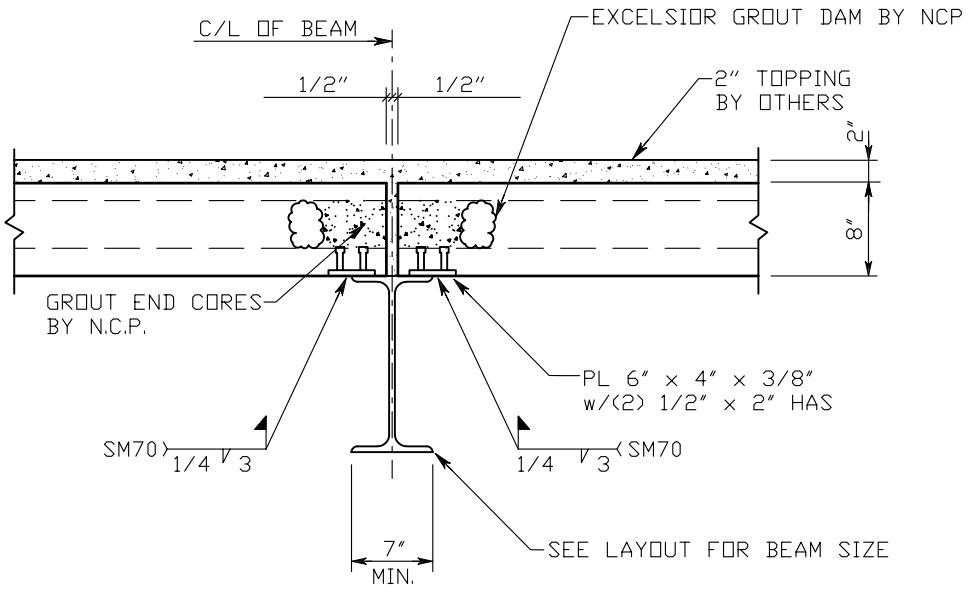
HOLLOW CORE PLANK CONNECTION

DETAIL OF BEARING ON STEEL BEAM



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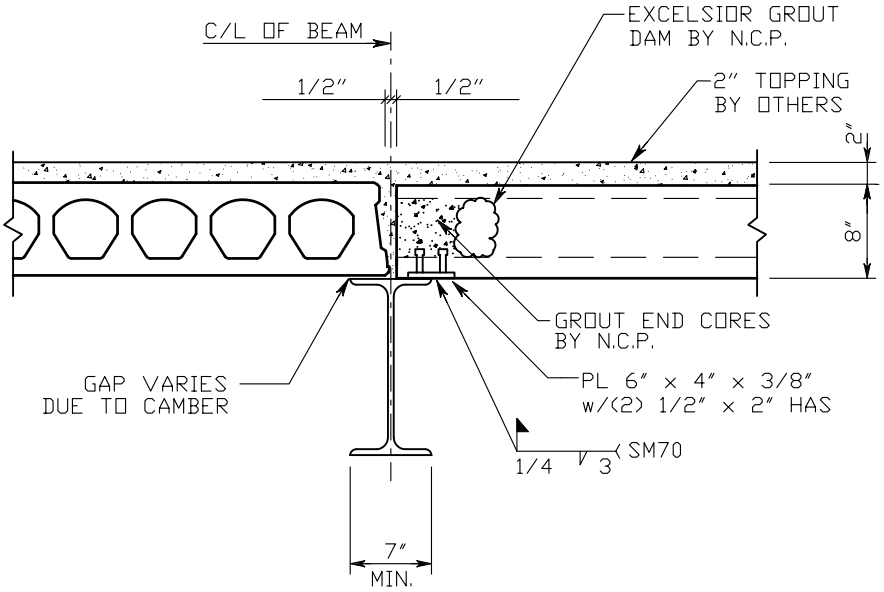
NITTERHOUSE CONCRETE PRODUCTS

HOLLOW CORE PLANK CONNECTION

DETAIL OF BEARING ON STEEL BEAM



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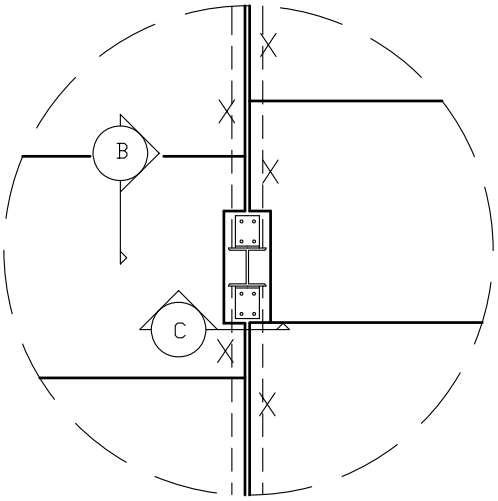
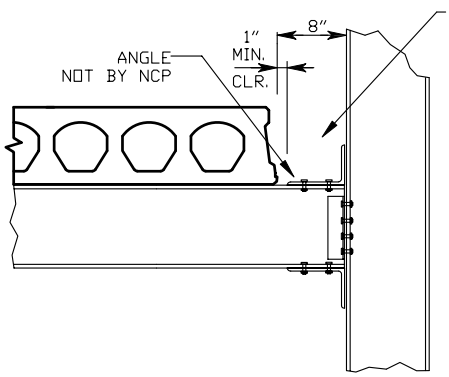
NITTERHOUSE CONCRETE PRODUCTS

HOLLOW CORE PLANK CONNECTION

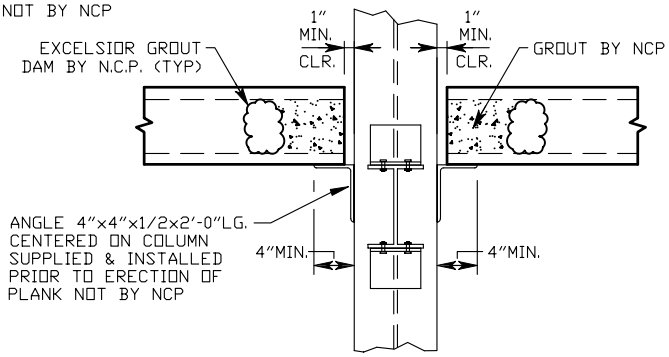
STEEL COLUMN/BEAM CONNECTION



DETAIL A
PLAN VIEW



SECTION B
NOT TO SCALE



SECTION C
NOT TO SCALE

NOTES:

1. THE E.O.R. AND THE GENERAL CONTRACTOR ARE RESPONSIBLE FOR DESIGNING, SUPPLYING AND INSTALLATION OF PLANK BEARING SUPPORT AT STEEL COLUMN/ BEAM CONNECTION NOTCHES.

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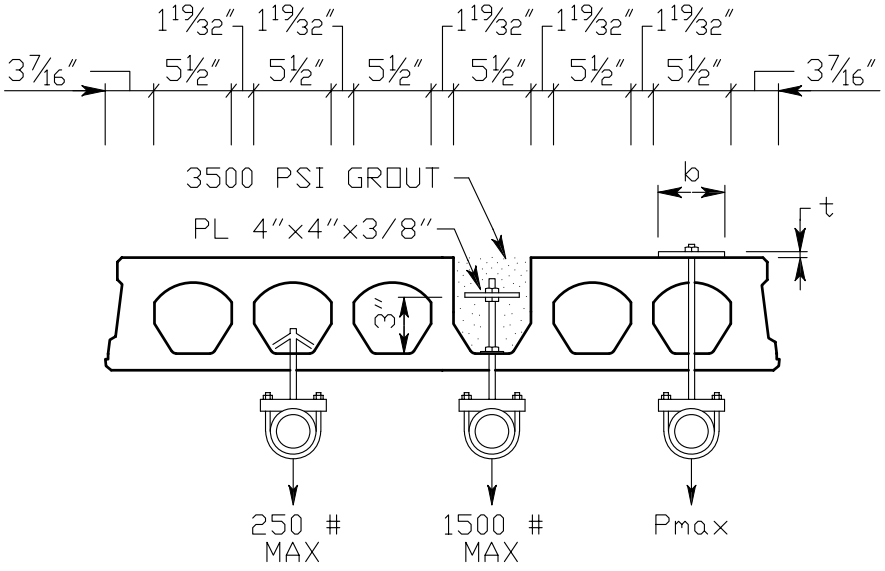
NITTERHOUSE CONCRETE PRODUCTS

HOLLOW CORE PLANK CONNECTION

CAPACITIES FOR MECHANICAL HANGERS



(HANGERS TO BE SPACED NO CLOSER THAN 7⅛" O.C.)

NOTE: FOR LIGHTER LOADS DRILL-INS AND POWDER ACTIVATED FASTENERS CAN BE USED WITH A MAXIMUM DEPTH OF 1".

b (in.)	t (in.)	Pmax
2"	3/8"	710#
3"	3/8"	890#
4"	3/8"	1130#
5"	3/8"	1500#

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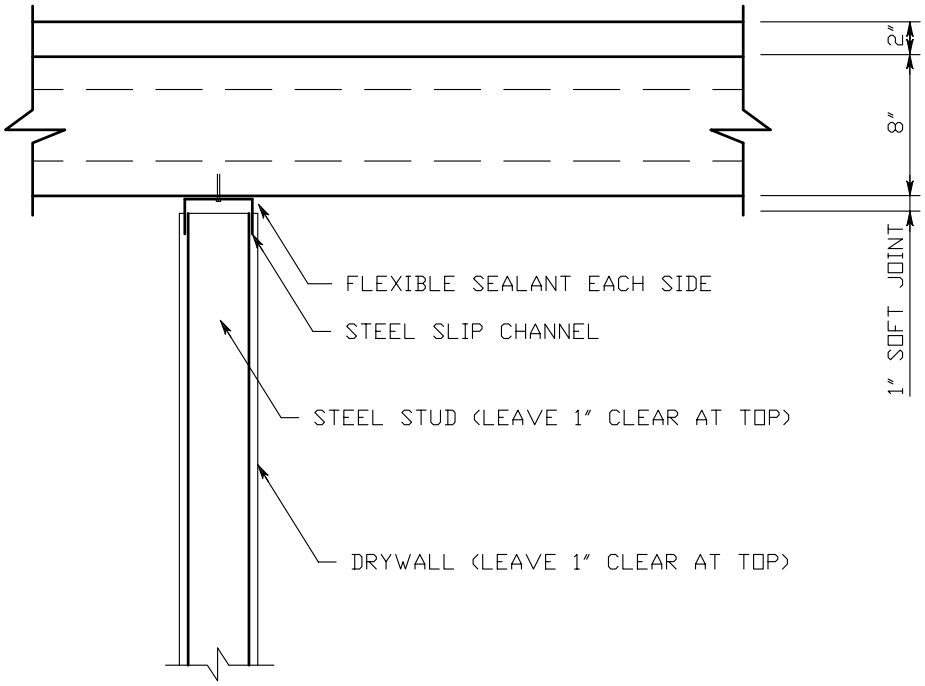
HOLLOW CORE PLANK CONNECTION

SOFT JOINT AT NON-BEARING PARTITION WALL



NOTES:

1. 1" CLEARANCE (SOFT JOINT) SHALL BE PROVIDED ABOVE NON-LOADBEARING PARTITIONS TO ALLOW FOR DEFLECTION OF THE HOLLOW CORE PLANK.

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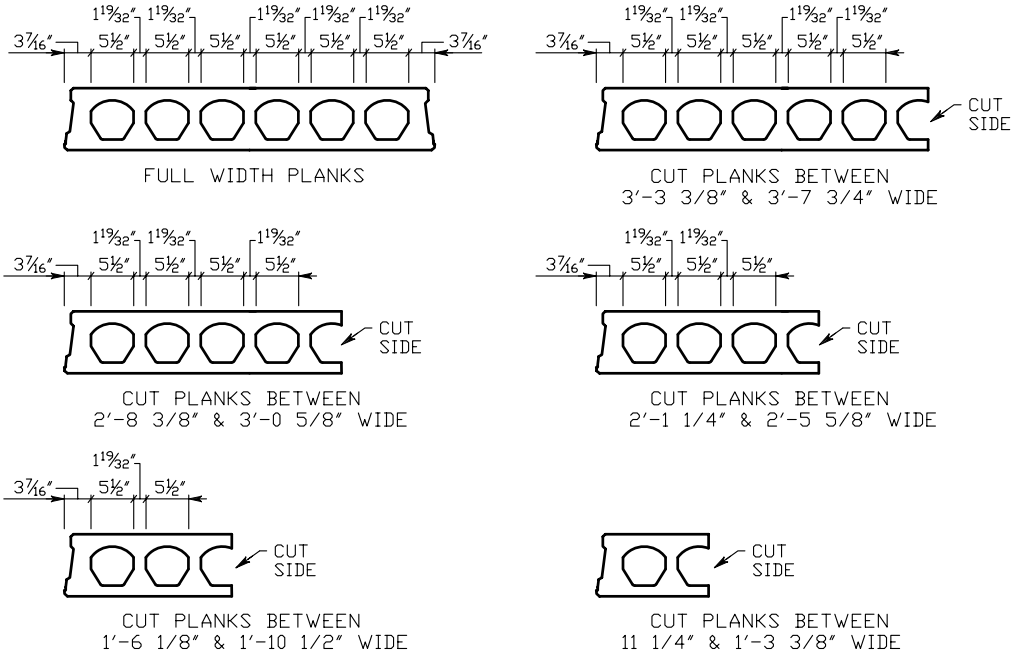
NITTERHOUSE CONCRETE PRODUCTS

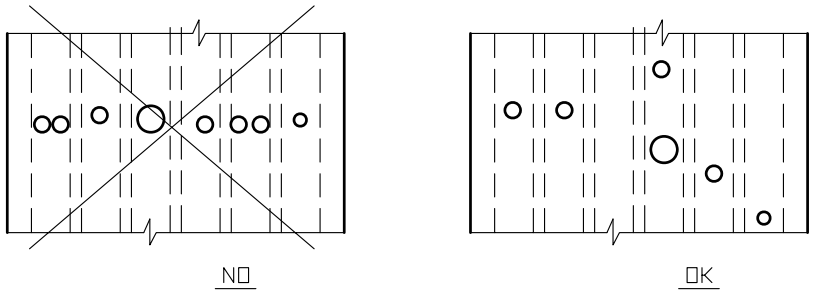
HOLLOW CORE PLANK CONNECTION

GENERAL INSTRUCTIONS FOR DRILLING HOLES IN HOLLOW-CORE PLANKS

1. HOLES SHOULD BE DRILLED IN CORES WHEREVER POSSIBLE.
(NOTE CUT SIDES OF PLANKS ARE MOST VISIBLE FROM THE UNDERSIDE)



2. DO NOT CONCENTRATE HOLES AT ONE PLACE IN PLANK



3. OBVIOUSLY SOME CASES MIGHT INVOLVE CUTTING A WEB. IN GENERAL THIS MAY BE DONE IN PLANKS THAT MEET ALL OF THE FOLLOWING:

a.) ONLY IN 4'-0" WIDE PLANKS
b.) ONLY CUT INTO TWO WEBS PER PLANK
c.) PLANKS WITH NO FACTORY CUT OPENINGS
d.) PLANKS NOT SUPPORTING OTHER PLANKS
e.) NO CLOSER THAN EVERY FOURTH PLANK

4. FOR SPECIFIC LOCATION QUESTIONS, EITHER MORE CRITICAL THAN ABOVE OR NOT MENTIONED ABOVE, PLEASE CONTACT THE ENGINEERING DEPARTMENT AT N.C.P. @ (717-267-4505) OR FAX (717-267-4518) A DETAIL OF THE LOCATION FOR OUR APPROVAL

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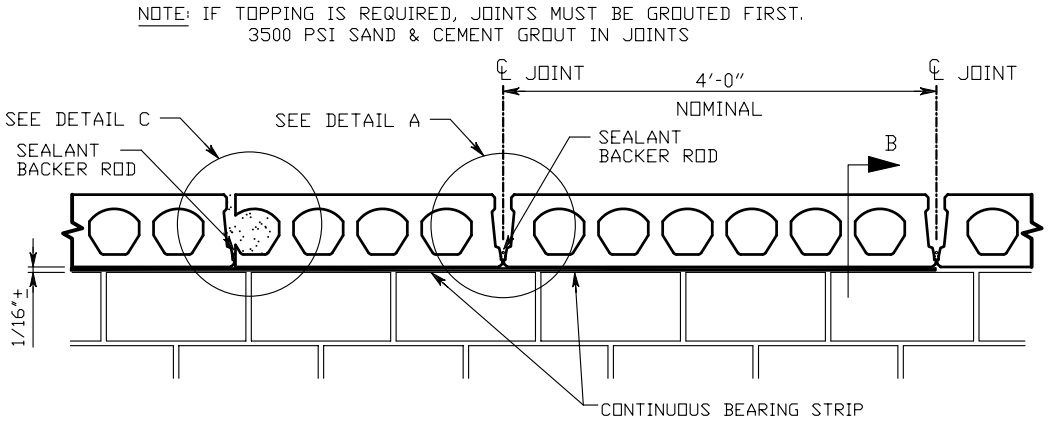
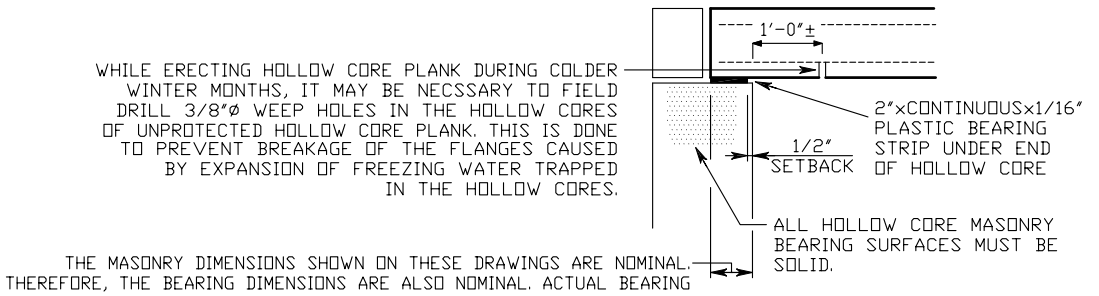
NITTERHOUSE CONCRETE PRODUCTS

HOLLOW CORE PLANK CONNECTION

TYPICAL ERECTION DETAILS

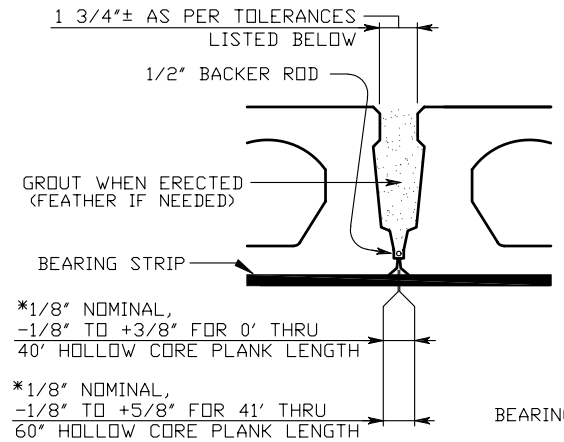


TYPICAL ERECTION DETAILS FOR HOLLOW CORE PLANK



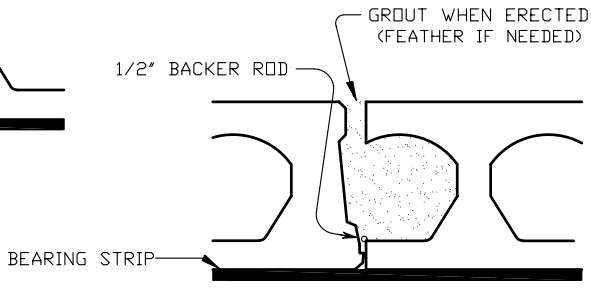
SECTION B

(REFER TO CONTRACT FOR WEEP HOLE INCLUSION OR EXCLUSION FROM NCP SCOPE OF WORK)



DETAIL A

* ADJUST AS REQUIRED TO ACCOMODATE CONSTRUCTED BUILDING DIMENSIONS.



DETAIL C

FACTORY CUT SIDE OF PLANK DENOTED BY "*" ON LAYOUT

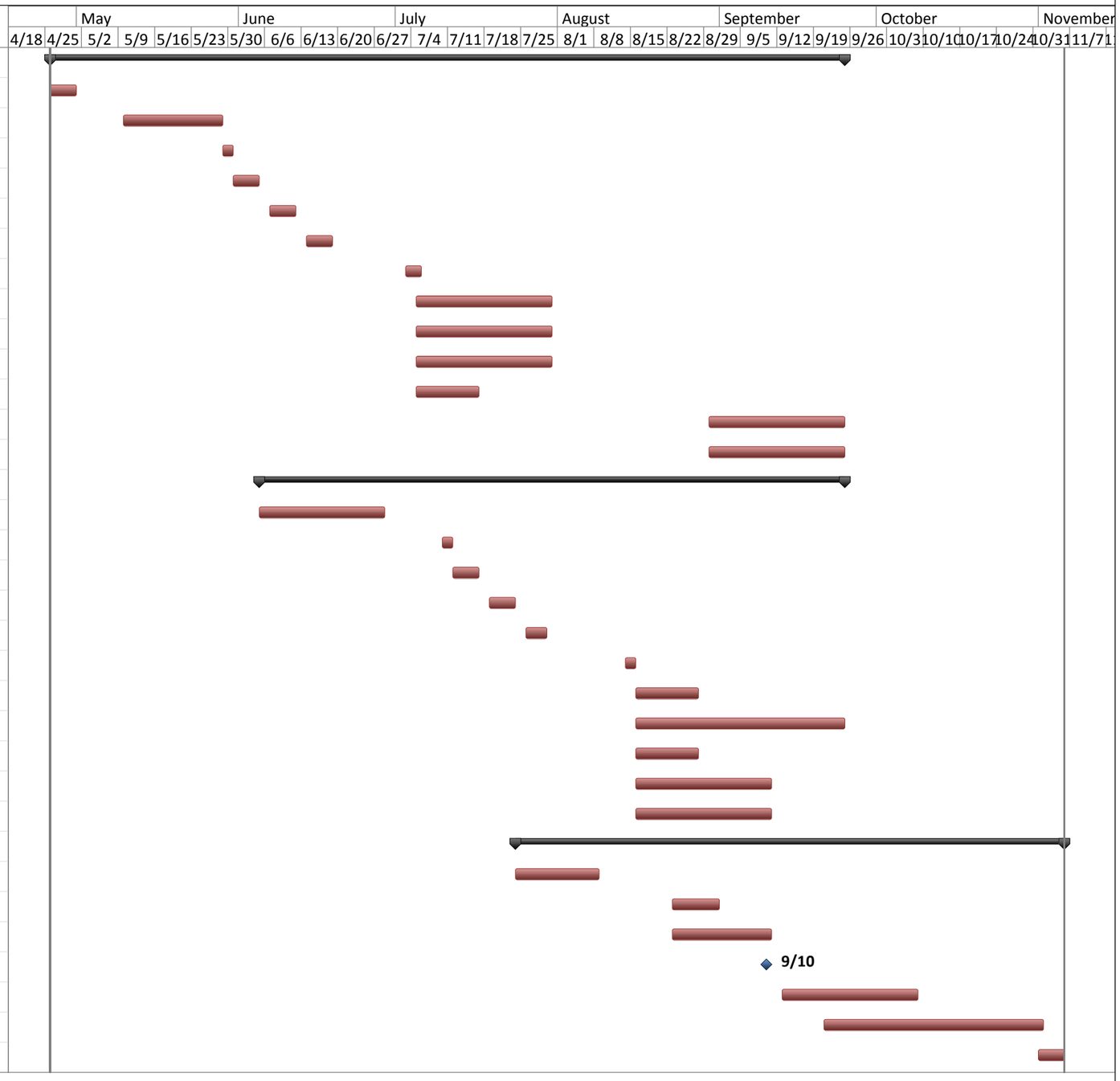
NOTE: HARDBOARD STRIPS MAY BE SUBSTITUTED, IF REQUESTED AND AGREED TO BY CONTRACT.

Appendix H:

Revised EEE Erection Schedule

REVISED EEE STRUCTURAL SYSTEM SCHEDULE- HOLLOW CORE PRECAST PLANKS

ID	Task Mode	Task Name	Duration	Start	Finish
1		**2nd Floor**	**110 days**	**Mon 4/26/10**	**Fri 9/24/10**
2		Salvage Roof Pavers for Reuse	5 days	Mon 4/26/10	Fri 4/30/10
3		Steel Framing 2nd Floor EEE	15 days	Mon 5/10/10	Fri 5/28/10
4		< Set Hollow Core Planks >	2 days	Sat 5/29/10	Sun 5/30/10
5		< Precast Grouting and Connections >	5 days	Mon 5/31/10	Fri 6/4/10
6		< Pour and Cure 2 " Topping >	5 days	Mon 6/7/10	Fri 6/11/10
7		< Form, Cast, and Cure Equipment Pads >	5 days	Mon 6/14/10	Fri 6/18/10
8		Rigg Switchgear & Transformers	2 days	Sat 7/3/10	Mon 7/5/10
9		Set/Connect Parl Switchgear	20 days	Mon 7/5/10	Fri 7/30/10
10		Set/Connect MV Switchgear North	20 days	Mon 7/5/10	Fri 7/30/10
11		Set/Connect MV Switchgear South	20 days	Mon 7/5/10	Fri 7/30/10
12		Assemble & Protect Switchgear	10 days	Mon 7/5/10	Fri 7/16/10
13		Set/Connect 5KV Chiller SWGR NW	20 days	Mon 8/30/10	Fri 9/24/10
14		Set/Connect 5KV Chiller SWGR NW	20 days	Mon 8/30/10	Fri 9/24/10
15		**4th Floor**	**81 days**	**Sat 6/5/10**	**Fri 9/24/10**
16		Steel Framing 4th Floor EEE	17 days	Sat 6/5/10	Mon 6/28/10
17		< Set Hollow Core Planks >	2 days	Sat 7/10/10	Sun 7/11/10
18		< Precast Grouting and Connections >	5 days	Mon 7/12/10	Fri 7/16/10
19		< Pour and Cure 2 " Topping >	5 days	Mon 7/19/10	Fri 7/23/10
20		< Form, Cast, and Cure Equipment Pads >	4 days	Mon 7/26/10	Thu 7/29/10
21		Rigg Generator & Switchgear	2 days	Sat 8/14/10	Sun 8/15/10
22		Assemble & Protect Generator	10 days	Mon 8/16/10	Fri 8/27/10
23		Set/Connect Generators 1,2,3	30 days	Mon 8/16/10	Fri 9/24/10
24		Set Generator EEE	10 days	Mon 8/16/10	Fri 8/27/10
25		Set/Connect SWGR#1 NW Transf	20 days	Mon 8/16/10	Fri 9/10/10
26		Set/Connect LVDO SWGR#1	20 days	Mon 8/16/10	Fri 9/10/10
27		**Roof**	**75 days**	**Sat 7/24/10**	**Fri 11/5/10**
28		Steel Framing Roof EEE	12 days	Sat 7/24/10	Sun 8/8/10
29		Concrete Roof EEE	7 days	Mon 8/23/10	Tue 8/31/10
30		Install Louver Framing EEE	15 days	Mon 8/23/10	Fri 9/10/10
31		Crane Use and Structural Activities Complete	0 days	Fri 9/10/10	Fri 9/10/10
32		Spray Fireproofing EEE	20 days	Mon 9/13/10	Fri 10/8/10
33		Install Membrane & GR Components EEE	30 days	Tue 9/21/10	Mon 11/1/10
34		Install Roof Plantings EEE	5 days	Mon 11/1/10	Fri 11/5/10



Project: RevisedEEESchedule
Date: Sat 4/2/11

Summary | Project Summary | Manual Task | Manual Milestone | Manual Summary

Appendix I:

PV System Details

New Zero Tolerance
Greater Field Performance

210 WATT

HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

KD210GX-LPU

NEC 2008 Compliant
UL 1703, ISO 9001
and ISO 14001
Certified and Registered
Class C IEC 61215

c UL us

Cutting Edge Technology
As a pioneer with 35 years in solar, Kyocera demonstrates leadership in the development of solar energy products. Kyocera's *Kaizen* Philosophy, commitment to continuous improvement, is shown by repeatedly achieving world record cell efficiencies.

Quality Built In
- New frame technology allows for end mounting with 2400 Pa (50 psf) load
- UV stabilized, aesthetically pleasing black anodized frame
- Supported by major mounting structure manufacturers
- Easily accessible grounding points on all four corners for fast installation
- Proven junction box technology
- Quality locking plug-in connectors to provide safe & quick connections

Fully Integrated Manufacturing
Kyocera manufactures and assembles solar cells and modules at its own worldwide production sites using a true vertical integration process. This superior approach gives Kyocera complete control over every step of the manufacturing process, producing modules with the industry's tightest power tolerance, promising high quality and efficiency.

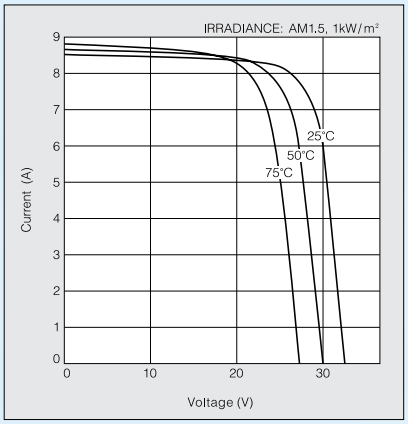
Reliable
- Superior built-in quality
- Proven superior field performance
- Tight power tolerance

Warranty
- Kyocera standard 20 year power output warranty and 5 year workmanship warranty applies in USA
- Extended warranties available per project requirements
- Kyocera standard 20 year power output warranty and 2 year workmanship warranty applies outside of USA
- Refer to Kyocera warranty policy for details

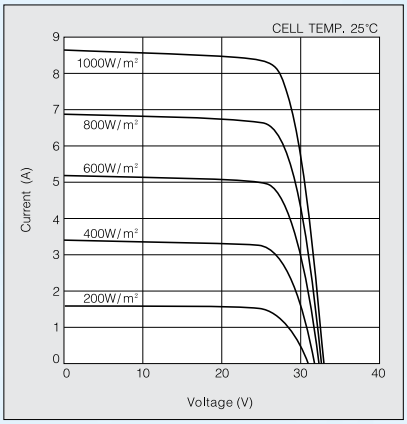
KD210GX-LPU

ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics of Photovoltaic Module KD210GX-LPU at various cell temperatures



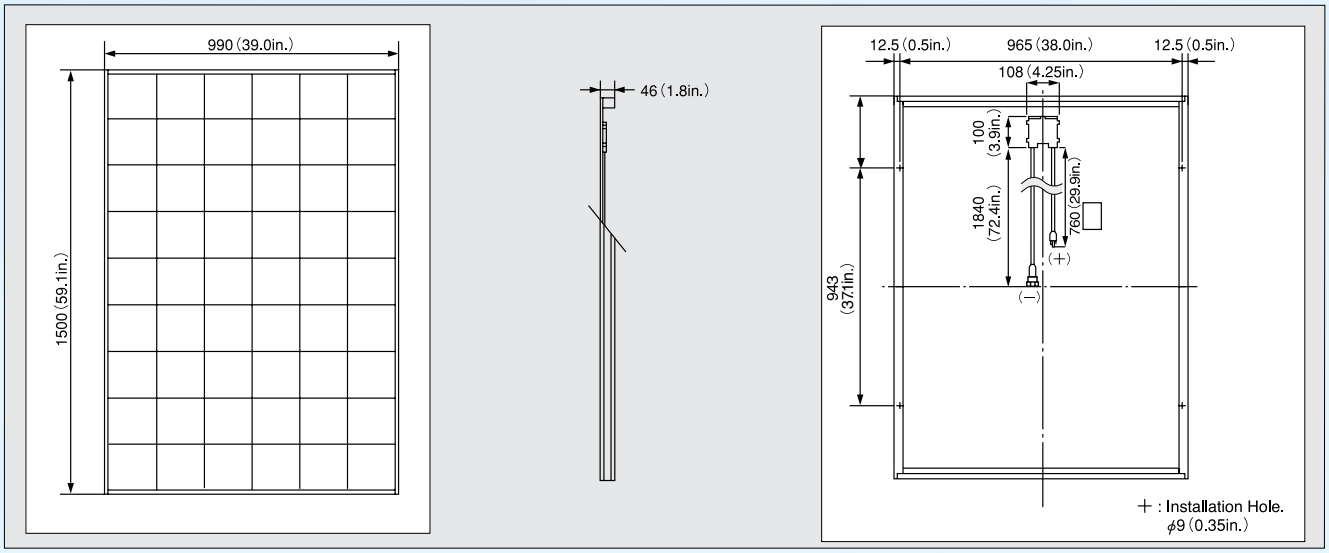
Current-Voltage characteristics of Photovoltaic Module KD210GX-LPU at various irradiance levels



SPECIFICATIONS

Physical Specifications

Unit : mm (in.)



Specifications

Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (Pmax)	210W (+5W/−0W)
Maximum Power Voltage (Vmpp)	26.6V
Maximum Power Current (Impp)	7.90A
Open Circuit Voltage (Voc)	33.2V
Short Circuit Current (Isc)	8.58A
Max System Voltage	600V
Temperature Coefficient of Voc	-1.20×10^{-1} V/℃
Temperature Coefficient of Isc	5.15×10^{-3} A/℃

*STC : Irradiance 1000W/m², AM1.5 spectrum, cell temperture 25℃

Electrical Performance at 800W/m², *NOCT, AM1.5	
Maximum Power (Pmax)	149W
Maximum Power Voltage (Vmpp)	23.6V
Maximum Power Current (Impp)	6.32A
Open Circuit Voltage (Voc)	30.0V
Short Circuit Current (Isc)	6.62A

*NOCT (Nominal Operating Cell Temperature) : 47.9℃

Cells	
Number per Module	54

Module Characteristics	
Length × Width × Depth	1500mm(59.1in)×990mm(39.0in)×46mm(1.8in)
Weight	18kg(39.7lbs.)
Cable	(+)760mm(29.9in),(-)1840mm(72.4in)

Junction Box Characteristics	
Length × Width × Depth	100mm(3.9in)×108mm(4.3in)×15mm(0.6in)
IP Code	IP65

Others	
*Operating Temperature	−40℃～90℃
Maximum Fuse	15A

*This temperature is based on cell temperature.

ISO 9001 and ISO 14001 Certified and Registered
Design and specifications are subject to change without notice.

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KYOCERA

- Highest CEC efficiency in its class
- Integrated load-break rated lockable DC disconnect switch
- Integrated fused series string combiner

- Sealed electronics enclosure & Opticool™
- Comprehensive SMA communications and data collection options

- Ideal for residential or commercial applications
- Sunny Tower compatible
- 10 year standard warranty
- UL 1741/IEEE-1547 compliant

c UL US

SUNNY BOY 5000US / 6000US / 7000US / 8000US

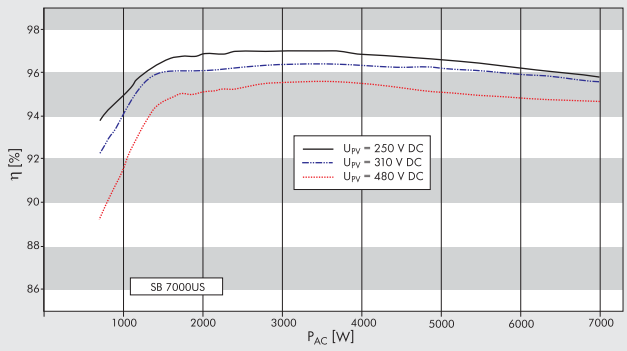
The best in their class

Our US series inverters utilize our proven technology and are designed specifically to meet IEEE-1547 requirements. Sunny Boy 6000US, Sunny Boy 7000US and Sunny Boy 8000US are also compatible with the Sunny Tower. Increased efficiency means better performance and shorter payback periods. All four models are field-configurable for positive ground systems making them more versatile than ever. Throughout the world, Sunny Boy is the benchmark for PV inverter performance and reliability.

Technical Data

	SB 5000US	SB 6000US	SB 7000US	SB 8000US
Recommended Maximum PV Power (Module STC)	6250 W	7500 W	8750 W	10000 W
DC Maximum Voltage	600 V	600 V	600 V	600 V
Peak Power Tracking Voltage	250–480 V	250–480 V	250–480 V	300–480 V
DC Maximum Input Current	21 A	25 A	30 A	30 A
Number of Fused String Inputs	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)
PV Start Voltage	300 V	300 V	300 V	365 V
AC Nominal Power	5000 W	6000 W	7000 W	8000 W
AC Maximum Output Power	5000 W	6000 W	7000 W	8000 W
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 21 A, 18 A	29 A, 25 A, 22 A	34 A, 29 A, 25 A	N/A, 32 A, 29 A
AC Nominal Voltage Range	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	N/A @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V
AC Frequency: nominal / range	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz
Power Factor (Nominal)	0.99	0.99	0.99	0.99
Peak Inverter Efficiency	96.8%	97.0%	97.1%	96.5%
CEC Weighted Efficiency	95.5% @ 208 V 95.5% @ 240 V 95.5% @ 277 V	95.5% @ 208 V 95.5% @ 240 V 96.0% @ 277 V	95.5% @ 208 V 96.0% @ 240 V 96.0% @ 277 V	N/A @ 208 V 96.0% @ 240 V 96.0% @ 277 V
Dimensions: W x H x D in inches	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5
Weight / Shipping Weight	141 lbs / 148 lbs	141 lbs / 148 lbs	141 lbs / 148 lbs	148 lbs / 152 lbs
Ambient Temperature Range	–13 to 113 °F	–13 to 113 °F	–13 to 113 °F	–13 to 113 °F
Power consumption at night	0.1 W	0.1 W	0.1 W	0.1 W
Topology	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave
Cooling Concept	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling
Mounting Location: indoor / outdoor (NEMA 3R)	●/●	●/●	●/●	●/●
LCD Display	●	●	●	●
Communication: RS485 / wireless	❍/❍	❍/❍	❍/❍	❍/❍
Warranty: 10 years / 15 years / 20 years	●/❍/❍	●/❍/❍	●/❍/❍	●/❍/❍
Compliance: IEEE-929, IEEE-1547, UL 1741, UL 1998, FCC Part 15 A & B	●	●	●	●
Specifications for nominal conditions	● Included ❍ Optional			
NOTE: US inverters ship with gray lids.				

Efficiency Curves



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SMA America, LLC

- 10 year standard warranty
- Prewired at factory for 3-phase utility interconnection
- Integrated load-break rated lockable AC/DC disconnect switch

- Internet-ready with Sunny WebBox
- Improved CEC efficiency
- Integrated fused series string combiner
- Sealed electronics enclosure & Opticool™

- Ideal for commercial applications
- Rugged stainless steel outdoor-rated enclosure
- UL 1741/IEEE-1547 compliant

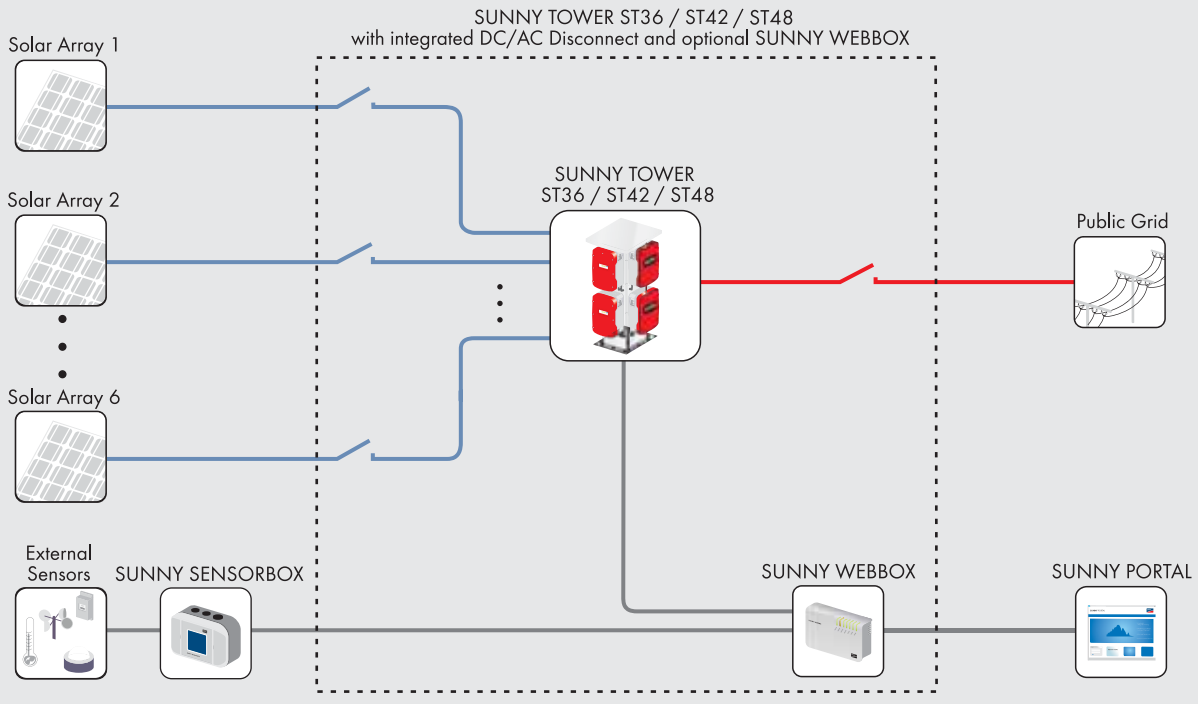
SUNNY TOWER 36 / 42 / 48

The flexible solution for commercial PV systems

SMA brings you the best in commercial inverter solutions: the Sunny Tower. Designed with the installer in mind, we've combined ease of installation, lowest specific cost ($/watt), and the highest efficiency to maximize rebates and power production while minimizing your payback period. The Sunny Tower combines all the advantages of string inverters with the installation advantages of central inverters. The Sunny Tower offers you the flexibility and reliability you've come to expect from SMA.

Technical Data

	Sunny Tower with 6 Sunny Boy 6000US	Sunny Tower with 6 Sunny Boy 7000US	Sunny Tower with 6 Sunny Boy 8000US
Recommended Maximum PV Power (Module STC)	45.0 kW	52.5 kW	60 kW
DC Maximum Voltage	600 V	600 V	600 V
Peak Power Tracking Voltage	250 – 480 V	250 – 480 V	300 – 480 V
DC Maximum Input Current	150 A	180 A	180 A
Number of Fused String Inputs	24 x 15 A (AC / DC disconnect)	24 x 15 A (AC / DC disconnect)	24 x 15 A (AC / DC disconnect)
PV Start Voltage (Adjustable)	300 V	300 V	365 V
AC Nominal Power / Maximum Power*	36.0 kW / 36.0 kW	42.0 kW / 42.0 kW	48.0 kW/ 48.0 kW
AC Maximum Output Current (3-Phase Only) (per phase @ 208 V, 240 V, 277 V)	100 A, 87 A, 44 A	117 A, 101 A, 51 A	N/A, 116 A, 58 A
AC Nominal Voltage Range (3-Phase Only)	187 – 229 V @ 208 V Delta or WYE 211 – 264 V @ 240 V Delta 244 – 305 V @ 277 V WYE	187 – 229 V @ 208 V Delta or WYE 211 – 264 V @ 240 V Delta 244 – 305 V @ 277 V WYE	N/A @ 208 V 211 – 264 V @ 240 V Delta 244 – 305 V @ 277 V WYE
AC Frequency: nominal / range	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz
Power Factor (Nominal)	0.99	0.99	0.99
Peak Inverter Efficiency	97.0%	97.1%	96.5%
CEC Weighted Efficiency	95.5% @ 208 V, 240 V 96.0% @ 277 V	95.5% @ 208 V 96.0% @ 240 V, 277 V	N/A @ 208 V 96.0% @ 240 V, 277 V
Dimensions: W / H / D in inches	43.3 / 70.5 / 39	43.3 / 70.5 / 39	43.3 / 70.5 / 39
Weight: Tower / 6 Inverters / Total Shipping	330 lbs / 846 lbs / 1388 lbs	330 lbs / 846 lbs / 1388 lbs	330 lbs / 888 lbs / 1430 lbs
Ambient Temperature Range	–13 to 113 °F	–13 to 113 °F	–13 to 113 °F
Power consumption at night	0.6 W	0.6 W	0.6 W
Topology	LF transformer	LF transformer	LF transformer
Cooling Concept	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling
Mounting Location: indoor / outdoor (NEMA 3R)	●/●	●/●	●/●
LCD Display	●	●	●
Communication: RS485 / wireless	❍/❍	❍/❍	❍/❍
Warranty: 10-year	●	●	●
Compliance: IEEE-929, IEEE-1547, UL 1741, UL 1998, FCC Part 15 A & B	●	●	●
NOTE: US inverters ship with gray lids.			
● Standard ❍ Optional			
Data at nominal conditions			
*ST48 is current limited to 46kW @ 240 V			
Type Designation	ST36	ST42	ST48



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DC Power Systems
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SMA America, LLC

Appendix J:

Room Data Sheet Example

Room Data Sheet

(Click links for guidance, visit www.FreeRDS.org for latest versions of forms)

Project Title:		Project Number:	
Room Name:		Room Number:	
Room Function:		Ocupancy:	
Ceiling Height:		Room Area:	
		Room Volume:	

Surface Finishes: (Guidance Notes)

Wall Finish: ◯ Fair Faced ◯ Matt Paint ◯ Vynal Paint ◯ Washable Silk

Floor Finish: ◯ Carpet Tile ◯ Sheet Vinyl ◯ Entrance Matting ◯ Floor Tile

Ceiling Finish: ◯ Suspended Tile ◯ Plasterboard

Other Requirements:

Windows: (Guidance Notes)

Material: ◯ Aluminium ◯ Upvc ◯ Timber

Solar Control: ◯ Not Required ◯ Solar Glazing ◯ Solar Film ◯ Vertical Blinds

Security: ◯ Not Required ◯ Roller Shutter ◯ Concertina Shutters

Other Requirements:

Doors: (Guidance Notes)

Access Control: ◯ Not Required ◯ Mechanical ◯ Fob

Signage: ◯ Not Required ◯ To Read:

Key Suiting: ◯ Not Required ◯ Suite As:

Fire Rating: ◯ Not Required ◯ 30 Min Fire and Smoke

Other Requirements:

Heating: (Guidance Notes)

Design Temp: ◯ Celsius ◯ Fahrenheit

Heat Source: ◯ Radiator ◯ Fan Convector ◯ Under Floor ◯ Over Head

Other Requirements:

Electricity: (Guidance Notes)

Wall Sockets: Singles: Doubles:

Lighting Level: Lux:

Lighting Control: ◯ Master Switch ◯ Presence Detection ◯ Daylight Dimming

Other Requirements:

Sign Off:

Client Name: Date:

Signature: