Executive Summary

The Senior Thesis Final Report displays the research and findings of four analyses that were performed on the project. This project is a new construction high rise building located in a major city and is being built as it is an investment for the owner. The project is a $208 million job that has a construction schedule of approximately 26 months. The building is roughly 475,000 GSF large which gives it a cost per square foot of approximately $438. The goals of these analyses are to target schedule, coordination, and cost concerns.

Analysis #1: Guided Formwork to Self-Climbing
This first analysis looked into using a different formwork system for the construction of the concrete core of the building in order to decrease the schedule, and increase safety on the project. The current system used is the Xclimb 60 which requires 26 form walls for the project. Each form wall is individually lifted by hydraulic cylinders. The Super Climber was analyzed to be implemented and it was found that with the use of this system that it would save a total of 30 working days and roughly $1.5 million in General Conditions costs.

Analysis #2: Implementation of Photovoltaic Curtain Wall
This second analysis looked into replacing the current curtain wall glass with photovoltaic glass in order to add value to the building. After a solar study was conducted and confirmed the photovoltaic glass can be used, various cost analyses were conducted. It was found that the photovoltaic glass would roughly save potential tenants$1000 off the electric bill annually, along with a tax benefit based on an IRS private letter ruling and other energy benefits would significantly decrease the payback period to two years. *Note this analysis contains a structural and electrical analysis

Analysis #3: SIPS
This analyses looking into breaking the concrete core schedule down to either the hour or minute. The purpose of this was for the benefit of the project team and the subcontractors, allowing them to be able to keep on track of the schedule and be responsible for getting the work done at a certain time. After increasing the crew size for the installation of rebar, the schedule was decreased by 30 working days, but the general conditions increased for this portion of the project.

Analysis #4: Integration of Material Tracking Technologies
This analysis looked into various material tracking technologies in order to enhance the coordination on the project and prevent delays in deliveries. After conducting a complete analysis, the material tracking system cost estimated $6,300, which is an minimal amount in order to prevent delays in deliveries and enhance coordination.

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Project Background

The following report details the new construction commercial high rise project and the construction techniques employed to build it. The exact project location and name is to be held confidential but it can be known that the project is located in a major US city. The owner, Hines, is a privately owned real estate firm, specializing in developing and investing in various properties throughout the world. Hines has offices in 18 countries and has a presence in more than 100 cities. One of the main reasons for pursuing the project was because it is an investment for Hines. Hine's has experience in investing in projects in major cities such as this project and is confident that it is profitable and feasible. The main goal for Hines is to construct the project safely but also ensure quality for potential tenants.

The project delivery system is a Construction Manager at risk with a Guaranteed Max Price contract. Hines has been actively pursuing the project for 10 years and once the project was awarded to Hines they hired the design/production architect Pei Cobb Freed & Partners to design the building. Lump sum contracts were then established between Pei Cobb Freed and Hines. Hines leased the land where the project will be built upon from Pacolet/Milliken for 100 years and was then awarded to Turner Construction Company. Turner had established lump sum contracts with the subcontractors and Pei Cobb Freed also established contract with the trade engineer firms.

The GMP preparation for the project started on July 2nd 2012. With a start construction date of December 24th 2012 various milestones needed to be accomplished. An interesting portion of this project is the addition of a Metro tunnel connection to the existing tunnel. With this having the longest duration it was critical that this portion of construction started as soon as the excavation had reached the proper depth. Various milestones that the owner and the project team had set for themselves include the start of steel erection on December 5th 2013, the construction start of the curtain wall on March 24th 2014, topping out of the structure on May 19th 2014, and substantial completion of March 3rd 2015.

Sixteen major roles are filled by Turner personnel for this particular project. The office is located a block away from the project site and everyone works out of this office. The role of Project Manager is filled by Mike Nolan and the General Superintendent is Randy Brzenzinski. A BIM team has been place in the office which is led by Arthur D'Antonio. Each member of the team coordinated with the different trades of the project. An example is Chris Stafford, who is an MEP engineer and maintains relations with all MEP subcontractors and the MEP engineering firm Jaros, Baum, Bolles. A detailed staffing plan can be found in Appendix A.

Once construction is completed the building will be the tallest in the vicinity at 450 feet with 29 floors above grade. All utility lines enter into the building from the north and south ends of the building. Due to the project sights location future deliveries will difficult because of the one way and one lane streets at the north and south ends of the site. The surrounding streets make the project sight very tight. Jersey barriers have been placed to separate the path from traffic patterns.

Site Layout

Three main phases of construction were analyzed and from this site layouts were created. The following are the three phases analyzed.

- Excavation
- Superstructure: Level 10 – Roof
- Exterior Envelope & Roof/Bulkhead

In this section each phase will be discussed in detail and key features will be discussed. In each phase a similar approach was used as Turner due to the size of the site and its restrictions. Each phase can be seen in Appendix B

Excavation

Going back to the schedule the Excavation phase begins on December 24th 2012 and ends on July 29th 2013. The detailed site layout can be seen in Appendix B. The safety for this phase is very important because of surrounding streets and MTA tunnels. As seen in the layout, an excavation of 34 feet was done. A dirt ramp is used in order to bring the excavated dirt away from the site. As the site is very tight and surrounded by three one way streets, lanes were closed in order to extend the site. A temporary path for pedestrians was designed and is guarded by jersey barriers. It is also important to note that there is an existing subway entrance still used during this phase of construction. Also during this phase of construction the subcontractor trailers are placed on the existing sidewalk. Guardrails are protecting all sides of the excavation as well. Vehicles will enter through the site through one of the six gates around the site. The project location is in a major city and in this city, the excavation must follow a code of having to means of ingress and egress that is kept available all times. This is covered by the ramp and stairs seen in the layout.

Superstructure: Level 10 – Roof

The superstructure phase from level 10 – roof was chosen in order to show the complexity of this site in greater detail. The site is very cluttered. During this phase there as two cranes present on site with loading stations very close to the building. The following are items that are different from the excavation phase to this superstructure phase

- News stand torn down
- MTA entrance closed
- Netting used to protect floors below as structural framing is set.
- Site Fence extended due to news station tear down
- 17’ 3” between building and site fence
- Overhead protection installed
- Subcontractor Trailers move into building.
- Standpipes and Stairs within Concrete Core

The site fence being extended allows for loading stations to be within the site perimeter. The area where the contractor trailers were has become the layout areas for concrete and steel. These temporary facilities have moved within the interior floors that have been completed. The steel crane is used for the steel framing, while the concrete crane is used for pouring the concrete core at the high levels using a bucket. Each floor is poured using the concrete trucks seen at the northern portion of the site. During this phase it is critical for pedestrian protection hence the construction of overhead protections above the temporary path created in the earlier phase. Also communication between the concrete crane crew and steel crane crew is critical as both are in the radius of each other. As part of the city's fire department requires an active standpipe with in 50ft. The department of buildings also requires two paths of egress within the core.

Exterior Envelope & Roof/Bulkhead

This is the final phase that involves the use of a crane and hoists. Once this phase is completed the focus turns to the interior floors that remain. This phase is important because once this is completed the building will be dried and water tight. The following are items that are different from the superstructure phase to the envelope phase and can be seen in Appendix B

- Concrete Crane dismantled
- Protective netting no longer required
- Mechanical equipment is being installed
- Trolley Beam system to be engineered for the west side curtain wall system

This phase moves into full effect after the roof slab has been fully set and the concrete crane has been dismantled. There are only a handful of levels that the exterior curtain wall need to be installed on. The steel crane is still available to finish the remaining steel on the roof and hoist assist. A trolley beam system was engineered in the previous phase but was not able to be seen. It is shown in Appendix B. This is used to install the west side curtain wall as the space between the project and the adjacent building is very narrow.

Building Systems Summary

The Tower is a new construction building and when completed will have twenty eight floors of occupancy. Floors 2- 9 are roughly 21,500 RSF and floors 10-28 are roughly 15,000 RSF. The building will not include any fitouts and will be determined by the floor tenants. Floors 10 and 17 will have outdoor terraces overviewing the existing park. The 10th floor terrace will range from 1500 SF to 2,070 SF and can occupy up to 139 people whereas the 17th floor terrace will be a bit smaller at a SF of 555 allowing occupancy of 37 people.

Building Features

The building is oriented where all floors have a view of the park, along with the grand circular entrance at the corner. The massive entry canopy has a diameter of 46'. What is really interesting is that there will be a new subway entrance closer to the building allowing the flow of pedestrians to pass by The Tower.

Building Façade

The building façade is a combination of different size glass panels, aluminum, and steel. The insulating glass ranges from 1-1/4th" – 1-3/4th" The interior portion includes insulation, vapor barrier, firesafing, smoke seal, and a silicone weatherproofing sheet.

Building Roofing

The majority of the roofing consists of a precast concrete paver with a 4" rigid insulation, waterproofing membrane, base flashing, 1"fiberglass insulation a sealant and cap flashing. There is a partial green roof which includes sedum planting, 4" growing medium, drainage and retention mats.

Sustainability

The goal for the Tower is to achieve a LEED gold rating and it is designed to earn Energy Star. To achieve this, the building consists of a high performance façade, air side heat recovery system, co-generation system, 30,000 gallon storm water reclamation, recycling center and bicycle storage.

Structural Steel

The structural steel supports the concrete core for the building and beams range in a variety of sizes.

- Beams throughout the floors range from W12x14 to W40x593
- 6" and 9" NWC slabs
- WWF (6x6 –W2.9xW2.9) and #4 Rebar used depending on floor
- Cast in place concrete core
- Core contains nine elevators, mechanical, telecom, and electrical rooms

Mechanical System

The mechanical system utilizes seven condenser boilers to provide heating and cooling to the building. Three chillers can be found on top of the roof with a space for an additional chiller in the future. Along with this a combined heat and power system is used a secondary circuit which uses three 65 kW micro turbines. These turbines can be found in the mechanical penthouse and are sized to handle the base load of the building. A still water detention tank is installed on the roof which collects rain water and stores it in case a loss of power. It is also used to prevent water directly discharging into the sewer during heavy storms.

Electrical System

A complex electrical system is used for the building using three transformers provided by Con Edison which are located in Lower Level 1. There is also space for an additional transformer in the future. These transformers are responsible for stepping down the power to a 265/460V. A diesel generator at 750 kW 3 phase 4 wires is also found in the mechanical penthouse. This is a backup system if there is a loss of power.

Fire Protection Systems

An automatic sprinkler system will be used with standpipe outlets at each floor level within every exit stairway. Hose connections will be located at the rise on each floor level landing and on the entrance floor above the standpipe riser control valve. Because the building is a high rise, a voice alarm communication system will be used.

Detailed Project Schedule

This detailed schedule breaks down the scope of the work by trade and details the work that will be performed by those different trades. The schedule consists of 200 activities and milestones that starts with the GMP preparation and finishes with the final completion and can be seen in Appendix C. The project start date is December 12th, 2012, and is scheduled to finish on May 29th 2015. This is roughly twenty six months or 600 working days. The level of detail in this schedule allows for the sequencing of work to be understood without being too excessive in detail. The detailed schedule is organized by the different major trades / activities such as excavation and foundation, concrete core, structural steel, and enclosure. The phases which drive the project will be discussed in detail in the following section. Table 1 below gives an overview of the project and some of these phases will be summarized in order to give a quick overview of the project.

Table 1: Detailed Project Schedule Overview

Detailed Schedule Overview			
Phase	**Start Date**	**Finish Date**	**Duration (Days)**
Excavation/Foundation	24-Dec-2012	29-Jul-2013	152
Metro Transit	13-Mar-2013	3-Mar-2015	499
Concrete Core	24-Jul-2013	13-May-2014	212
Structural Steel	20-Nov-2013	13-Aug-2014	184
Superstructure Concrete	10-Jan-2014	21-Jul-2014	133
Envelope	24-Mar-2014	20-Feb-2015	232
Building Dried in and Water Tight (Top Down)		29-Oct-2014	1
Core Fit Out	10-Mar-2014	12-Feb-2015	237
Elevators	20-Mar-2014	23-Jan-2015	215
Interiors (Lobby, Loading Dock, Lower Levels)	9-May-2014	7-Jan-2015	170
MEPS	10-Feb-2014	28-Apr-2015	308
Full Building TCO		29-Mar-2012	1
Full Project	24-Dec-2012	29-May-2012	610

The major activities that drive the schedule of the project are as follows

- Concrete Core
- Structural Steel
- Superstructure Concrete
- Core Fit Out
- Envelope

Below in Table 2 shows the schedule of work for these trades for a typical floor.

Table 2: Schedule of Typical Floor

Schedule of Typical Floor			
Activity	**Start Date**	**Finish Date**	**Duration (Days)**
Install Reinf and Pour 4th Floor Core Shear Walls	4-Nov-2013	8-Nov-2013	5
Set 4th Floor Framing	30-Dec-2013	3-Jan-2014	4
Insall Deck and Studs 4th Floor	23-Jan-2014	28-Jan-2014	4
4th Floor Reinforce & Pour Concrete Deck	14-Feb-2014	20-Feb-2014	4
Install Spray on Fireproofing 4th Floor	6-Mar-2014	11-Mar-2014	4
Core Fit Out 4th Floor	24-Mar-2014	12-Aug-2014	100
Install Curtainwall 4th Floor	7-Apr-2014	11-Apr-2014	5

As seen in Table 2 the average duration for each activity is four days, with each trade set a month or two apart from each other. It roughly takes six months to complete a floor. While construction of a certain trade is taken place on one floor another trade will start or be taking place on a different floor.

Concrete Core

Table 3: Concrete Core Erection Dates

Important Concrete Core Erection Dates		
Actvity	Start Dat	End Date
Layout and Install Climbing Form System	24-Jul-2013	20-Aug-2013
Install Reinforce and Pour LL2-7th Floors	20-Aug-2013	19-Nov-2013
Install Crane for Steel Erection	20-Nov-2013	4-Dec-2013
Concrete Core Completion	27-Mar-2014	1-Apr-2014

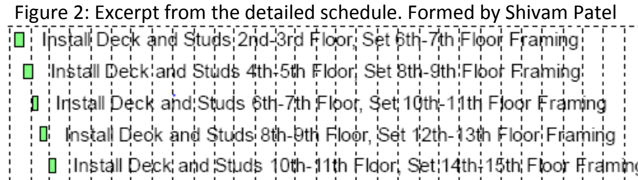
With the concrete core being the first trade to start construction after the foundation wall was completed; the first seven floors for the core were critical path activities. This is because the crane for the structural steel is set to arrive the day after the seventh floor core activity is to be completed. The dates of these start and end dates can be seen in Table 3. The core follows typical high rise construction sequencing; each floor's walls will be reinforced and poured in its entirety before the glided formwork moves up to the next building level. The crane located in a bay of the core is used for the pouring of the core walls and lifting the formwork. As mentioned earlier the average erection duration per floor is five days, with a total duration of 202 days.

Figure 1: Concrete Core Erection. Courtesy of Turner

Structural Steel

The structural steel phase starts immediately after that installation of the crane on December 5th 2013 with the framing of Lower Level One. Once the framing for Lower Level One is complete the Ground Floor framing and the installation of the metal deck and stud for Lower Level one will begin on the same day. The duration of the installation of the metal deck and stud for Lower Level One is ten days and immediately after the framing for the ground floor is complete the framing for the second floor will begin. It's not until the completion of the deck and studs on the ground floor and framing for the fifth floor where we see a steady construction sequence between the decking and studs for a floor and the framing for a floor. The average duration per floor is four days with the deck and studs and four days for the framing.

Figure 2: Excerpt from the detailed schedule. Formed by Shivam Patel



In Figure 2 it can be seen that activities were grouped together in order to narrow the schedule down to 200. This was done because the start date and end date for the deck and studs of a floor and framing for a floor were the same. (2nd floor deck and studs and 6th floor framing: start and end date same) The duration of the steel framing decreases to three days once the 17th floor framing begins and is because of the decrease in floor area. This occurs for the rest of the structural steel phase until its completion. Before the crane can be dismantled it will be used to hoist penthouse equipment starting on July 17th 2014. This can only occur after the hoist installation is completed on July 8th 2014. These are critical activities because the equipment has specific delivery dates and this work must be completed in time for these deliveries.

Superstructure Concrete

Following the completion and turnover of a floor by the steel erection team the cast-in-place concrete contractor will be responsible for installing the concrete decks. This project has an average schedule lag of 15 working days between the steel turnover of a floor until the concrete workers start roughing in their work. This is to allow the structural steel team to work their way up a few floors so that there are a few layers of metal decking protecting and workers below from safety hazards such as falling debris. Once again the average duration for a floor is four days. The entire phase of the superstructure is critical work with a start date of January 10th 2014 and end date of July 21st 2014

Enclosure

As described in the first technical report the enclosure consists of high vision glass with low iron IGU with Low E coating and a mullion module of linen finish stainless steel spandrel panels. The schedule of activities for the wall enclosure starts with the curtainwall installation on the second floor on March 24th 2014 with the milestone date of October 29th 2014 for the building dried-in and water tight (top down. The curtainwall system is installed using a monorail system and the average duration is five days per floor.

Project Cost Evaluation

In order to fully comprehend the costs associated with the project, it was important to review the cost data for the project and to prepare some estimates. This includes reviewing the overall building cost data and the breakdown of the different systems within the building.

Tables 4 and 5 display the building cost data and the cost of specific systems in the building. The construction cost is the costs associated with the physical construction of the building. This leaves out land costs, site work, permitting, general conditions, and fees. The total project cost is the cost associated with the delivery of the entire building. This cost data includes the previous mentioned costs.

Table 4: Building Cost Data

Building Cost Data				
Description	**Cost ($)**		**Cost ($/SF)**	
Construction Cost	$	162,803,910.00	$	379.74
Total Project Cost	$	208,000,000.00	$	398.72

Table 5 highlights the cost of each individual system. It breaks the cost down into total cost, cost per square foot, and the percent of the total building cost. As you can see the Curtain Wall and Storefront Panels is the highest priced system on the building. This is because the curtain wall is a unitized module system involving various high end materials.

Table 5: Building Systems Cost Data

Bulding Systems Cost Data					
Building System	**System Total (Turner)**		**$/SF (Turner)**		**Percent of Total**
Excavation and Foundations	$	12,292,510.00	$	28.43	7.13%
Superstructure Concrete	$	19,457,000.00	$	45.01	11.29%
Curtain Wall/Storefront Panels	$	26,154,000.00	$	60.50	15.17%
Roofing and Waterproofing	$	1,296,000.00	$	3.00	0.75%
Electrical	$	22,276,380.00	$	51.53	12.92%
HVAC	$	21,009,090.00	$	48.60	12.19%
Equipment/Hoisting	$	5,042,000.00	$	11.66	2.93%
Plumbing	$	4,833,000.00	$	11.18	2.80%

General Conditions Estimate

The general conditions estimate for the project can be considered the operating costs for the job site. It can be seen on page fourteen and its cost includes personnel, field offices, temporary utilities, insurance and bonding, and other miscellaneous costs. The estimate is broken down into three main sections:

- Personnel
- Miscellaneous costs
- Insurance and bonding.

Personnel costs are the costs of the staff's salary and benefits. Miscellaneous costs are associated with items such as the field office rent, supplies, temporary utilities, telephone bills, and job clean up. Finally the insurance and bonding costs include builders risk insurance, general liability insurance, and performance bonds.

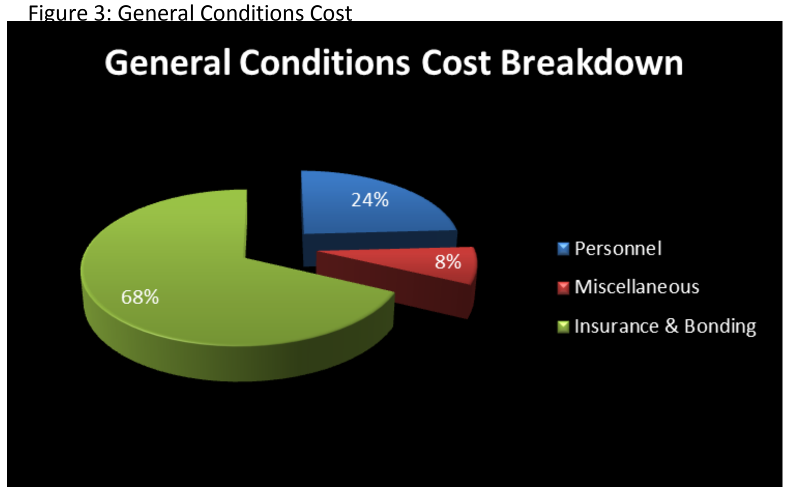
Table:6 General Conditions Summary

General Conditions Summary		
Section	Total Cost	Cost per Month
Personnel	$ 3,780,000.00	$ 145,384.62
Miscellaneous	$ 1,232,021.33	$ 47,385.44
Insurance & Bonding	$ 10,649,600.00	$ 409,600.00
Totals	$ 15,661,621.33	$ 602,370.05

The general conditions estimate is based off a 26 month construction schedule. From this the monthly cost for each cost breakdown can be determined. This along with a summary of the general conditions estimate can be seen above in Table 6. The total estimate came out to be $15,661,621 for the project, and a cost per month of $602,370.05. The pricing was obtained from 2013 RS Means Construction Cost Data. The most costly general conditions section was the insurance and bonding at 68%, followed by the personnel section at 24%. The miscellaneous section makes up the rest with 9%. This can be seen in Figure 3.

The insurance and bonding section is higher than the other sections due to high contract value of the project which is $208 million. Turner estimated the general conditions to be $18.7M so these two estimated match up closely. Turner did not release the details of their general conditions estimate so the sub sections of the estimate cannot be compared in detail.

Figure 3: General Conditions Cost



As seen in the estimate various miscellaneous costs were chosen. These were chosen as an assumption based off viewing the site logistic plans Turner had provided. Costs such as barriers, cranes, security, hoists, and safety netting were all included.

Table 7: General Conditions Estimate

General Conditions Estimate					
Description	**EA**	**Quantity**	**Unit**	**Rate**	**Total Cost**
Personnel Costs					
Project Manager	1	105	Week	$ 3,400.00	$ 357,000.00
Project Engineer	1	105	Week	$ 2,800.00	$ 294,000.00
Project Superintendent	1	105	Week	$ 3,200.00	$ 336,000.00
Superintendent	3	105	Week	$ 2,900.00	$ 913,500.00
Engineer	7	105	Week	$ 1,800.00	$ 1,323,000.00
Safety	1	105	Week	$ 2,700.00	$ 283,500.00
Accountant	1	105	Week	$ 2,600.00	$ 273,000.00
Miscellaneous Costs					
CPM Schedule (Large Scaled Project)	1	0.03%	Job	$208,000,000.00	$ 62,400.00
Computers	1	20	EA	$ 1,200.00	$ 24,000.00
Temporary Utilites Electric	1	84.127	CSF	$ 47.99	$ 4,037.25
Temporary Utilities Water	1	26	Month	$ 250.00	$ 6,500.00
Field Office	1	26	Month	$ 6,500.00	$ 169,000.00
Office Equipment Rental	1	26	Month	$ 216.60	$ 5,631.60
Office Supplies	1	26	Month	$ 81.23	$ 2,111.98
Coffee & Water Cooler	1	26	Month	$ 100.00	$ 2,600.00
Internet	1	26	Month	$ 325.00	$ 8,450.00
Messenger Service	1	26	Month	$ 500.00	$ 13,000.00
Telephone Bill	1	26	Month	$ 225.00	$ 5,850.00
Testing & Inspection Steel and Concrete Building	1	1	Job	$ 71,544.00	$ 71,544.00
Daily Clean Up	1	105	Week	$ 300.00	$ 31,500.00
Barricades	1	30	EA	$ 422.37	$ 12,671.10
Site Fence (plywood 4"x4" frame 8' high)	1	300	LF	$ 109.68	$ 32,904.00
Security	1	3000	HR	$ 24.18	$ 72,540.00
Safety Netting	1	3000	SF	$ 1.20	$ 3,600.00
Saftey supplies and first aid kits	1	26	Month	$ 25.50	$ 663.00
Hoist	1	24	Week	$ 4,205.15	$ 100,923.60
Steel Tower Crane	1	9	Month	$ 31,689.20	$ 285,202.80
Concrete Crane	1	10	Month	$ 31,689.20	$ 316,892.00
Insurance & Bonding					
Builders Risk Insurance	1	By Owner	Job	$208,000,000.00	By Owner
General Liabilty Insurance	1	0.62%	Job	$208,000,000.00	$ 1,289,600.00
Permits	1	2%	Job	$208,000,000.00	$ 4,160,000.00
Payment and Performance Bonds	1	2.50%	Job	$208,000,000.00	$ 5,200,000.00
					$ 15,661,621.33

Analysis 1: Guided Formwork to Self-Climbing

Opportunity Identification

The concrete core is currently the main focus of the project as it is the first activity for each floor and because of this it needs to stay ahead of the other activities. A guided formwork system is currently being used to cast the system. While this system is quick and efficient, there are always safety concerns and each formwall is individually lifted. With a schedule timeline of five days per floor, staying on track and completing the work on time is a critical portion of the project. This analysis will look into how changing the formwork into a pneumatic system could possibly develop benefits with regard to cost and scheduling.

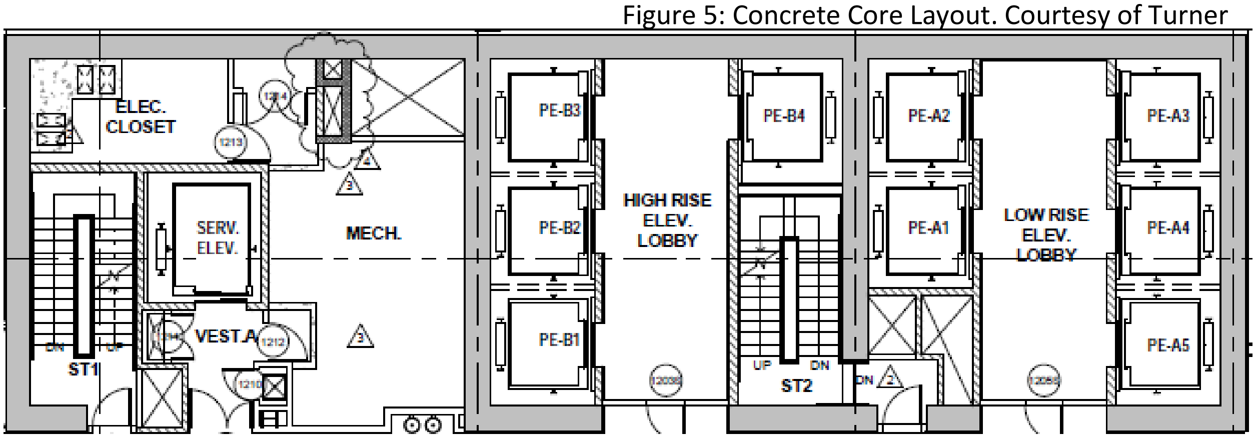
Background Research

Once this analysis was determined, background research pertaining to the core was conducted. The current system used on the project is a guided formwork known as the Xclimb 60 manufactured by Doka and is a system commonly used on high-rise construction projects. The formwork systems can be seen in Figure 4 on the right. The system is guided on vertical profiles that are fixed to the concrete core and the climbing units are repositioned in a single crane cycle. The concrete core has a layout as seen in Figure 5 below.

Figure 4: Xclimb 60 Formwork System
Courtesy of Doka

The formwork is sectioned off resulting in multiple lifts to the next level. In order for the formwork to be lifted guiding shoes are connected to the structure. Additional crew members are used for the installing and dismounting of these guiding mechanisms on top of the crew members used for the reinforcement and the pouring of the concrete.

Figure 5: Concrete Core Layout. Courtesy of Turner



Current System Schedule

The construction of the concrete core is considered the main activity that drives the schedule, as it is the first construction sequence for a particular floor. This was one of the main reasons the use of a new formwork system was investigated. With the XClimb 60 system there are 52 climbing brackets in sets of two resulting in 26 form walls. Each form is lifted individually through portable hydraulic cylinders. The core construction starts on July 24th 2013 and is expected to be completed on April 22nd 2014 with the erection of the 29th floor. The formwork is then removed followed by the dismantling of the concrete crane with the activity coming to a close on May 13th 2014 resulting in a total of 210 working days.

Each floor is on a five day cycle up until the 18th floor when the concrete core becomes a two bay system. Once the core drops from three bay's to two bay's each floor is then completed in a four day cycle. The core schedule starts with the stripping and lifting of the formwork. As mentioned above there are 26 form walls that need to be lifted. After reviewing the concrete core schedule, it was found that the formwork takes an entire workday to complete. The next day is the start of the installation of the rebar and embeds. The rebar takes three and a half days to install when the core is a three bay system and two and a half days to install when the core is a two bay system. The final day is the pouring of the concrete. An overview of the full concrete core schedule can be seen in Appendix D.

Self – Climbing System

The proposed system is similar to the Xclimb 60 formwork system where it is lifted using hydraulic cylinders, but instead of having to lift each form wall, the Super Climber SCP manufactured by Doka raises all interior and exterior formwork with a push of a button. Unlike the Xclimb 60 the Super Climber does not need guiding shoes for the form to be lifted by the hydraulic cylinders. Also the Super Climber can utilize stripping corners which allows the interior core wall formwork to strip without the need of a crew. The biggest difference between the Xclimb 60 and the Super Climber is that the Super Climber is a closed system, having three levels. This is a much safer system for the workers, protecting them from weather conditions, and open areas where a person could fall. Figure 6 below shows the storage area of the Super Climber.

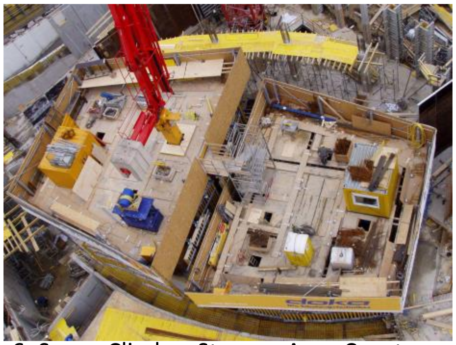


Figure 6: Super Climber Storage Area Courtesy of Doka

Proposed System Schedule

As mentioned above the benefit of the Super Climber is that the form can be lifted as one unit. This significantly decreases the amount of time needed to construct one floor of the concrete core. After speaking with several contractors that have had experience with the Super Climber or a system similar, it was determined that the entire form system would lift within an hour. Also stripping the form in order for it to be lifted would take roughly three to four hours. With this new system, the activities are completed a day ahead of the original schedule. Below is Table 8 comparing the original schedule verses the new schedule for a given week.

Table 8: Original Vs New Core Schedule

Original Concrete Core Schedule		
Lift Formwork from 3rd Floor to 4th Floor	Monday	11/4/2013
Install Rebar and Embeds for 4th Floor	Tuesday	11/5/2013
Install Rebar and Embeds for 4th Floor	Wednesday	11/6/2013
Install Rebar and Embeds for 4th Floor	Thursday	11/7/2013
Install Remaining Rebar and Embeds & Pour 4th Floor Concrete Core Walls	Friday	11/8/2013
New Concrete Core Schedule		
Lift Formwork From 3rd Floor to 4th Floor/ Start Install of Rebar and Embeds for 4th Floor	Tuesday	10/29/2013
Install Rebar and Embeds for 4th Floor	Wednesday	10/30/2013
Install Rebar and Embed for 4th Floor	Thursday	10/31/2013
Install Remaining Rebar and Embeds & Pour 4th Floor Concrete Core Walls	Friday	11/1/2013

As seen from this table the schedule is ahead by a week if the Super Climber formwork system is used. With the formwork taking only half of a work day to lift, the workers can begin the installation of the rebar and embeds on the same day. After rescheduling the concrete core with the use of the Super Climber it was found that the installation of the core (ie 29th floor) would be completed on March 17th 2014. The activity would come to a close on April 7th 2014, resulting in 30 less working days. A full schedule of the concrete core if the Super Climber was used can be found in Appendix D.

Cost Analysis

The Super Climber system is favorable in terms of reducing the project schedule. The next step was to look at the cost impact it would have on the project. After speaking with Maritha Buckley who is an Engineering Manager at Doka, she was able to give me the rental cost for the daily Super Climber formwork system based on the concrete core drawings. She also told me that the purchase items that are associated with the formwork systems would be the same. The costs for the Xclimb 60 formwork used on the project were given by Jon Ingerson. Below is Table 9 showing the differences in these costs.

Table 9: Formwork System Costs

Xclimb 60 Formwork System				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Below 18th Floor	$ 1,820.00	Day	143	$260,260.00
18th Floor & Above	$ 1,104.54	Day	57	$ 62,958.78
Purchase Items - All Lifts	$79,424.00	EA	1	$ 79,424.00
Frieght to & from Jobsite	$28,800.00	EA	1	$ 28,800.00
Total				**$431,442.78**
Super Climber Formwork System				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Below 18th Floor	$ 2,691.40	Day	125	$336,425.00
18th Floor & Above	$ 1,975.57	Day	45	$ 88,900.65
Purchase Items - All Lifts	$79,424.00	EA	1	$ 79,424.00
Pre Assembly	$71,952.00	EA	1	$ 71,952.00
Freight to & from Jobsite	$28,800.00	EA	1	$ 28,800.00
Total				**$605,501.65**

According to Maritha Buckley, purchase items would include, reusable cone bolts, engineering services, four weeks of field services, and 1600 stop anchors among other custom items. Another cost that would assume to be used for the Super Climber was Pre-Assembly because it is one form system unlike the Xclimb 60 where there are multiple form walls. As seen in the table the Super Climber formwork system is $174,058.87 more expensive than the Xclimb 60 formwork system.

Although the Super Climber is a more expensive system, it reduces the schedule by 30 working days. Various other costs that are based on the work schedule will decrease, such as the crane rentals, and subcontractor fees. Again after speaking with John Ingerson, I was able to calculate the savings the Super Climber would bring to the project because of the decrease in schedule, based on the numbers given me. Table 10 compares these costs.

As seen in Table 10, the Xclimb 60 system would cost more towards the general conditions of the project than the Super Climber system would. Due to the Super Climber saving roughly 30 working days, this saves $1,530,878 off the general conditions.

Table 10: Formwork Systems General Conditions

Xclimb 60 Formwork System				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	11	$ 687,500.00
Concrete Placing Boom	$27,400.00	Month	11	$ 301,400.00
Tower Crane Operator (1)	$ 125.89	Hour	2100	$ 264,369.00
Maintenance (1)	$ 103.29	Hour	2100	$ 216,909.00
Pump Operator (1)	$ 99.67	Hour	2100	$ 209,307.00
Oiler (2)	$ 90.21	Hour	2100	$ 378,882.00
Laborers (9)	$ 111.45	Hour	2100	$ 2,106,405.00
Carpenters (9)	$ 89.34	Hour	2100	$ 1,688,526.00
Ironworkers (16)	$ 91.41	Hour	2100	$ 3,071,376.00
Lathers (12)	$ 85.36	Hour	2100	$ 2,151,072.00
Total				$11,075,746.00
Super Climber Formwork System				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	10	$ 625,000.00
Concrete Placing Boom	$27,400.00	Month	10	$ 274,000.00
Tower Crane Operator (1)	$ 125.89	Hour	1800	$ 226,602.00
Maintenance (1)	$ 103.29	Hour	1800	$ 185,922.00
Pump Operator (1)	$ 99.67	Hour	1800	$ 179,406.00
Oiler (2)	$ 90.21	Hour	1800	$ 324,756.00
Laborers (9)	$ 111.45	Hour	1800	$ 1,805,490.00
Carpenters (9)	$ 89.34	Hour	1800	$ 1,447,308.00
Ironworkers (16)	$ 91.41	Hour	1800	$ 2,632,608.00
Lathers (12)	$ 85.36	Hour	1800	$ 1,843,776.00
Total				$ 9,544,868.00

Conclusion & Recommendation

As shown in the schedule and cost analyses, implementing the Super Climber formwork system would be beneficial to all parties involved in the construction of the project. First, the owner would benefit due to the lower overall cost of the project. Also, due to the early finish the general contractor would be able to allocate their human and equipment resources to other jobs that need attention.

Even though the Super Climber is a more expensive system, I would still recommend that it be implemented. This is because the Super Climber provides a safer work environment for the workforce and an increase in worker comfort and productivity because the system is easier to manage.

Analysis 2: Implementation of Photovoltaic Curtain Wall

Problem Identification

The buildings enclosure consists of high vision glass with low iron IGU with Low E coating and a mullion module of linen finish stainless steel spandrel panels. With the building being a core and shell project, tenants will choose the layout of the floor they decide to rent. Changing the current system to a Photovoltaic system can be used as a source of renewable energy for the building and relieve the demand of the building. This adds value to the tenants that wish to rent space in the building and also adds value for the owner.

Background Research

Photovoltaic arrays are becoming an increasingly popular way to produce green energy, improve buildings sustainability and to reduce energy costs. Photovoltaic arrays not only produce electricity to reduce the amount of electricity purchased from the utility company, but also produce the most energy at the peak of a buildings load profile. This means that a building could reduce its peak demand charge as well. Before photovoltaic array can be installed on any project the system must be studied to make sure that it will fiscally makes sense. Many projects are not viable candidates for photovoltaic arrays because the payback period is too long. This period can sometimes be shortened by taking advantage of some state and federal incentives.

Solar Study

In order to determine if the photovoltaic array is viable, a solar study was conducted in order to determine if solar shading would be a problem. By recreating the surrounding environment in Google Sketch-Up and importing the model into Revit, it was determined that solar shading would not affect the photovoltaic array. The height at which the array would be installed was also determined by going through each hour of the day of the winter solstice and analyzing where the shadows from the surrounding buildings would be cast. Figure 7 and 8 show the highest point at which the shadows are cast upon the building on the east and south side.

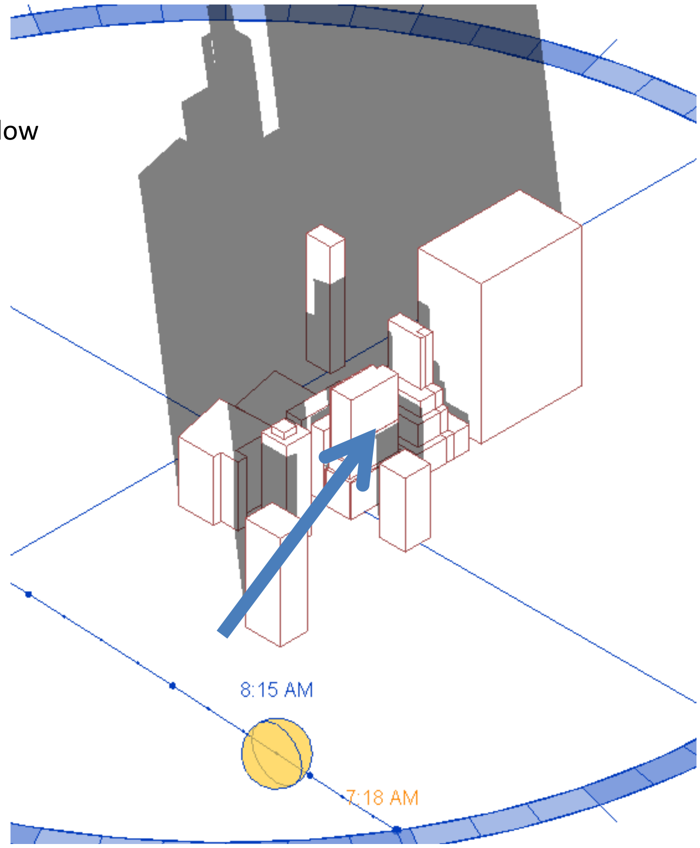


Figure 7: East Side Shadow

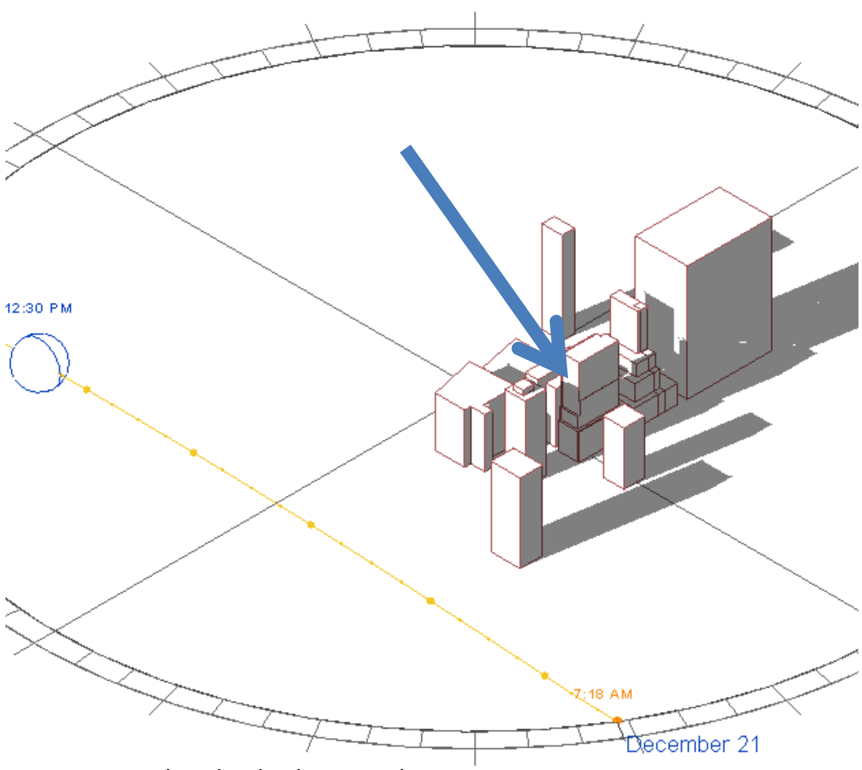


Figure 8: South Side Shadow Height

Through this solar study it was determined that the photovoltaic glass would be installed on floors 19 through 28 on the east side of the building, and floors 25 through 28 on the south side. The area that these photovoltaic panels will cover can be seen in Figures 9 and 10. The heights at which the installations begin are at 270 feet on the east side and 355 feet on the south side. The installations go up to a height of 415 feet on both sides. The current curtain wall glass is two panels separated by a horizontal mullion and the dimensions of the glass panels are 9.5 ft by 3.8 ft and 9.5 ft by 6.8 ft. This can be seen in the Figure 11 on the right. On the east side of the building there will be a total of 200 PV panels totaling to a square footage of 10,165. On the south side there will be a total of 64 PV panels totaling to a square footage of 3,253.

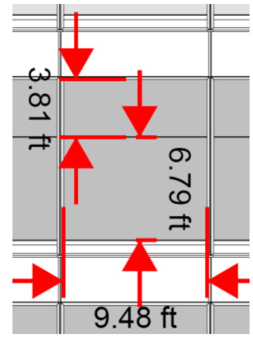


Figure 11: Panel Sizes

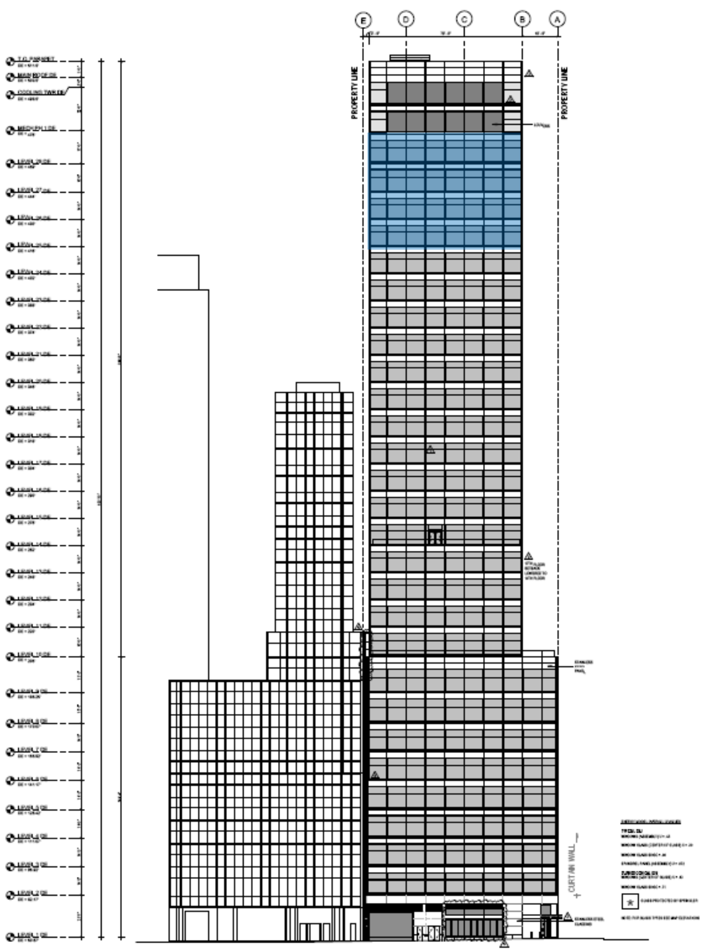


Figure 9: South Side PV Panels. Courtesy of Turner

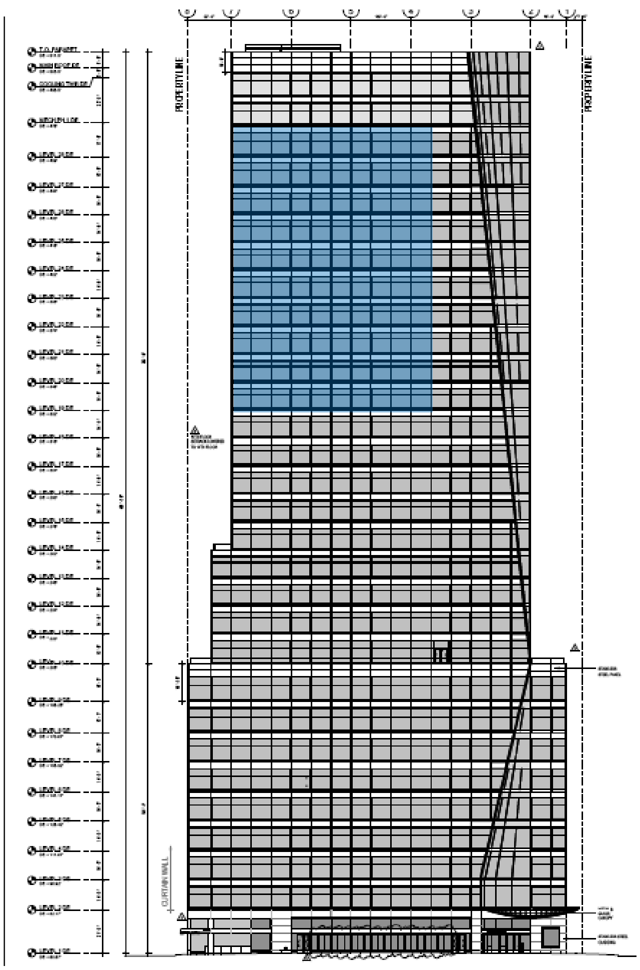


Figure 10: East Side PV Panels. Courtesy of Turner

Sizing and Manufacturing

Once the area of installation was determined the manufacturer of the photovoltaic glass was determined next. After researching various manufacturers it was determined that Onyx Solar would be the best provider due to their experience with photovoltaic curtain wall units. The current curtain wall system is a unitized system manufactured by Benson Industries. According to Jeff Rosenburg from Benson Industries and is the consultant for this project, once the successful completion of performance mockup testing is complete, full unit production will take place. At this point Benson will order the necessary materials in order to manufacturer these panels i.e. glass.

It was suggested by Diego Cuevas from Onyx Solar to use the 20% semi-transparent glass that Onyx manufacturers. The technical guide found in Appendix E shows the specifications of the panel, such as peak power, and weight. The panel in the technical guide is the largest glass that Onyx had on file and since the glass would have to be custom manufactured, the specifications needed to be adjusted for the new panel size. This was done by a square footage ratio calculation as seen below. The square footage of the panel from the technical guide was 32.84 square feet. The custom panels would have a square footage of 36.575 square feet and 65.075 square feet.

$$\text{Nominal Peak Power: } \frac{120}{32.8} = \frac{X}{36.575} = 133.65\ Pmpp\ (Wp)$$

This ratio calculation was done to all of the specifications that changed with the size of the panel. Table 11 shows these changes.

Table 11: PV Panel Specifications

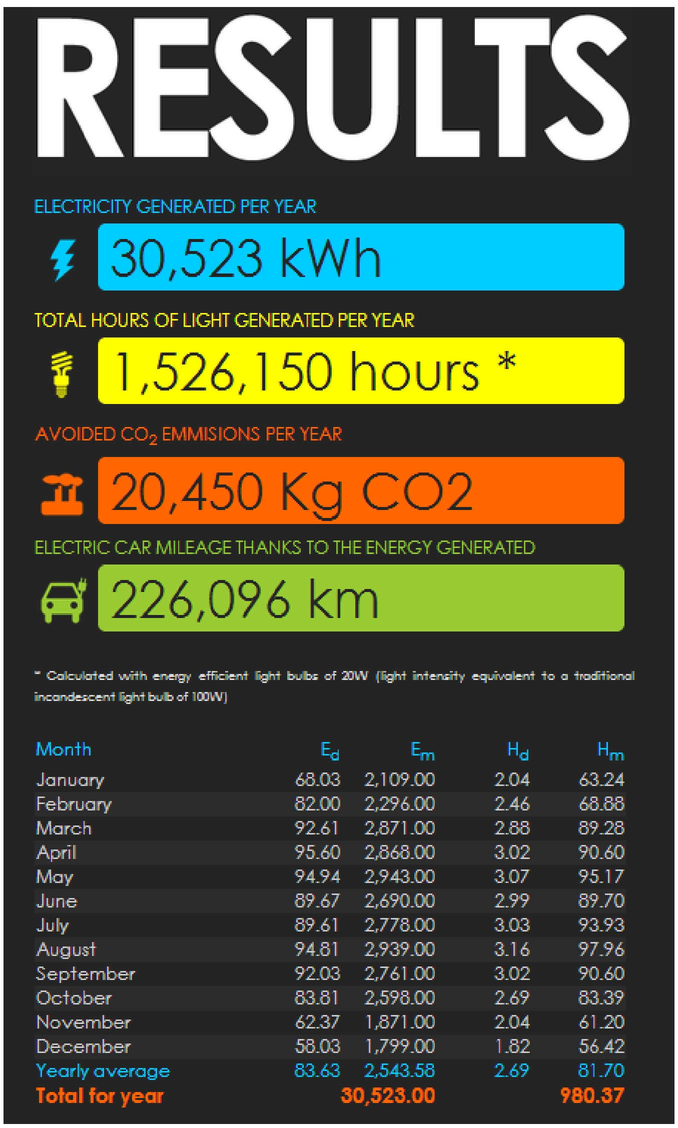
9.5 X 3.8 Panel		
Specification	**#**	**Unit**
Nominal Peak Power	133.65	Watts
Open Circuit Voltage	185	Volts
Short Circuit Voltage	1.1	Amps
Voltage at Nominal Power	140	Volts
Current at Nominal Power	0.97	Amps
Weight	285.5	Lbs
9.5 X 6.8 Panel		
Specification	**#**	**Unit**
Nominal Peak Power	237.79	Watts
Open Circuit Voltage	185	Volts
Short Circuit Voltage	1.94	Amps
Voltage at Nominal Power	140	Volts
Current at Nominal Power	1.724	Amps
Weight	507.98	Lbs

Photovoltaic Generation

Once these numbers were determined the next step was to determine how much energy the panels could generate. By calculating these values, the amount of energy savings these panels can produce can be calculated and will be seen later in the report. The Photovoltaic Estimation calculator found on Onyx's website allows a user to input the location of where the panels would be installed, the power of said installation and the orientation and tilt in order to determine the amount of energy generated in the location. First the power of the installation needed to be determined. This was determined by using the equation below

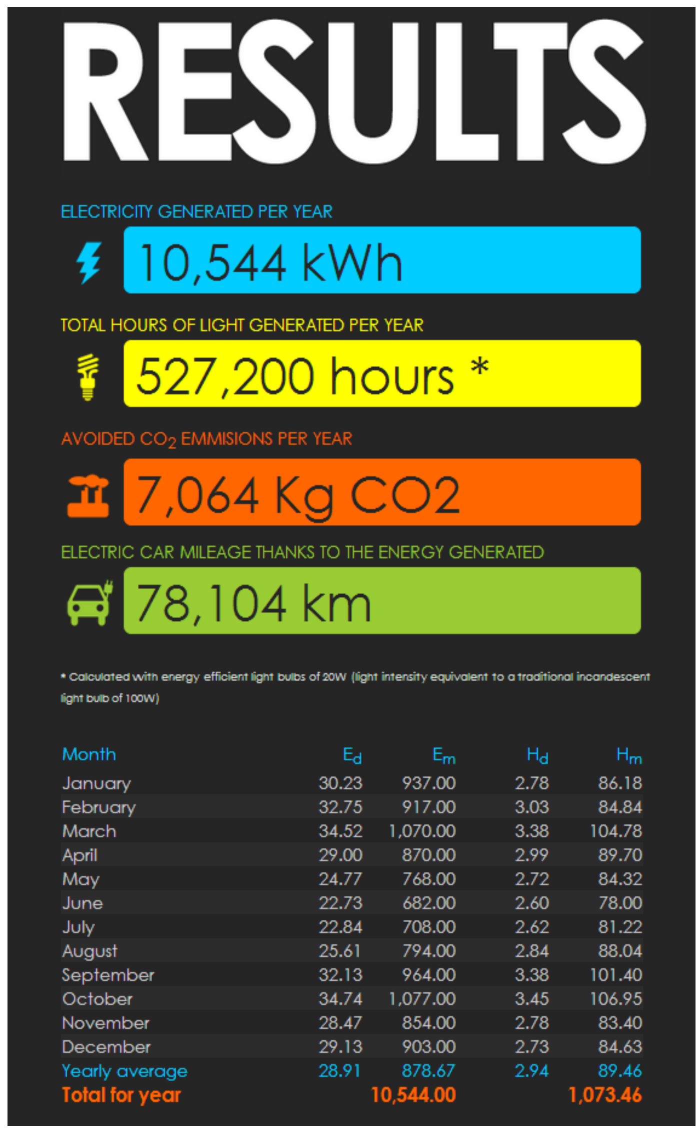
$$\text{Size (kW)} = \text{Module Nameplate Capacity (W)} \times \text{Number of Modules} \div 1{,}000 \text{ W/kW}$$

The module nameplate capacity can be considered as the nominal peak power. By using the numbers found in the table above it was calculated that the south side of the building had a power rating of 11.88 kW and the east side of the building had a power rating of 37.144 kW. The results can be seen below.



Month	E_d	E_m	H_d	H_m
January	68.03	2,109.00	2.04	63.24
February	82.00	2,296.00	2.46	68.88
March	92.61	2,871.00	2.88	89.28
April	95.60	2,868.00	3.02	90.60
May	94.94	2,943.00	3.07	95.17
June	89.67	2,690.00	2.99	89.70
July	89.61	2,778.00	3.03	93.93
August	94.81	2,939.00	3.16	97.96
September	92.03	2,761.00	3.02	90.60
October	83.81	2,598.00	2.69	83.39
November	62.37	1,871.00	2.04	61.20
December	58.03	1,799.00	1.82	56.42
Yearly average	83.63	2,543.58	2.69	81.70
Total for year		30,523.00		980.37

Figure 12: East Side PV Panels



Month	E_d	E_m	H_d	H_m
January	30.23	937.00	2.78	86.18
February	32.75	917.00	3.03	84.84
March	34.52	1,070.00	3.38	104.78
April	29.00	870.00	2.99	89.70
May	24.77	768.00	2.72	84.32
June	22.73	682.00	2.60	78.00
July	22.84	708.00	2.62	81.22
August	25.61	794.00	2.84	88.04
September	32.13	964.00	3.38	101.40
October	34.74	1,077.00	3.45	106.95
November	28.47	854.00	2.78	83.40
December	29.13	903.00	2.73	84.63
Yearly average	28.91	878.67	2.94	89.46
Total for year		10,544.00		1,073.46

Figure 13: South Side PV Panels

Cost Analysis

The amount of energy that these panels can generate for the building determines if installing them is a feasible option from a cost standpoint. A cost comparison of the two systems can be seen in 12 and 13.

Table 12: Original vs PV glass cost

Cost Comparison of Glass			
	Cost Per Square Foot	Square Footage	System cost
Original Glass	$ 20.00	13200	$ 264,000.00
Photovoltaic Glass	$ 34.60	13200	$ 456,720.00
			$ (192,720.00)

Table 13: Original vs PV module cost

Original Module Vs Photovoltaic Module				
	Module Cost	Installation Cost	Number of Modules	System Cost
Original Glass	$ 2,500.00	$ 750.00	264	$ 858,000.00
Photovoltaic Glass	$ 3,985.00	$ 1,595.00	264	$ 1,473,120.00
				$ (615,120.00)

After speaking with Diego Cuevas, he was able to give me a cost per square foot for the photovoltaic glass based upon the installation size that was provided. The cost was $34.60 per square foot. With the square footage of the panels being roughly 13,200 the total cost of the panels would be $457,403.76. As the photovoltaic glass is replacing the original glass, an additional $192,720.00 would be spent for the new material. The unit cost for one curtain wall module according to Jeff Rosenburg from Benson Industries is roughly $2,500. Assuming the installation of the original module is 30% of the unit price, the original system that is being replaced would cost $858,000.00. With the glass of the original system being $20.00 per square foot, it was calculated that the other materials of the module such as the steel, connections and mullion costs roughly $470. The equation below determined the cost of the remaining materials for the original module

$$\$2500 - (\$20 \frac{\$}{SF} \text{ x } 101.65 \text{ SF}) = \text{Cost of Remaining materials} = \$470$$

The module cost for the photovoltaic module was determined by multiplying the cost of the glass by the square footage and adding the remaining material cost resulting in a total of $3985.00. Onyx Solar installs a junction box to each panel when it is manufactured. Assuming the installation of the photovoltaic module is now 40% due the wiring and connections for the panels, the new system would cost $1,473,120.00 resulting in a total system difference of $615,120.00

The next step was to calculate the payback period for the photovoltaic modules. In order to accomplish this, it was important to calculate an average annual electric bill for the building. According to the electric company that provides electric service to the city, the building is charged based on the amount of electricity used during the entire billing period and also is charged for the greatest amount of electric power used in any one-half hour during the billing period.

Since the building is currently under construction and is still in the process of leasing the spaces, the amount of electric power used during a billing period could not be obtained. Assuming the building's maximum demand was the amount of kilowatts the Service Switchboard's are, and is the number the electric company would base a monthly bill off of, an average bill was calculated. There are three service switchboards for the building each at an amperage of 4000. Assuming this amperage is in AC rating, we must convert the amps into kilowatts using the equation below.

$$P_{(kW)} = \sqrt{3} \times PF \times I_{(A)} \times V_{L\text{-}L\,(V)} / 1000$$

With the voltage of the switchboard being 480 and assuming a power factor of 0.8 it was calculated that one switchboard provides 2660.43 kW. With three switchboards installed this result in a maximum demand of 7981.3 kW for the building. Assuming the building uses this maximum demand every month, and this is also the highest electric power used in a half-hour period, the result of the electric bill can be seen in Appendix F. Realistically this would not be the case for the building, but this is a worst case scenario. As seen in Table 14 there are supply charges, and delivery charges. The rates for this type of building were found on the electrical company website.

With the solar panels installed, the amount of energy gathered would relieve a portion of the demand for the building, resulting in a lower monthly bill. Table 14 shows the amount of money that the photovoltaic panels will save during a given month.

Table 14:Energy Savings

Month	# days per month	Solar Energy (Daily) South Side	Solar Energy (Monthly) South Side	Solar Energy (Daily) East Side	Solar Energy (Monthly) East Side	Total Solar Energy	Con Ed Rate ($/kWh)	Monthly Total
January	31	30.23	937.13	68.03	2108.93	3046.06	$ 0.03	$ 76.15
February	28	32.75	917	82	2296	3213	$ 0.03	$ 80.33
March	31	34.52	1070.12	92.61	2870.91	3941.03	$ 0.03	$ 98.53
April	30	29	870	95.6	2868	3738	$ 0.03	$ 93.45
May	31	24.77	767.87	94.94	2943.14	3711.01	$ 0.03	$ 92.78
June	30	22.73	681.9	89.67	2690.1	3372	$ 0.03	$ 84.30
July	31	22.84	708.04	89.61	2777.91	3485.95	$ 0.03	$ 87.15
August	31	25.61	793.91	94.81	2939.11	3733.02	$ 0.03	$ 93.33
September	30	32.13	963.9	92.03	2760.9	3724.8	$ 0.03	$ 93.12
October	31	34.74	1076.94	83.81	2598.11	3675.05	$ 0.03	$ 91.88
November	30	28.47	854.1	62.37	1871.1	2725.2	$ 0.03	$ 68.13
December	31	29.13	903.03	58.03	1798.93	2701.96	$ 0.03	$ 67.55
			10543.94		30523.14	41067.08		$ 1,026.68

As you can see, the amount of money the solar panels reduces the monthly bill by is fairly low. This alone would deter many from installing these panels as the payback period would be too long. Thomas Peters, whom has experience in modeling and selling commercial photovoltaic systems, had pointed me to an IRS benefit for curtain walls. Standard Unitized Curtain Wall containing regular transparent glass (i.e. glass no photovoltaic capacity) would ordinarily be depreciated over 39.5 years for tax purposes. However, when unitized curtain wall arrives at the project site with photovoltaic glass inserted in place of standard glass, then according to a 2009 Private Letter Ruling (PLR) from the IRS, the entire unitized curtain wall (including its design, manufacturing, shipping and installation costs) becomes "energy property" as defined by Section

48 of the Internal Revenue Code. Energy property is depreciated according to the 5 year, Modified Accelerated Cost Recovery System (MACRS) and until December 31, 2016 is also entitled to a 30% Investment Tax Credit (ITC). In other words, the wall containing photovoltaic glass basically becomes a collection of PV modules for tax purposes. The additional value of the tax incentives resulting from the MACRS depreciation and ITC attributed to the curtain wall costs significantly improves the return on investment for the photovoltaic installation as shown in Appendix G

When analyzing Appendix G, there are various line items that are involved within the calculation. The net operating income involves three line items of the calculations. (Energy Savings, SREC Income and Operating Expenses) The energy savings line is the amount of electricity generated by the photovoltaic panels per year in kilowatt hours multiplied by the commercial rate paid to the utility company for electricity. This value is added to the SREC Income value which equals the market value received by the building owner for selling the environmental attribute for solar renewable energy. The operating expenses are the maintenance costs for the photovoltaic panels.

The yellow line item is the credit obtained from the Standard Curtain Wall 39.5 Depreciation rate. Depreciation is an expense that is not paid from income as an operating expense is paid. Some refer to it as a “paper loss” since it reduces taxable income but not cash flow. 25 years which is the PV warranty period is used as the projection term. Out of this the standard curtain wall 39.5 depreciation is Net Present Valued and then divided equally over a six year period so that its benefit can be deducted from the 5 year MACRS benefit. As far as the MACRS depreciation, when ITC is taken, the full cost of the curtain wall with the original glass must be reduced by 50% of the ITC. MACRS annual depreciation percentages from year one thru year six are 20%, 32%, 19.2%, 11.52%, 11.52% and 5.76%. The next line item is the Photovoltaic Glass and Balance of Systems depreciation. This is the premium value for replacing the original glass with the photovoltaic glass plus the cost of string wiring, combiner boxes, wiring to electrical room on the floor, inverter and inverter wiring to AC service. The same depreciation values are used as mentioned above.

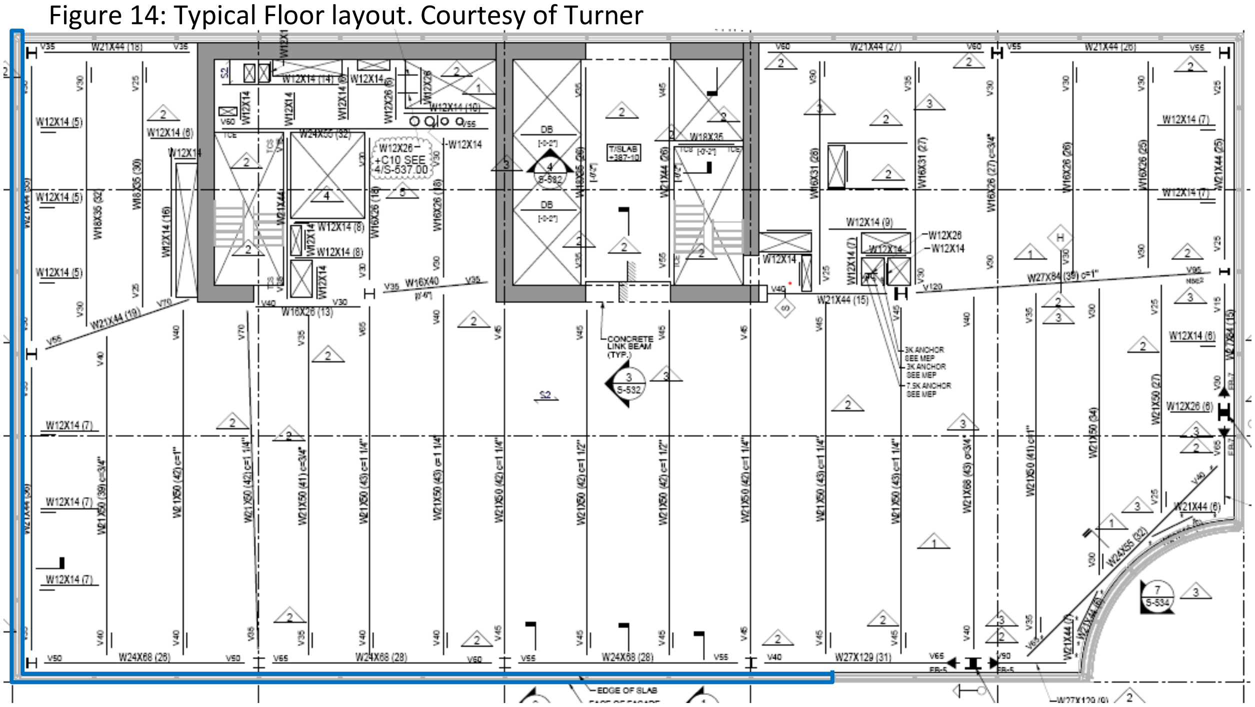
Since depreciation acts like an additional expense for purposes of determining taxable income, the sum of all the depreciation amounts is deducted from Net Operating Income. This is the Net Gain or Loss line. Although this line is a negative number, this is not a cash flow loss but a “paper loss”. As such it can be used as a deduction from taxable income from other investments. It’s value is determined by multiplying the owner’s tax rate times the loss and reflecting it as a positive number. In the event that the owner has an insufficient amount of other taxable income to use all of the depreciation deductions, the losses can be carried back 2 years and forward 15 years. The Investment Tax Credit increases cash flow because it is a direct deduction from taxes.

As it can be seen in the Photovoltaic Tax Performa found in Appendix G, the net cumulative return varies every given year. The owner will still being paying off the cost of the installation after a year. In year two. the owner starts to see a positive cumulative return. This number is the money saved in taxable income from the other investments that are included in the building. With the cost of the photovoltaic panels costing and additional $615, 120, the payback period for the owner would be one year.

Structural Breadth

In order to accommodate the new curtain wall panels with Photovoltaic Glass installed, the structural steel for the project needed to be checked. As seen in Figure 14, which is a typical layout of a floor, the structural steel design is very complex and utilizes a variety of sizes.

Figure 14: Typical Floor layout. Courtesy of Turner



The blue highlight represents where the curtain wall panels that have photovoltaic glass are proposed to be installed. As mentioned earlier, floors 25 through 28 will have photovoltaic curtain wall on the south side, and floors 19 through 28 will have photovoltaic curtain wall on the east side. From column to column on the east side a total of three panels are installed, and on the south side a total of four panels are installed. As the same girders are uses throughout the proposed installation, it was decided to check the two girders shown in Figure 15.

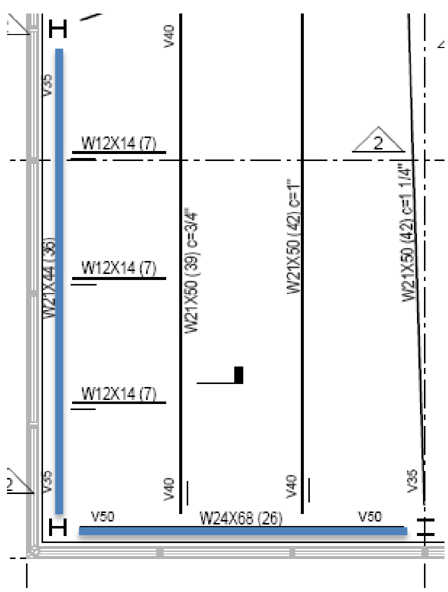


Figure 15: Girders. Courtesy of Turner

The girder sizes are W24X68 on the east side and W21X44 on the south side. In order to calculate if the girders can support the new system, the moment and deflection of the girders need to be calculated. For this to value to be calculated the weight of the panels needed to be found. After speaking to Jeff Rosenburg from Benson Industries, he was able to tell me the curtain wall glass weighs roughly 10 pounds per square foot. With a square footage of 101.65 square feet, this results in the glass weighing 1016.5 pounds. One module weighs a total of 2200 pounds, so the remaining weight which would include the steel, mullion, connections etc, would be 1183.5 pounds. With just the glass being replaced in the module, the Oynx Panel weight needed to be calculated. The total weight of the two panels would sum to 793.5 pounds. Adding this value to the remaining weight value, one module with the photovoltaic glass installed would weigh 1977 pounds.

As it can be seen in Figure 15, the beams on the east and south side also place a load on the girder. The calculation of the east side girder was done first. In order to find the load on the beams a simple calculation needed to be done as seen in Appendix H. As this building is going to be used for office purposes, a live load of 100 pounds per square foot was used. The concrete slab weight was found using the Vulcraft Steel Roof and Floor Decking Catalog which can be found in Appendix I. With the metal decking being composite it was found that the slab was 51 pounds per square foot, as it is 3VLI based on the decks dimensions, normal weight concrete and five and a half inches thick. Using an additional dead load of 20 pounds per square foot, and the beam self-weight was 50 pounds per square foot, the load on the beams came to be 2.512 klf.

In order to find the loads on the girder, the load found on the beams needed to be converted to a factored point load which came out to be 52.8 kips and an unfactored load of 35.7 kips. A distributed load will also be placed on the girder from the curtain wall panels. The factored distributed load is found to be .264 klf with an unfactored distributed load of .22 klf. When calculating the maximum moment the factored loading needs to be used, and when calculating deflection the unfactored loading needs to be used. Using the Steel Construction Manual, the moment and deflection equations were found based on the free body diagram seen in Appendix J. The equations from the Steel Construction Manual can also be found in Appendix J.

Using these equations, the maximum moment, and the total deflection was found for the original curtain wall modules and the proposed photovoltaic curtain wall modules. The girder does not need to be changed as the moment and deflection differ by 2.9 foot-kip and 0.007 inches respectively and this is a very minimal amount.

The same process was done for the south side and it was found the new modules would only give a .05” less deflection, and 5 foot-kip less moment. Again due to the minimal amount of change the beam size does not need to be changed. The calculations for the moment and deflection can be seen in Appendix H

Electrical Breadth

With the implementation of the photovoltaic curtain wall units, the need for solar inverters and a dedicated panelboard are required. With each photovoltaic panel supplied with a junction box, the next step was to determine the way they would be wired together. Daniel Carnovale, who is the Power Systems Experience Center Manager at EATON, explained that there can be various ways to connect the panels to each other, but the simplest way would be to connect them in series. Appendix K shows the calculations that were completed in order to determine the amount of inverters needed based on how the panels were connected.

With the photovoltaic curtain wall installed on the east and south side for the first four floors, it was assumed that the units would be connected in a series of three. Also since the units consists of two different sizes, it was necessary to connect the smaller panels with each other and the larger panels with each other. As seen in Appendix K the first four floors will have six connections if the units are connected in a series of three. When the units are connected in series, the amperage, the voltage, and the power add together. As seen through the calculations the small panels will total to a power of 2.412 kilowatts per floor and the large panels will total to a power of 4.212 kilowatts per floor. Daniel Carnovale provided the technical data sheet found in Appendix L which was used to size the inverters for the photovoltaic system. The panels were connected in a series of three because the minimal voltages for these inverters are 360V. With the panels being 140 V each, this allows the inverter to be used because the panels will now run at 480 V through the inverter. With Eaton having inverters sizes ranging from 4 kilowatts to 7 kilowatts, it was necessary to calculate the minimal amount of inverters needed. With the first four floors, two of the floors could be connected to one five kilowatt inverter for the small panels because the total power would sum to 4.824 kilowatts. The larger panels would need a five kilowatt inverter per floor because the total power was 4.212 kilowatts.

The remaining six floors now only have photovoltaic units installed on the east side of the building. In order to determine how many inverters could be connected the same process as the first four floors was taken. The connections would be in a series of three again, resulting in the need of two five kilowatt inverters for the smaller panels, and two seven kilowatt inverters for the larger panels. Each inverter would service three floors worth of panels. Below are Figures 16 and 17, that show what photovoltaic units will connect to the inverter.

After the calculations were completed, it was found that the photovoltaic systems would need a total of eight five kilowatt inverters, and two seven kilowatt inverters. Each inverter would be placed in the electrical closet on floors 27, 25, 23, and 20.

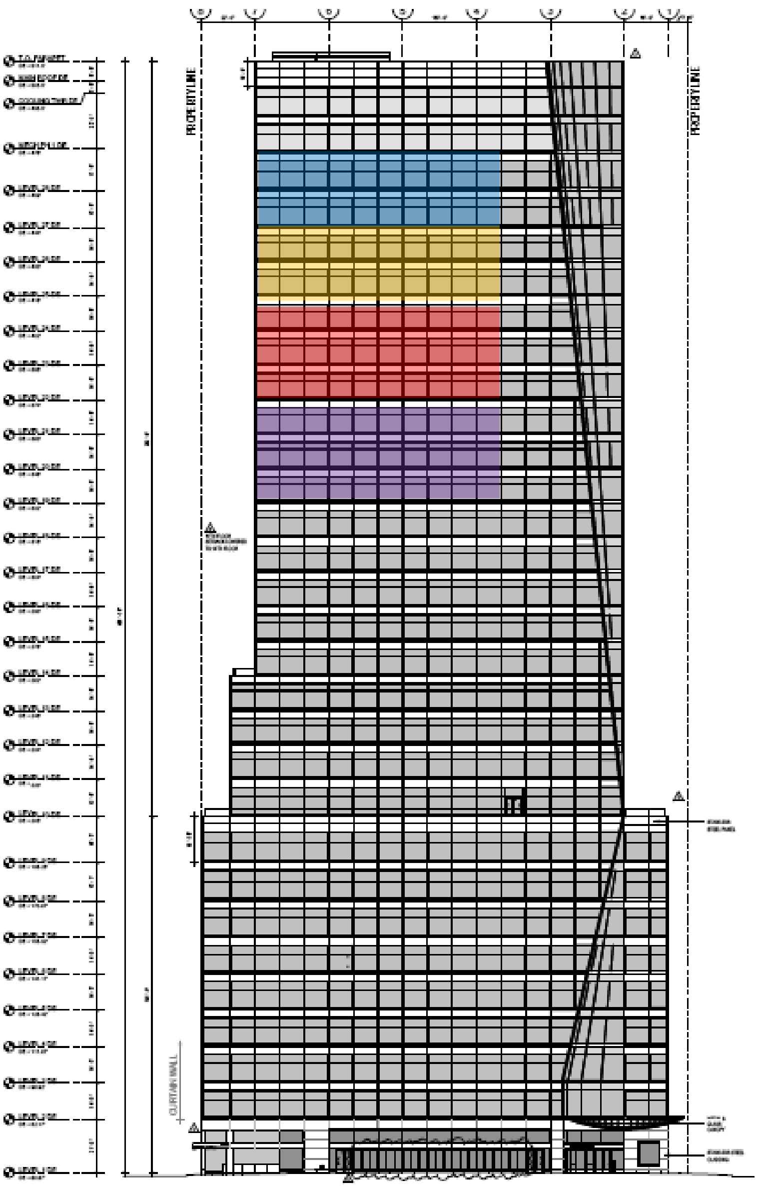


Figure 16: Small Panel Connection for Inverters. Courtesy of Turner

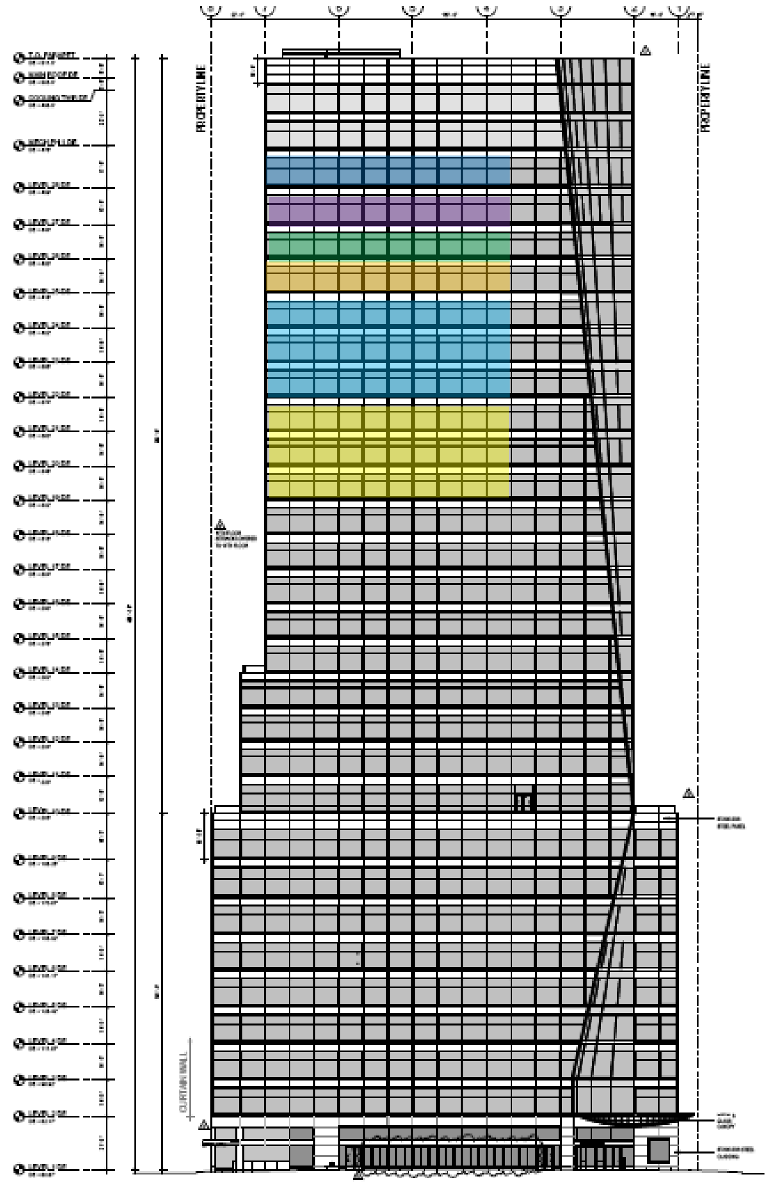


Figure 17: Large Panel Connection for Inverters. Courtesy of Turner

Once the inverter was sized, it was time to size the wiring and panelboard for the inverters. With a 480/277 V system, the amperage for the inverters would be based off the calculation below.

$$\frac{5\ kW\ Inverter}{277\ Volts} = 18 \text{ Amps} \quad \frac{7\ kW\ Inverter}{277\ Volts} = 25 \text{ Amps}$$

With the amperage being 18 and 25 it was assumed to use a 30 amp breaker. After going into the NEC handbook and using table 310.15(B)(16), it was found that based on this amperage the three phase copper wire would be a size of #10 AWG. This table can be found in Appendix M. The next step would be to size the ground wire and conduit. Using table 250.66 in the NEC handbook, it was found the ground wire would be #8 AWG based on the three phase wire size. The conduit was sized using table C.2. With there being three wires, the size of the conduit would be 3/4 inches. The proper nomenclature for the wiring from the inverter to the panelboard would be (1 set #10 + #8G) 3/4" C

Each inverter should have its own breaker for the panelboard. With the panelboard being three phase, in order to size the panel the total amperage of the breakers would be needed. Since the system is 277V, there would be a total of 10 30A single pole breakers, with one phase having four of them. This would be a total of 120 Amps on one phase with the other two phases having a maximum of 90Amps. The main breaker would be 1.5X the total size of the breaker sizes, making the size of the panelboard 200Amps. With the building having three service switchboards, it was found that there are spaces for other connections on each of them. This determined that the panelboard would be installed in the electrical room on Lower Level 2 of the building, which is where these switchboards are installed. Figure 18 below shows the layout of the panelboard.

Panel Designation: Solar Inverters						
CKT No.	Description	C/B Rating	ϴ	C/B Rating	Description	CKT No.
1	5kW Inverter	30A	A	30A	5kW Inverter	2
3	5kW Inverter	30A	B	30A	5kW Inverter	4
5	5kW Inverter	30A	C	30A	5kW Inverter	6
7	5kW Inverter	30A	A	30A	5kW Inverter	8
9	7kW Inverter	30A	B	30A	7kW Inverter	10
		Voltage	Phase	Wires		
		277/480	3	4		

Figure 18: Solar Inverter Panelboard

In order for the panelboard to connect to the service switchboard, another set of wiring needs to be sized. Since the panelboard is 200 amps, the size of the wire was found to be (1 set of 3/0 + # 4G) 2 ½" C after using the same process as before.

Conclusion & Recommendation

As shown through the cost analysis, implementing the Photovoltaic Curtain Wall would be beneficial to not only the owner, but also for the tenants of the building. With the PV panels reducing the demand of the building, the tenants save roughly $1000 annually from their electrical bill, and as shown by the Tax Performa, is a good investment for the owner. By taking advantage of the tax benefits offered by the IRS and other energy benefits, the owner sees a return on investment after the second year of installation through tax deductions.

Analysis 3: SIPS

Problem Identification

Being a core and shell office building the schedule activities are very repetitive. With the current schedule there is a greater need for coordination and planning to ensure that the schedule remains on pace. Although the entire schedule is considered critical, the most important activity is the casting of the concrete core. The core is the first activity to be completed for each floor, which makes the entire schedule dependent on this activity. Without the core in place, steel framing, superstructure, SOFP, and enclosure cannot begin.

Background Research

A SIPS breaks down a project sequence into more detail than a typical project schedule would. It defines durations for each activity, crew size needed to complete that activity in a certain time frame, and the area that the work will be performed in. Doing this allows all members of the project team to know what they will be doing at all points of the day.

Usually, SIPS will be used on a project that is highly repetitive in nature such as a prison or high rise such as this project. Also, the project is split up into defined construction zones. These zones should be similar in size and nature so that it takes a trade or team the same amount of time to complete each zone. The project schedule is already in a form of a SIPS schedule, but could be broken down further by the amount of hours. The reasoning for breaking the schedule down further is for the benefit for the subcontractor and project team in case of a delay in schedule; SIPS can determine what areas the project can be accelerated to bring the project back on schedule or decrease the overall schedule. As mentioned before this analysis will focus on the concrete core, but a SIPS analysis will be done on both the Xclimb 60 schedule, and the Super Climber Schedule. Also, worth noting is the fact that using a SIPS will typically increase the worker productivity.

Activity Analysis

The next step is to identify all of the activities that will be used in the SIPS schedule for the concrete core of the project. Table 15 shows the activities involved with casting the concrete core for a typical floor.

Table 15: Concrete Core Schedule

Original Concrete Core Schedule		
Lift Formwork from 3rd Floor to 4th Floor	Monday	11/4/2013
Install Rebar and Embeds for 4th Floor	Tuesday	11/5/2013
Install Rebar and Embeds for 4th Floor	Wednesday	11/6/2013
Install Rebar and Embeds for 4th Floor	Thursday	11/7/2013
Install Remaining Rebar and Embeds & Pour 4th Floor Concrete Core Walls	Friday	11/8/2013
New Concrete Core Schedule		
Lift Formwork From 3rd Floor to 4th Floor/ Start Install of Rebar and Embeds for 4th Floor	Tuesday	10/29/2013
Install Rebar and Embeds for 4th Floor	Wednesday	10/30/2013
Install Rebar and Embed for 4th Floor	Thursday	10/31/2013
Install Remaining Rebar and Embeds & Pour 4th Floor Concrete Core Walls	Friday	11/1/2013

After speaking with Jon Ingerson, I was informed that roughly 44 tons of rebar is installed when the core is a three bay system, and roughly 30 tons of rebar is installed when the core becomes a two bay system. As far as the pouring of the concrete, when the core is a three bay system there is roughly 246 cubic yards of concrete poured for a floor, and when the core is a two bay system there is roughly 172 cubic yards of concrete poured per floor. After calculating the durations based on the 10 hour work day schedule, I was able to break the activities down even further. Appendix N shows the calculations for each activity and breaks it down to either the minute or hour. With there being 26 form walls and the formwork activity takes an entire work day, it was found that each form wall would take 23 minutes to lift when the core is a three bay system, and 33 min when the core is a two bay system.

When calculating the rebar, it was found that 16 ironworkers would be placing 1.26 tons of rebar an hour when the core is a three bay system and 1.2 tons of rebar an hour when the core is a two bay system. If the crew was to increase to 32 ironworkers, productivity would increase to 2.52 tons an hour and 2.4 tons an hour. Although this is an extra cost for more workers, it is believed the schedule could decrease even further as now multiple walls could be installed with rebar and embeds at the same time. The activity was further broken down by how long each wall would take based on how much rebar was in the wall and the duration that was found. Figures 19 and 20 show how the core was broken down by wall and each wall number on the figure correlates to the calculations in Appendix N.

When calculating the amount of concrete that was poured, it was found that the concrete boom would pour roughly 49.2 cubic yards of concrete per hour when the core is a three bay system and 34.4 cubic yard of concrete per hour when the core is a two bay system. Figures 21 and 22 show how each core wall was poured and each wall number on the figure correlates to the calculations in Appendix N.

After the calculations were completed, it was time to schedule the SIPS based on each formwork system. These schedules can be seen in Appendix O. Looking at the first schedule which is a SIPS of the Xclimb 60 formwork system for any given three bay floor, it can be seen that each activity is broken down to the minute or hour. The times labeled in each line are when that line activity is completed. By having this schedule, the subcontractors and the project team can keep better track of the work that needs to be done for a given day. With the crew size increased to 32 men, the schedule decreased by one and a half days. This was because there were two crews of 16 men working on the rebar, which allowed two walls to be started at the same time. The red and green label represents a crew. The darker green lines represent both crews working on the same wall in order for the wall to be completed on that day. This decrease in schedule was applied to each floor, resulting in a decrease in 30 working days which was the same result in Analysis 1. Using the same steps, a SIPS schedule was made based off the use of the new formwork system. Looking at this schedule which again represents any given three bay floor, it can be seen that the schedule becomes a three day cycle. Once again this is because of the increase in crew size with the combination of the Super Climber.

Figure 19: Three Bay Rebar Installation Breakdown. Courtesy of Turner

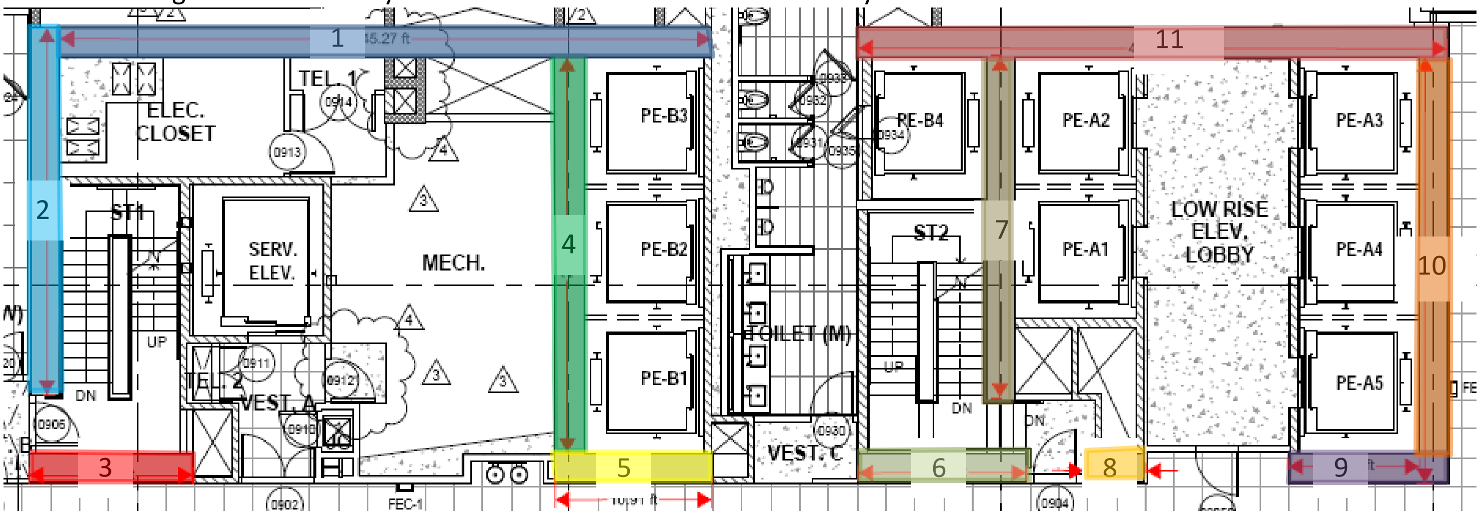


Figure 20: Two Bay Rebar Installation Breakdown. Courtesy of Turner

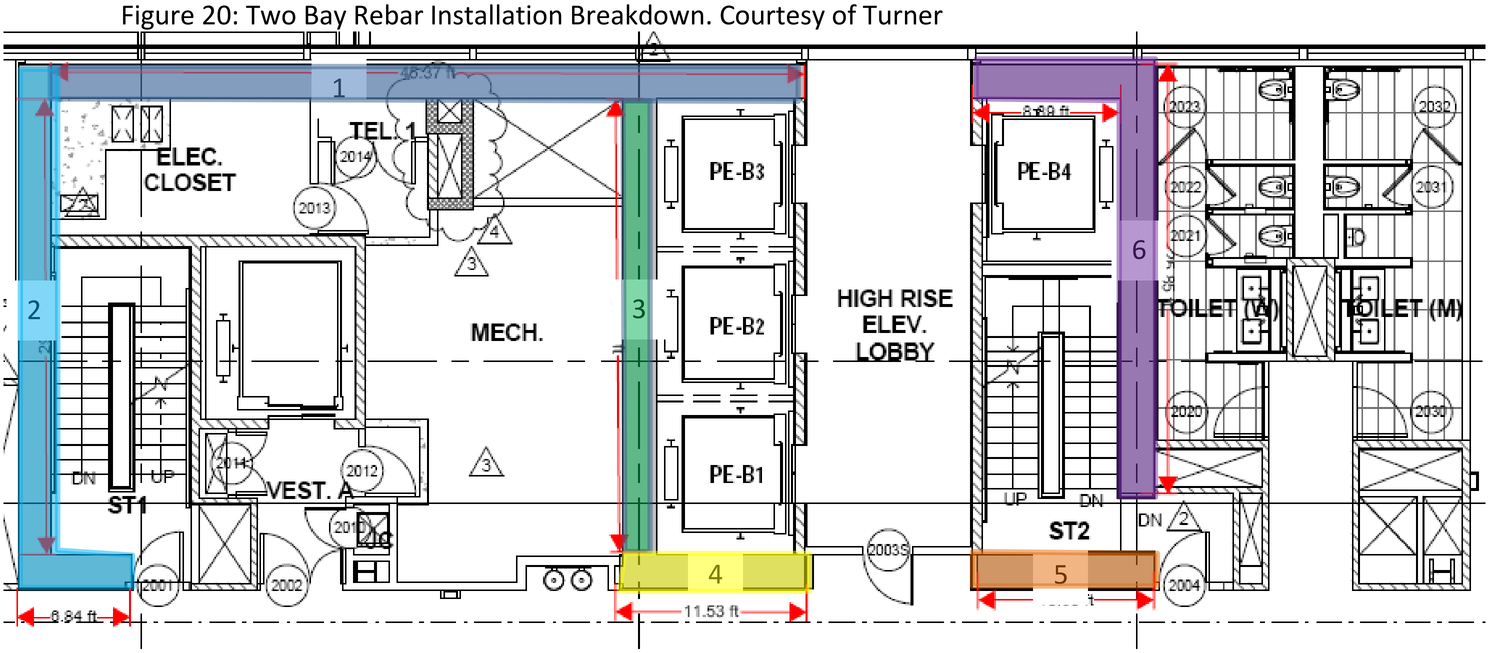


Figure 21: Three Bay Concrete Pour Breakdown. Courtesy of Turner

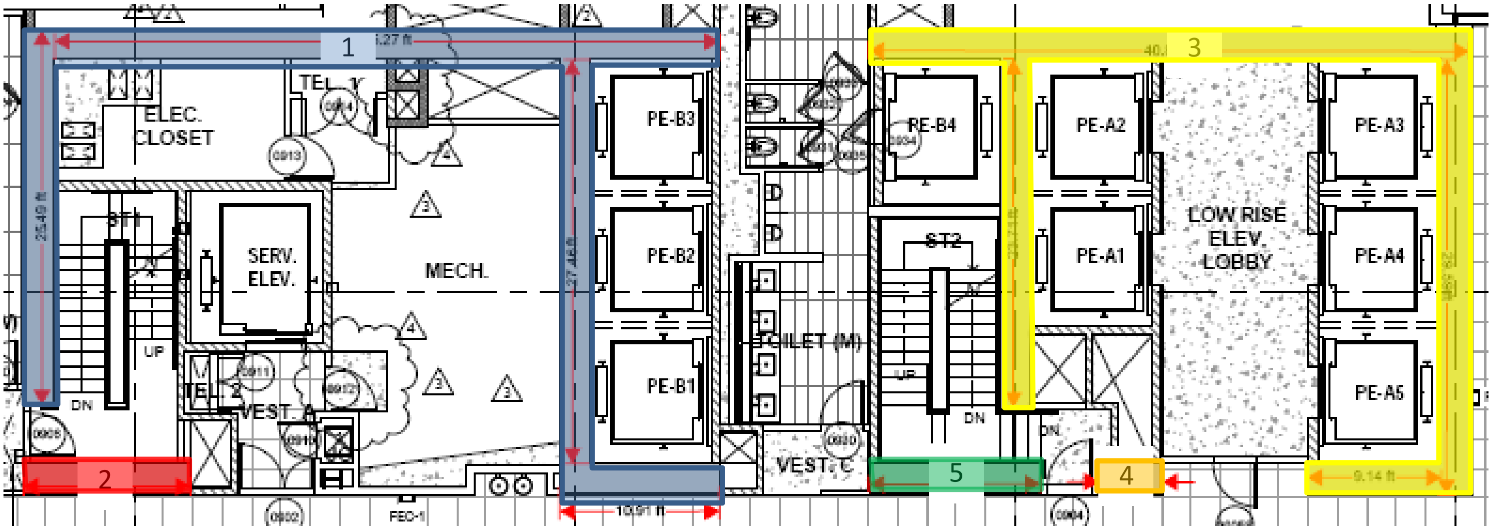
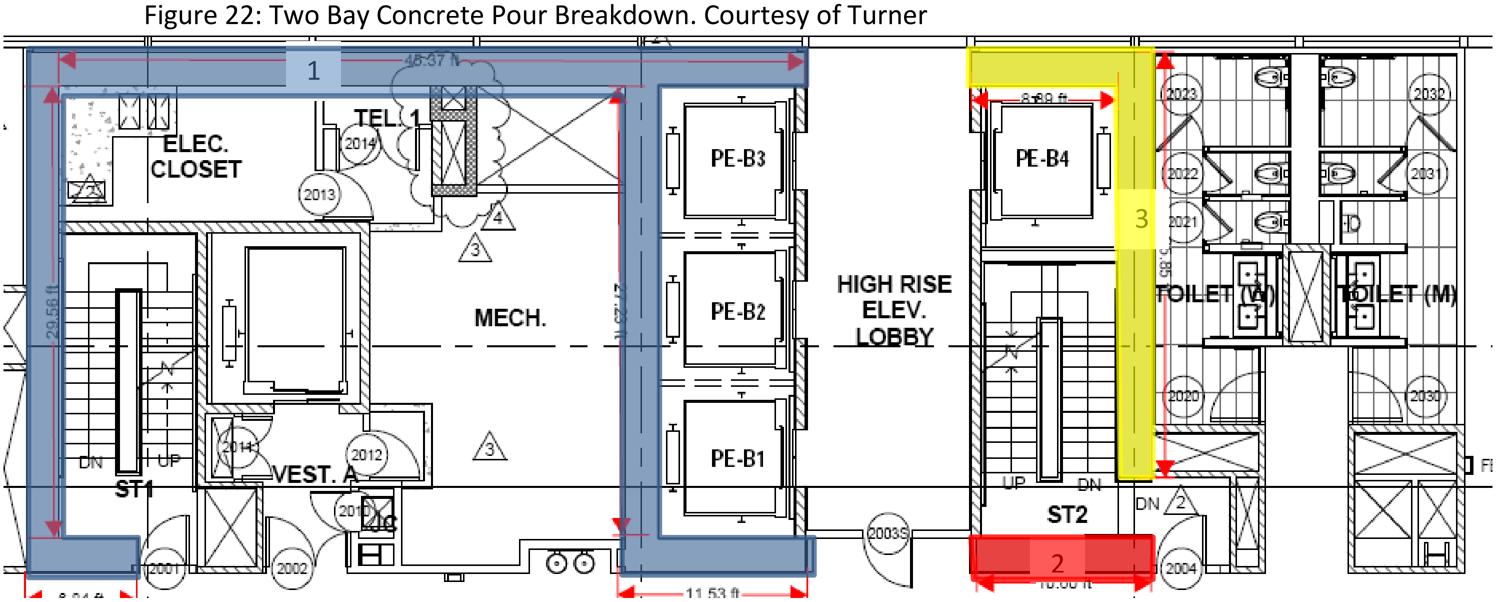


Figure 22: Two Bay Concrete Pour Breakdown. Courtesy of Turner



When combing SIPS with the Xclimb 60 formwork schedule, the concrete core will be completed on March 17th 2014 with the completion of the 29th floor. The activity comes to a close on April 7th 2014 with the dismantling for the concrete crane resulting in 180 working days. When combing SIPS with the Super Climber formwork schedule, the concrete core will be completed on January 29th 2014 with the completion of the 29th floor and the activity comes to a close on February 19th 2014. With the SIPS and Super Climber combined the total amount of working days is 150.

Cost Analysis

With the SIPS schedule decreasing the amount of work days off the Xclimb 60 formwork system is used, there will be a change in general conditions. Tables 16 and 17 show these changes.

Table 16: Formwork without and With SIPS

Xclimb 60 Formwork System with out SIPS				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	11	$ 687,500.00
Concrete Placing Boom	$27,400.00	Month	11	$ 301,400.00
Tower Crane Operator (1)	$ 125.89	Hour	2100	$ 264,369.00
Maintenance (1)	$ 103.29	Hour	2100	$ 216,909.00
Pump Operator (1)	$ 99.67	Hour	2100	$ 209,307.00
Oiler (2)	$ 90.21	Hour	2100	$ 378,882.00
Laborers (9)	$ 111.45	Hour	2100	$ 2,106,405.00
Carpenters (9)	$ 89.34	Hour	2100	$ 1,688,526.00
Ironworkers (16)	$ 91.41	Hour	2100	$ 3,071,376.00
Lathers (12)	$ 85.36	Hour	2100	$ 2,151,072.00
Total				$11,075,746.00
Xclimb 60 Formwork System with SIPS				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	10	$ 625,000.00
Concrete Placing Boom	$27,400.00	Month	10	$ 274,000.00
Tower Crane Operator (1)	$ 125.89	Hour	1800	$ 226,602.00
Maintenance (1)	$ 103.29	Hour	1800	$ 185,922.00
Pump Operator (1)	$ 99.67	Hour	1575	$ 156,980.25
Oiler (2)	$ 90.21	Hour	1575	$ 284,161.50
Laborers (9)	$ 111.45	Hour	1800	$ 1,805,490.00
Carpenters (9)	$ 89.34	Hour	1800	$ 1,447,308.00
Ironworkers (32)	$ 91.41	Hour	1800	$ 5,265,216.00
Lathers (12)	$ 85.36	Hour	1800	$ 1,843,776.00
Total				$12,114,455.75

Table 17: Formwork without and With SIPS

Super Climber without SIPS				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	10	$ 625,000.00
Concrete Placing Boom	$27,400.00	Month	10	$ 274,000.00
Tower Crane Operator (1)	$ 125.89	Hour	1800	$ 226,602.00
Maintenance (1)	$ 103.29	Hour	1800	$ 185,922.00
Pump Operator (1)	$ 99.67	Hour	1800	$ 179,406.00
Oiler (2)	$ 90.21	Hour	1800	$ 324,756.00
Laborers (9)	$ 111.45	Hour	1800	$ 1,805,490.00
Carpenters (9)	$ 89.34	Hour	1800	$ 1,447,308.00
Ironworkers (16)	$ 91.41	Hour	1800	$ 2,632,608.00
Lathers (12)	$ 85.36	Hour	1800	$ 1,843,776.00
Total				$ 9,544,868.00
Super Climber with SIPS				
Description	**Rate**	**Unit**	**Quantity**	**Total**
Concrete Crane	$62,500.00	Month	8	$ 500,000.00
Concrete Placing Boom	$27,400.00	Month	8	$ 219,200.00
Tower Crane Operator (1)	$ 125.89	Hour	1500	$ 188,835.00
Maintenance (1)	$ 103.29	Hour	1500	$ 154,935.00
Pump Operator (1)	$ 99.67	Hour	1500	$ 149,505.00
Oiler (2)	$ 90.21	Hour	1500	$ 270,630.00
Laborers (9)	$ 111.45	Hour	1500	$ 1,504,575.00
Carpenters (9)	$ 89.34	Hour	1500	$ 1,206,090.00
Ironworkers (32)	$ 91.41	Hour	1500	$ 4,387,680.00
Lathers (12)	$ 85.36	Hour	1500	$ 1,536,480.00
Total				$10,117,930.00

As seen in the table, there is an increase in general conditions due to doubling the crew size for the installation of rebar and embeds. The Xclimb 60 SIPS increases by $1,038,709.75 and the Super Climber SIPS increases by $573,062. Even though there is an increase in the general conditions for the concrete core, it can be assumed with the decreased schedule, the activities that follow the concrete core can be started sooner, thus potentially decreasing the overall cost and overall schedule of the project.

Conclusion & Recommendation

Using a SIPS will accelerate the concrete core for both the formwork systems by an extra 30 working days. The SIPS will increase the coordination between the workers, and also the workers will know exactly where they will be at every step in the process which will eliminate any unproductive work stoppages and make them responsible for getting their work done. The worker productivity should increase as they work through multiple floors of construction and become familiar with the tasks they need to complete.

Although there is an increase in cost, it is still recommended that the SIPS be implemented on the project. This is because with the decrease in the concrete core schedule, the activities that follow the concrete core can be started sooner, thus potential decreasing the overall cost and overall schedule of the project.

Analysis 4: Integration of Material Tracking Technologies

Problem Identification

The project has various different materials that will be fabricated and delivered to the site. The deliveries can be very complicated due to the location of the project and the site is very condensed. Many of the materials have long lead times, are manufactured off-site, and require careful planning for deliveries. With the use of such specialized building materials it is critical that extreme planning and consideration goes into tracking materials. Due to the surrounding streets traffic is a major concern when deliveries are being brought into the site.

Research Goal

There are a number of software programs that are on the market that can be used to track the materials being manufactured in the shop and delivered. The goal of implementing a specific tracking technology known as radio frequency identification (RFID) tags on materials will be to track these items easily and have the project team be prepared for onsite deliveries. The tags have the capability of storing information in regards to installation, delivery, storage, and warranties within the tags.

Background Information

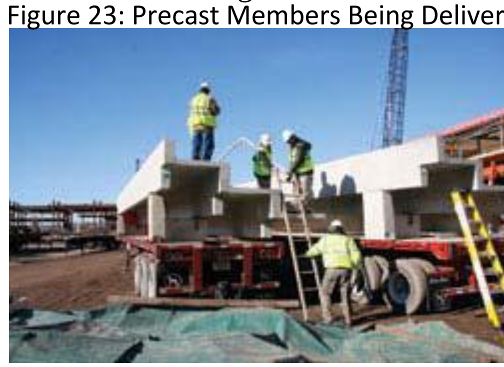
Software that has been used on construction projects includes Autodesk Systems, Latista and LocateWate. These programs, in addition to the growing collaboration with 4D modeling software, such as NavisWorks and Tekla, has sparked great interest in their implementation on the construction site. The programs involve complex tracking systems that have the capabilities of tracking materials from the manufacturing phase to the final installation of the product on-site. The technology can consist of material tracking software, scanners, and material tags, which can use high-end RFID tags with GPS capabilities to cheaper, simpler barcode tags. These systems have shown incredible worth on large scale projects, and it is believed the project can benefit from implementing this technology There are a number of implementation items that will need to be decided, such as what tagging system to use and what software to select and in order for this technology to be successful the manufacturers, subcontractors, and construction management team to buy-in to the system.

Case Study

MetLife Stadium

A successful use of material tracking technologies was the MetLife Stadium in New Jersey. The project was a $998 million, 2.2 square foot stadium, which is the home of the two New York national football teams. Skanska USA Building was the lead contractor on the design-build project and was forced to identify the critical-path materials and resolve the potential conflict issues in the earlier stages of the project due to the upcoming football season being the schedule driver.

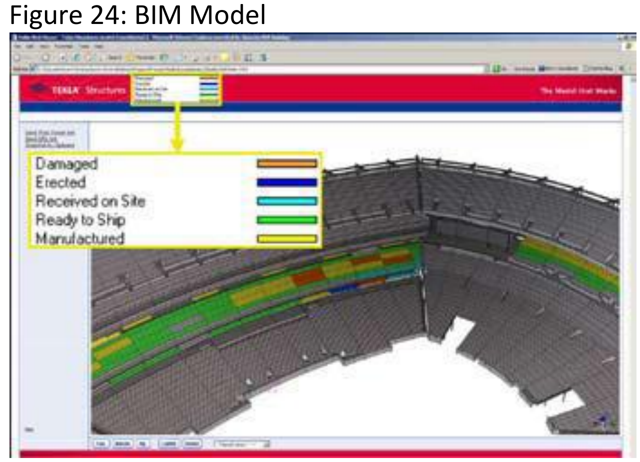
Figure 23: Precast Members Being Delivered



The 3,200 precast members was the key activity that Skanska had addressed. The members weighed 45,000 pounds and measured 44 feet by 10 feet. The members were also custom-made for a specific location within the stadium, which eliminated the possibility of interchanging pieces. Skanska used a just-in-time supply chain technique that allowed the members to be erected directly off the trucks upon delivery, which eliminated timely material movement activities. Due to the tight schedule, Skanska used Vela systems and Tekla Corporation to complete the stadium on time using a Field BIM Solution.

Vela Systems is a company that specializes in field software, which in combination with tablet PCs has the capability of streamlining and expediting field processes. Their software can be used to compose field reports, work lists, safety inspections, punchlists, schedule updates, and has the ability to store the project's construction drawings for editing and reviews. The use of their software has shown savings of 5-10 hours per week per user, an acceleration of two days per month, a reduction in litigation through proper documentation, and greater quality control.

Figure 24: BIM Model



Over 3,000 pre-cast concrete elements that formed the seating bowl of the stadium featured RFID tags that were embedded in the elements upon casting. The pieces proceeded through four scanning phases of the production process. The precast elements are first scanned upon casting and moved to the desired location in the supplier's facility. The third scan is performed upon successful delivery to the project site and inspection for damages. The fourth and final scan is completed during the erection process to ensure that the elements have been placed in the proper location. As the pieces move through the various phases of the production process, the information gathered from the RFID tags are fed into Tekla Structures, a BIM software that models the stadiums structure from the earlier design stages, to fabrication, and into the installation of the pieces. The combination of Tekla;s BIM technology with Vela's material tracking software creates the ability for Skanska to track the status of each precast member throughout the supply chain. The status of each piece can be checked by looking into Tekla's 3D model of the stadium, where each concrete member displays varying colors that depict the status of the elements. This innovative material tracking solution serves as the first example in the United States to combine the material tracking software, tablet PCs, RFID tags, and the BIM in the construction industry. With the introduction of this material tracking strategy, the project was able to reduce the construction schedule by 10 days, which resulted in a savings of $100,000 per day or a total savings of $1 million.

Material Tags

Material tracking systems require four critical components to work together in order to reach a desired end result: software, tagging, hardware, and services.

The first key decision to make is to decide on what tags to utilize, which depends on the level of sophistication and intended use of the system. Within the proposed material tracking technology, there are a number of different tagging systems to utilize, which includes RFID, barcodes, and QR.

RFID is composed of three major components, the reader, tags and antenna. The antenna enables the chip to transmit the information from the tag to the reader. From here, the reader takes the information and transmits the information into a computer data base for use. Within RFID tagging, there are two forms of tags: active and passive.

The active tags are internally powered by a battery and GPS capabilities. The more sophisticated active RFID tags have the capability of storing information in regards to delivery, storage, installation, and warranties within the tags. Additionally, these tags demonstrate the ability to contain GPS and proximity tracking to allow for inventory sweeps of construction sites. This is advantageous, since the project team can know exactly where any given item is located on-site without having to manually search for the item.

Passive tags are operated using the power generated from the reader. Although the passive tags are much cheaper, they have a limited read range and don't contain the data storage capacity that active tags possess. Although these tags have greater capabilities over other tagging systems, there cost heavily deters there use on most projects.

Active RFID Tags	Passive RFID Tags	Barcode Tags	Barcode Labels
100 Meter read range; can be read under snow & ice	10 – 20' read range; cannot be read under snow & ice	Less than 1' read range; cannot be read under snow and ice	Less than 1' read range; cannot be read under snow and ice
Does not require line of site to scan; can be used with inventory sweeps to update GPS location	Does not require line of site to scan	Does require line of site to scan	Does require line of site to scan
$$$	$$	$	--

Figure 24: Types of Tags

Another form of tags is barcodes. Barcoding systems have been utilized throughout the industrial and manufacturing processes for some time and are now becoming the front-runner in the construction world due to its affordability. Barcodes are much cheaper in comparison to RFID tags and have greater versatility for coordination. Using material tag

generating software, such as Bartender, tags can be printed in the manufacturing facility or on-site and attached to the desired material. Although the system is advantageous from a cost standpoint, barcodes have limited data storage and requires line of site scanning.
In order to decide which tags to proceed with, it is important to determine the logistics of the sire. If the site is very dynamic and involves moving materials frequently around the site, it may be in the best interest of the team to deploy active RFID tags with GPS capabilities. This eliminates the possibility of not being able to find critical materials and having to reproduce the desired items. IF the materials are to be located in the same spot upon arrival, it may be best to utilize barcodes or passive tags, since the cost of these tags are much cheaper.

For the case of this project, the intended purpose of applying tags to the curtain wall modules, and mechanical penthouse equipment is solely for tracking capabilities and not data storage.

Hardware

The next item of consideration is the hardware to utilize on the project. There are a number of different potential scanning methods, but the use of the iPad along with a scanner is a desired choice. Due to the recent decline in the price of the iPad, its use is being adopted throughout the industry with one example being Turner. Turner has used Vela systems software in combination with the iPad for project management purposes on-site.

Along with the iPad, Opticon's latest scanners have made material scanning easier than ever. The scanners have been reduced in size to make their accessibility and transportation incredibly favorable. Opticon has even developed a Bluetooth scanner, so that the scanning process can take place hands free. The cost attached to the recommended Bluetooth scanner is around $250, slightly expensive but its use is seen as incredibly advantageous by freeing up the hands of the individual responsible for performing the material scanning on-site.

Software

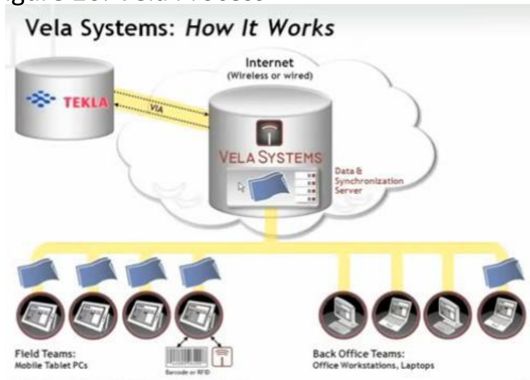
One of the most critical items to establish is the type of material tracking software to utilize on the project. Currently there is a number of software on the market, including Latista and LocateWare but the most prominent and commonly utilized is Vela System now known as Autodesk BIM 360 Field. Due to BIM 360 growing versatility and its use on the project for quality control, documentation, and punch list items, this software was chosen to investigate further.

Figure 25: Vela Software

Autodesk acquired Vela Systems which was a company that specialized in field software, which in collaboration with tablet PCs had the capability of improving and expediting field processes. Although its capacity to manage and track materials is the primary focus of this analysis, their software has the ability to perform a number of other tasks, including composing field reports, work lists, safety inspections, punch lists, schedule updates, BIM model referencing, and documentation reviews.

BIM 360 operates through a webserver, so the database can be accessed in any location that has internet available. Regarding material tracking, the material tags are scanned using the tag reader and is then wirelessly sent to the iPad where it is registered by BIM 360 systems. The information is then synced to the BIM 360 network by entering a Wi-Fi zone or through the use of the BIM 360's mobile program, which allows updates anywhere using 4G wireless internets. Once the information has been updated, any computer with a login name can access the information via the internet.

Figure 26: Vela Process



In addition to managing the materials through BIM 360, the items can be tracked through collaboration with BIM technology, a feature within BIM 360 called BIM 360 Glue. Currently, NavisWorks and Tekla are the two most utilized 4D modeling software on the market. The project utilizes NavisWorks for constructability issues, but with the addition of the material tracking system the program can serve as a 4D indicator. The curtain wall modules and equipment can be identified in the model and assigned a color, so that at any given time an individual could simply open the model and know where each item is currently located.

The project currently uses BIM 360 Field for quality purposes, safety, and access to plans and drawings, but did not get involved with the material tracking capabilities within the software. The project team utilizes a project fee license for the BIM 360 Field for the duration of the project which roughly cost $11,950. The license allows unlimited users to access the program. The project team has two members apart of the team that is familiar with BIM 360 Field, so this eliminated training costs. Overall Turner invested roughly $13,000 for the use of BIM 360 on the project. To add BIM 360 Glue, it would cost an additional $4,000 plus $1,500 for services.

The last piece of software critical for implementation is the barcoding software. Since the barcodes were found to be the more appropriate tagging alternative, software is needed to print the barcodes. Using the Bartender software allows for a cheap and flexible product for the project team. Barcodes can be printed for materials, equipment, tools, or even restrict access in certain areas. The Bartender bar coding software can be purchased online for $250 and is a one-time cost, which can be later used on future projects.

Implementation

Every project is different, and attempting to implement a successful strategy from another project may not be the right plan. It is important to define what materials are within the scope of work. Often, items are neglected by either the supplier, installer, or a third part because the scope of work was not defined adequately. For the case of this project, the curtain wall modules, and mechanical penthouse equipment will be analyzed due to their prefabrication and impact on the schedule.

The materials will be tracked from the beginning of manufacturing up until installation on site. It is important to decide which party is responsible for tagging the materials. The best solution is for Benson industries and the manufactures for the mechanical equipment to tag each item using unassociated tags and then scan each item upon completion, so that each item is linked to an identification number in BIM 360. It is absolutely critical to establish this work relationship upfront and in writing in the form of a contract, so that legal responsibility can be mitigated properly by the project team.

Another major item to decide is the scanning procedures for the materials. The process begins at the manufacturing facilities where the curtain wall modules are tagged upon creation. It is here that the modules are scanned for the first time. Next the tags are moved and prepared to be shipped. Prior to shipment, the modules are inspected for defects and if they are satisfactory, the modules are scanned for the second time. This is when Turner can start to prepare for deliveries by controlling traffic, and clearing a path for the delivery. The third scan takes place as the modules are removed from the trucks and placed on their given floor, and the final scan takes place when the module is to be erected.

Results

In order to combat many of the problems the construction industry faces in terms of material management, implementing material tracking technology can act as viable solution. The project consists of a number of long lead-time items that are manufactured off-site and heavily influence the project schedule. Tracking systems target detrimental information gaps at the planning, inventory, monitoring, and maintenance steps.

The cost of implementing material tracking systems was compiled between the current system used on the project, which used and unlimited amount of users, but BIM 360 Glue and the tracking software was not used, and the proposed system with that includes the BIM 360 Glue. The table below shows details the cost of both systems.

As seen in Table 18, an additional cost of $6,300 would be incurred if this system was implemented. This is a relatively small number for a system that increases coordination and can reduce potential schedule delays.

Table 18: Cost to Implement Material Tracking

Cost to Implement Material Tracking			
Item	**Existing System**	**Proposed System**	**Additional Cost**
Vela			
System	$ 11,950.00	$ 11,950.00	$ -
Base Services	$ 550.00	$ 550.00	$ -
BIM 360 Glue	$ -	$ 4,000.00	$ 4,000.00
Base Services	$ -	$ 1,500.00	$ 1,500.00
iPad	$ 500.00	$ 500.00	$ -
Opticon Scanner	$ -	$ 250.00	$ 250.00
Bartender	$ -	$ 250.00	$ 250.00
Barcodes	$ -	$ 300.00	$ 300.00
Total	$ -	$ 19,300.00	$ 6,300.00

Conclusion & Recommendation

Overall material tracking can increase overall coordination for a project, and prevent any delays within the schedule. Vela systems and other competitors are leading the way towards minimizing these issues. After conducting this analysis, I would recommend the use of this system on this project due to the various prefabricated items, and the site restrictions for deliveries.

Final Summary

Over the course of the academic year, this project was thoroughly analyzed to identify potential areas of design and construction has the opportunity to enhance the project. After carefully analyzing the project, four areas were chosen to be investigates. This report discusses the opportunities, implementation strategies, and results enacting four main research topics: Self-Climbing Formwork, implementation of Photovoltaic Curtain Wall, implementation of short interval production schedules, and integration of material tracking technologies.

Analysis #1: Guided Formwork to Self-Climbing Formwork

This first analysis looked into using a different formwork system for the construction of the concrete core of the building in order to decrease the schedule, and increase safety on the project. It was found that the Super Climber SCP manufactured by Doka, was a sufficient formwork system to implement on the project. With the formwork system able to be lifted all at once, it allowed for the installation of rebar and the pouring of the concrete to begin sooner. Overall it was found that the project could have saved 30 working days and save $1,530,878 off the General Conditions because of the decreased schedule.

Analysis #2: Implementation of Photovoltaic Curtainwall

This second analysis looked into adding value to the curtain wall system used on the project by replacing the existing glass with photovoltaic glass. Through a solar study it was found that implanting the glass based on the position of the building could add value to the owner and the building tenants by decreasing the demand load of the building. This resulted in lowering the electric bill by $1000 annually. Along with this the new curtain wall was able to considered energy property, allowing the owner to use the curtain wall as a deduction off of their taxable income based on a private letter ruling by the IRS and various energy tax benefits. Through this tax benefit, the payback period significantly shortened to two years after the initial installation.

Analysis #3: Implementation of SIPS

This third analysis aimed to shorten the concrete schedule even further by breaking the durations of each activity down even further to either the minute or hour. The purpose of this was for the benefit of the project team and the subcontractors, allowing them to be able to keep on track of the schedule and be responsible for getting the work done at a certain time. After increasing the crew size for the installation of rebar, the schedule was decreased by 30 working days, but the general conditions increased for this portion of the project. Although the cost increased, it is assumed that the activities following the concrete core can begin sooner, thus decreasing the overall schedule and overall cost even further.

Analysis #4: Integration of Material Tracking Technologies

The fourth analysis looked to provide better coordination for the deliveries of the curtain wall panels. Due to the site location, deliveries were delayed due to traffic and poor coordination. After researching the influence of material tracking on past and existing projects, it was found to that this technology should be implemented. An additional cost of $6,300 is believed to be a minimal cost for increased coordination and the potential to not have any delays in delieveries.

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