Rendering courtesy of Gensler

# Memorial Vista

## A North Virginia Office Building

# Final Report

William J. Gamble | 5th Year – Construction Option | April 9th, 2014

## Executive Summary

Over the course of the 2013 and 2014 academic year, Memorial Vista was analyzed to identify areas in which alternative solutions in either construction or design would enhance the project's goal of shortening the schedule. These analyses were brought forth after an unforeseen utility relocation extended the original base building completion date 68 work days. Through feedback from the project team, independent research, and advisor meetings, three major areas were chosen for additional analysis. The following report presents the three analyses as part of the Architectural Engineering senior thesis project at the Pennsylvania State University. It is important to note that the purpose of this thesis and analysis is strictly educational and is not intended to critique the project or team in any way.

**Analysis 1 – SIPS Scheduling Applied to the Building's Façade**

Memorial Vista has a façade that is made up of glazing, precast concrete panels, and metal paneling. All of these elements are bolted or welded directly to the concrete structure upon installation after they have been properly framed. For this analysis, the façade will be looked at to produce the most efficient installation of the materials that make up the façade. By implementing SIPS, the schedule will be reduced in its overall duration for enclosing the building, which in turn would reduce the duration of the entire project schedule. In the end, the analysis will yield a savings of 33 days if implemented, along with a general conditions cost savings of 2%.

**Analysis 2 – Prefabrication and Study of Photovoltaic Windows**

For this analysis, the installation of the windows will be studied even further. This building is made up of 65,558 square feet of glazing, where the possibility of prefabrication and modularization of the glass could be done to allow for a quicker installation time. Instead of hanging one window at a time, multiple window systems could be manufactured and then lifted into place to quickly attach to the structure. The result was that 10 days were saved in the prefabrication process alone on top of the 33 days saved from Analysis I. To potentially allow for more incentive of this analysis for the owner, the south façade of the building was also fitted out with photovoltaic glazing. In the end, the pay off period would be just under 24 years with only a 1% savings on the annual bill, which leads to that part of the analysis to be turned down.

**Analysis 3 – Implementation of an Automated Parking Garage**

The final analysis looks at the parking garage that was designed. The owner asked that the contractor excavate to the lowest foundation level across the entire 4.7 acre site looking for contaminated soil. This is extremely time intensive, where if an in-situ electrical thermal treatment was completed, time may have the potential to be saved. The cost will be increased 14 to 24%, but the time saved may be well worth the expense. To further reduce the schedule, an alternative to a conventional ramp style parking garage will be studied. The idea of implementing an automated parking garage will reduce the depth of excavation both horizontally and vertically. In the end, the goal of reducing the schedule should be accomplished with the potential for a garage with the same number of spaced for 40% of the overall cost.

## Acknowledgments


### Academic Acknowledgements:

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*Kevin Parfitt – Thesis Instructor*
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*Bill Moyer – Davis Executive Vice President*
*Patrick Hartford – Harmon Inc. Estimator*
*Fred Gorove – Unitronics Parking Development Assistant*
*PACE Industry Members*
*Family and Friends*

# Table of Contents

# MEMORIAL VISTA

## // A North Virginia Office Building

### Project Info

**Function** // Office Building
**Size** // 322,725 Gross S.F.
**Building Height** // 5 Stories above grade on North Wing
// 6 Stories above grade on South Wing
// 2 Underground levels (parking)
**Dates of Construction** // April 2011—October 2013
**Overall Project Cost** // $78.5 Million
**Project Delivery Method** // CM at Risk w/ GMP

### Structural

**Structure Composition** // Concrete
**Method** // Flat Plate Slabs with drop panels at columns
// Post tensioning above Lobby & Multipurpose Space
**Formwork** // Peri SKYDECK panels
**Concrete Placement** // Crane and Bucket & Pump truck

### Mechanical

**System** // Water to Air system
// 2 AHU's per floor branching to VAV units
// 2 Closed loops—1 for condenser water & 1 for chilled water
**Components** // 2 Cooling Towers, 2 Chillers, & 1 Heat Exchanger
**Fire Safety** // CPCV piping and wet standpipes in heated spaces
// Dry standpipes in unheated spaces (garage)

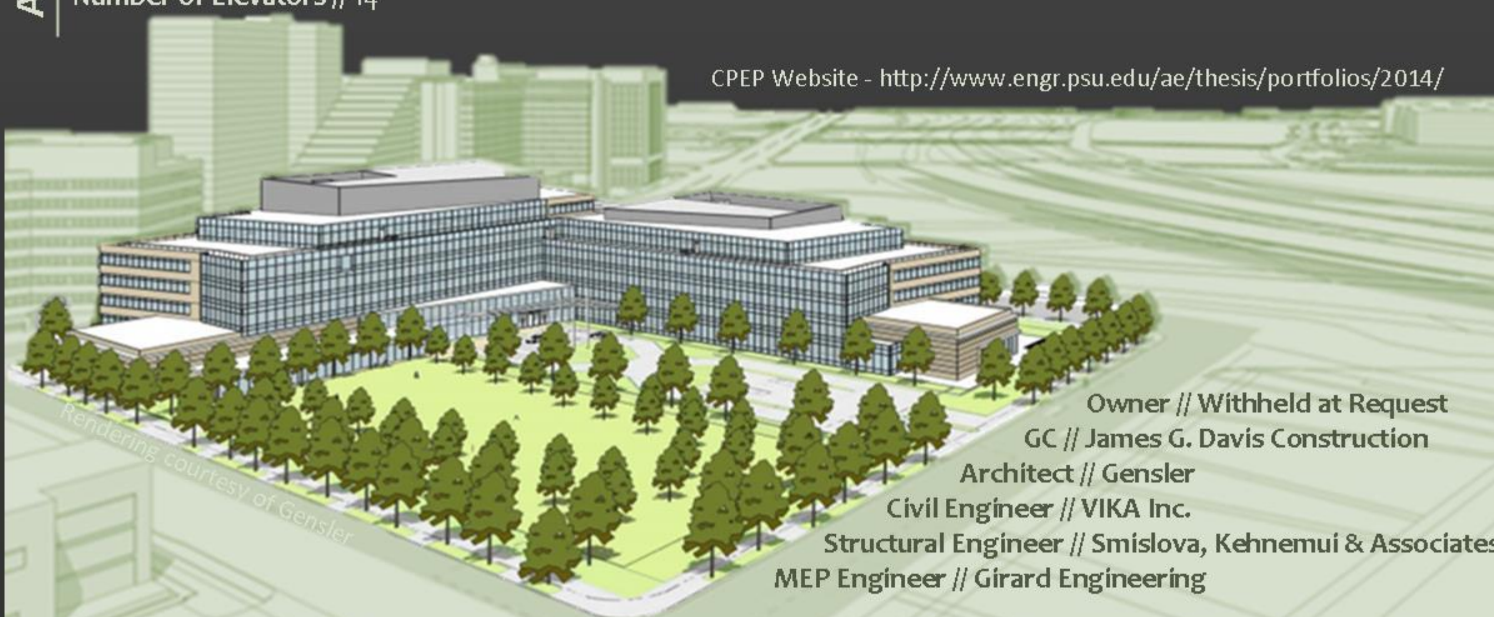
### Electrical

**System** // 3 transformers at 3750 kVA to 3 4000 A switchboards in Garage
// Bus-ways run feeders to panel boards on each floor
// 2 panel boars on each floor (1 in each wing)
**Voltage Needed** // 208 / 120 V
**Emergency Back-up** // ATS puts building on battery banks for short term
// Diesel generator then powers 2500 A emergency distribution panel to allow 100A fire pump, 250 A life safety loads, and 2500A stand by loads to continue to run

### Architecture

**Façade** // 7 different types of Glazing, precast concrete panels, & metal paneling
**Roof System** // Pavers, fluid- applied liquid membrane topped with stone, & some rooftop planters
**Sustainability** // LEED Gold - targeted to achieve 60 points
**Design** // Core and Shell - Interior fit out will be complete after base build
**Priorities** // Quality and Security
**Number of Elevators** // 14

CPEP Website - http://www.engr.psu.edu/ae/thesis/portfolios/2014/




**Owner** // Withheld at Request
**GC** // James G. Davis Construction
**Architect** // Gensler
**Civil Engineer** // VIKA Inc.
**Structural Engineer** // Smislova, Kehnemui & Associates
**MEP Engineer** // Girard Engineering

## Project Background

### Construction Overview

Memorial Vista is unique in the fact that it is a $78.5 million office building located on a 4.7-acre plot of land in northern Virginia that will house a leading aviation tenant in the near future as the main east coast office. The office building itself is split into two wings; those being the North and South, to form a 'V' shaped building as seen below in figure 1. The South wing is six stories above grade, where the North is only five stories. This is due to air restrictions in the area, where the North wing falls under more stringent building height restrictions. Memorial Vista's primary use is that of an office building, where building's root purpose is to combine two previously occupied offices into one functional space for the company. The building will be constructed to the limit of the core and shell phase, and then the interior job will be bid out upon the completion of the shell.

The price is rather on the higher end for an average office building that is 322,725 gross square feet, due to the owner's desires in how the building will appear, the unique high end finishes that the building will be accompanied, and the large security and data package that a building in this location is accompanied with. The owner made it clear that the main concerns throughout the construction of Memorial Vista were both the schedule and the quality, but also strived to make the building safer and extremely secure upon completion.

The general contractor brought on board was James G. Davis Construction through a CM at risk with a guaranteed maximum price contract. The core and shell of the building resulted in a schedule that began in November of 2011 when mobilization of the site began to the substantial final completion date in early January of 2014. Upon the completion of the core and shell, a bid will be accepted in mid-January of 2014 for the interior phase of the construction process before the tenant actually occupies the space.

Figure 1 – Rendering of Memorial Vista courtesy of Gensler

## Existing Conditions

Based on the fact that Memorial Vista is located in northern Virginia, the present conditions and existing utilities prior to construction are extremely complex in nature. Utilities are intertwined below grade along the property border, and beneath the road that runs directly through the future foundation of the north wing of the building. Since this road just north of the buildings is to be demolished for the construction process, the utilities that lie below it must also be relocated. This complex web of utilities both through and around the site can be seen in figure 2, below.

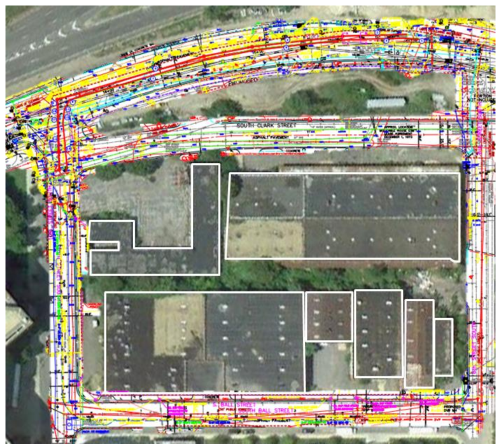


Figure 2 – Original Site with Existing Utility Overlay

Surrounding the construction site is and office building in the southwest corner of the site, and on the southeast side of the site is an apartment, a self-storage facility, and a gym. These locations are accessed daily and the roadways were required to remain accessible. The figure below shows the vehicular and pedestrian traffic that must remain accessible throughout the construction process.

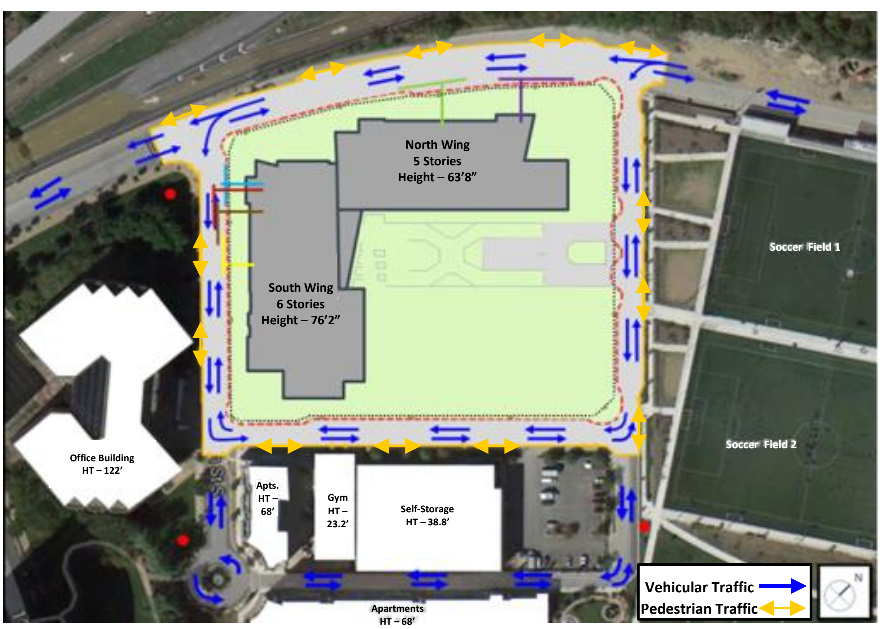



Figure 3 – Neighboring Structures, along with Vehicular & Pedestrian Circulation Plan

## Building Systems Overview

### Demolition

The original site of this project can be seen on the previous page, in figure 2. Here, it will be seen that there were seven buildings that accompanied the land that would one day make up Memorial Vista. These seven building are made up of industrial warehouse structures and a motel. Upon inspection, it was found that the buildings were constructed with asbestos materials and abatement would be a necessary procedure for demolition to be completed. Davis Construction did take this abatement process into account when formatting the schedule and creating an estimate, so no major schedule delays or monetary problems arose during this time frame.

### Excavation

Memorial Vista is inimitable due to the fact that during the excavation phase of the project, the owner had the special request that the entire site be excavated to the lowest footer depth. The owner's reasoning behind such a strenuous process was to both ensure the foundation of a future wing would be possible if the company expanded and to ensure that the soil was not contaminated. During this soil investigation process, very few amounts of contamination were found, but they were indeed found. During the excavation process, the contaminated soil was disposed of off of the site as it was found and the land was filled in where it needed to be done so. During the construction process temporary wood walers were used in two locations of the building - those being the level one and two of the underground parking garage in the south wing. This was done to safely hold back the walls of soil during excavation. To prevent water from ponding during the excavation process, two pumps were used to expel water out of the lowest depths. Figure 4, right, shows the excavation of the final portion of the site that does not make up the buildings foundation or parking garage, but rather the future expansion wing. This step was sequenced to take place and the structure was being built on the other portion of the land to reduce the overall duration of the project schedule.

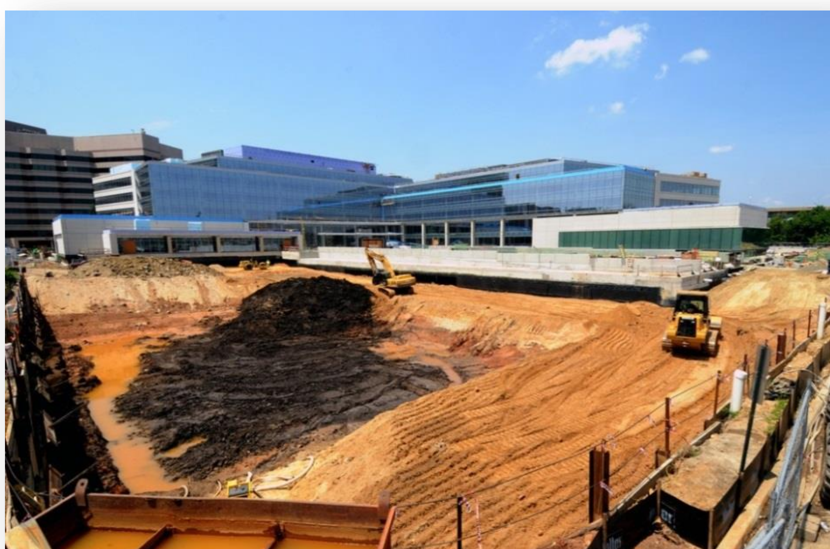


Figure 4 – Remaining Excavation of Memorial Vistas Site

**Structure**

This building is constructed of concrete to ensure more floors can be offered with a smaller building height as compared to a steel structure. This is due to the height restrictions of the area, and the ability to maximize retainable space. The slabs of this structure are cast-in-place concrete with rebar bracing. Post tensioning of the concrete was done above the Multipurpose Space and Lobby to allow longer spans of the slab with fewer columns. The actual superstructure was done with Peri SKYDECK panel slab formwork. This is composed of dropheads that temporarily support the aluminum formwork above. After the concrete has cured, the drophead is released 60 millimeters and moved to the next location. By using this SKYDECK process, the formwork process becomes easy and quick and the forms can be reused as the building goes up in elevation. To pour the actual concrete, two tower cranes were used on the job with the help of concrete pump trucks. One crane had a hook height of 102', and the other 116'. The smaller tower crane was a Potain MDT 412 and was placed in the center of the underground parking garage ramp, where the larger one was a Pecco SK 400 and was placed on the perimeter of the building of the south wing.

**Architecture**

The building itself is primarily cloaked in glass curtain walls, point supported glass, and strip windows on both wings of the structure along with precast concrete panels encasing the strip windows. Directly below the building is a two story parking garage that can be entered from the courtyard of the building. As one would enter the building, crossing through the courtyard on the south side of the building, one would be greeted by a mammoth canopy composed of aluminum composite steel panels and laminated glass. Once inside of the building's lobby, the tenants will see floors that consist of marble, and there will be a monumental stair case as the focal point of the gathering space. A breakdown of some of the main focus areas and materials of the façade can be seen in figures 5 and 6 to the right.

Figure 5 – South Entrance Façade Courtesy of Gensler

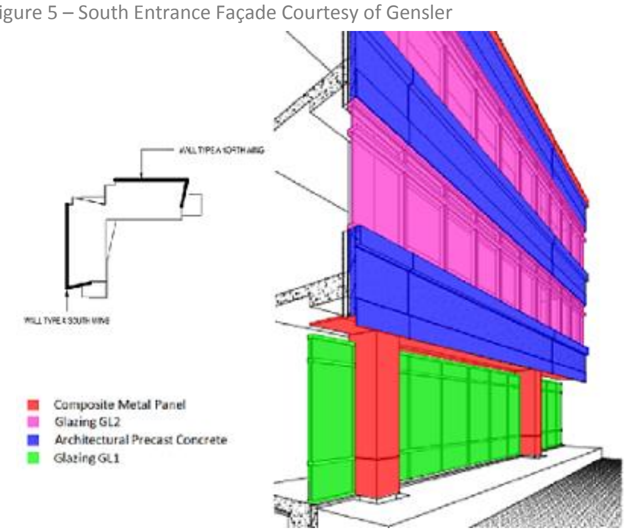


Figure 6 – Main Façade Layout for Building Wings Courtesy of Gensler

**Mechanical System**

This office building consists of two air handling units per floor in two separate mechanical rooms, where one unit serves each wing of the building. These AHU's then feed the variable air volume units throughout the individual floors in the ceiling plenum space. These air handling units can carry an average demand load between 20,000 and 30,000 CFM to their requested locations, based on the demand of the occupant of the building. Along with the air handling units, Memorial Vista is accompanied with two cooling towers, two chillers, three chilled water pumps, three condenser water pumps, and a heat exchanger on the Penthouse level of the building. This equipment makes a closed loop system with 2 separate loops for heating and cooling. One loop is comprised of the cooling tower and condenser water loop and the other with the chilled water loop and the air handling units on each individual level of the building.

**Electrical System**

Memorial Vista is composed of three transformers on the first floor of the parking garage for this building at 3750 kVA each. These transformers then run to three switchboards at 4000 Amps respectively. Bus-ways are then used to bring current to the feeders on each floor where they meet the panel boards. There are two panel boards per floor (one in each wing of the building). Within each electrical/ mechanical closet on the north and south wing of the building of every floor is also a transformer to step down the voltage from 480/277 V to 208/120 V.

In the case of an emergency, there is a 2500 A emergency distribution panel that is accessed through the use of automatic transfer switches. When the power goes out, the building automatically switches over to battery units until the diesel generator kicks on. The generator is a 480 / 277 V, 3 Phase Breaker that supplies 2500 A emergency distribution panel that allows for a 100 A fire pump, 250 A life safety loads, and 2500 A for stand by loads to run during emergencies. This building is primarily composed of recessed florescent lighting, where in public spaces and in the garage, occupancy sensory will be used to boost the efficiency of the building.

**Fire Protection**

The fire suppression system within the building is a wet standpipe system with CPCV piping to all levels of the building including the equipment rooms, elevator equipment rooms, and electrical rooms. This system will be an automatic system with voice activated fire alarms upon the indication of smoke within the building. Fire dampers are used where the ductwork penetrated the walls to ensure that smoke does not permeate to spaces that are not originally affected by the smoke. Two hour ratings are mandatory for most assemblies including shafts and the floors of the building. Within the garage, trash rooms, and other unheated areas will be a dry standpipe system to prevent the pipes from freezing in the winter. These pipes in the spaces with dry pipe systems are comprised of cast iron piping to ensure longevity and strength.

**Transportation**
Within the structure of Memorial Vista is 14 elevators that access various floors throughout the buildings different elevations. This number of elevators is based off of a request that the owner had in the initial design phase, where 12 of the elevators are for the use of all employees and the remaining 2 elevators are for the executive suites located on the top floors of the building.

**Telecommunications**
This building will be an office building in Northern Virginia. Because of the work that will be done here and because of the owner's request, the specifications regarding the telecommunications systems, safety systems, security systems, and data will be withheld. What can be stated is the data and security package implemented into this building exceeds the standard for an average office building.

## LEED Certification

This Office Building is aiming for LEED Gold with 60 points as a target. To do this, the construction process has stringently followed LEED methods to be more environmentally friendly, but all the while trying to reduce the cost of the project. This value engineering can be found anywhere from materials that do not contain CFC's to getting material for the construction process within 500 miles of the site. To help the building thrive when the construction process has been completed, and is occupied by tenants, the building has been equipped with environmentally friendly aspects such as rain water harvesting drums and planters on the roof. The rain water harvesting equipment can be used in a wide variety of common water intensive tasks such as irrigating the buildings landscape to the use of the water in restrooms. Further looking at the environmental impact of the buildings footprint, the design team decided to implement rooftop planters. These roof planters will create pleasing spaces on the roof as if it were a courtyard, but will also reduce the heat island effect on the structure. These planters can be seen in figure 7 below.


Figure 7 - Rendering courtesy of Gensler to show rooftop planters

# Analysis I – SIPS Scheduling Applied to the Building's Façade

## Problem Identification

The original site and the structures that accompany the area can be seen in figure 8. These six yellow industrial buildings and single orange motel are to be demolished to create a plot of land that Memorial Vista can lay its foundation. The red outline in the figure below is the property outline that Memorial Vista will be a part of. Here, it becomes apparent that the existing road that runs thought the site will have to be removed to allow the building foundation to be laid, due to the heavy congestion of utilities shown below the surface.

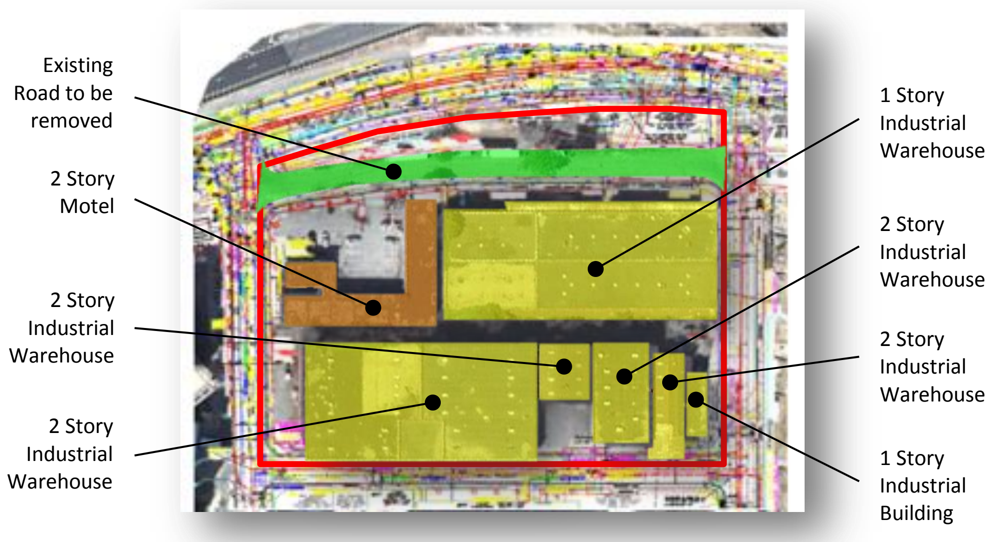



Figure 8 – Original Site Courtesy of Google Maps, with Utility Plan overlay

Knowing that the road will require utility relocations, the Davis team and excavation contractor assembled site utility plans from previous years in the neighboring locations to see what was below the surface. To check the accuracy of these utility drawings, spot checks were performed in various locations with a backhoe. After numerous checks were performed around the site, it was apparent that the drawings had utilities miss marked or simply not shown. In the end, an estimate was put together to determine the cost and duration to relocate the densely packed utilities below the green highlighted road

As the rerouting of the utilities for this road took place, tasks were being performed fairly closely to the duration of the line items specifically called out in the project schedule. This held true until a large sewer main was discovered below the road that had not been shown on any utility drawings. Shortly thereafter, it was discovered that there was no redundancy in the remote area for this specific main. The result would be that the team had to remove the gravity and forced main going through the site and route it to new lines installed outside of the project's perimeter. This forced the team to perform a complicated tie-in and swap process that cost more money than budgeted and pushed the schedule back by almost two months.

## Analysis Goals

After reviewing the problem, is was apparent that the schedule was slipping significantly from the original date that was told to the owner. To get the project back on schedule, the analysis that will be completed must somehow accelerate the project schedule to get the project closer to the original completion date promised in the projected schedule during the early stages of the project. This process of constructing the building in a faster manner must provide the same quality work within a safe atmosphere, but the overall product must be produced more efficiently. To do this an alternate phasing and scheduling plan will be produced for the building's façade, though the use of Short Interval Production scheduling (SIPS). The façade is specifically targeted in this process due to the apparent redundancy in the two wings of the building. A closer look at what floors have the potential to undergo the SIPS process will be completed in this report, as well as the overall durations to perform the analysis on the façade, and the final cost savings. In the end, it is believed that a total of around three to four days can be saved per floor if the building enclosure is installed efficiently and in a sequential and logical method.

## Process

*Original Study*

Short Interval Production Scheduling, or SIPS, is used in the construction industry when work is done in similar zones with continuous work. The procedure allows a formatted method to organize construction work by breaking an operation into detailed repeatable activities, as opposed to breaking the project into operations. The key to this type of scheduling operation is that the work must be repetitive in nature, to allow a "parade of trades" though each zone (Horman 2003). As the trades move from one zone to the next, the crews become more proficient, resulting in the project schedule being fast-tracked to allow the completion date to advance. The key points for a successful short interval production schedule analysis is that only one specific operation is analyzed, a much higher level of detail is needed, and that the personal involvement and commitment of everyone contributing to the operation must be involved in the development stages (Wang 2006).

This SIPS application was applied to both the MGM Grand Hotel Project in Las Vegas, Nevada and The Pentagon Building in Arlington, Virginia. The MGM Grand proceeded to use SIPS to complete the structure of the building within a nine month schedule to meet the owner's requirements and result in a profit for the job. Without the use of SIPS, neither the schedule or profit aspect could have been reached. The Pentagon also applies this scheduling process to accelerate the interior fit-out components, mechanical, electrical, and fire protection systems. Each of these projects used short interval production scheduling to formulate a schedule to keep the project on a stringent path, and in the end, both projects were completed on time and under their budget. Based on these studies, it is believed that a similar short interval production schedule can be executed on the Memorial Vista project, where a study of the building's enclosure could result in an accelerated schedule with the same amount of quality as a result.

*Analysis of the Original Schedule*

Prior to the study of the building's façade in order to perform a SIPS analysis, the actual project schedule had to be analyzed and compared to the projected schedule from the beginning stages of the project. To clearly see the differences between the projected schedule prior to the start of construction and the actual project schedule, the dates and durations were condensed in a graphical manner within Microsoft Excel. The two schedules were then overlaid to compare the durations of each line item to see how much they altered from one another. The main goal was to determine the overall difference in project length when looking at the projected schedule and the actual schedule. These Excel spread sheets can be seen in Appendix A in the back of the report. The actual break down of the main activities can be seen in table 1 below. Here, it should be noted that the utility relocation process was the first activity that severely altered the time frame between the actual schedule and the initial projected schedule.

Table 1 – Actual and Projected Durations on Memorial Vista

| Durations | | | | |
|---|---|---|---|---|
| **Description** | **Projected** | | **Actual** | |
| **PERMITS** | | | | |
| Issue Site Utilities Permit | | 9/30/2011 | | 10/11/2011 |
| Clearing, Grading, & Demo | 9/21/2011 | 11/27/2011 | 10/6/2011 | 2/3/2012 |
| Excavation, Sheeting, & Shoring | 12/20/2011 | 2/16/2012 | 11/29/2011 | 3/16/2012 |
| Footing to Grade | 2/17/2012 | 5/10/2012 | 2/21/2012 | 7/26/2012 |
| Building | 12/7/2011 | 5/24/2012 | 1/17/2012 | 8/2/2012 |
| **CONSTRUCTION** | | | | |
| Mobilization of Site | 11/17/2011 | 12/2/2011 | 11/21/2011 | 1/20/2012 |
| Utility Relocations | 11/28/2011 | 2/1/2012 | 1/16/2012 | 7/27/2012 |
| Demolition of Exisiting Buildings/ Hardscaping | 12/5/2011 | 2/19/2011 | 2/8/2012 | 6/14/2012 |
| Excavation/ Support of Excavation | 3/5/2012 | 7/13/2012 | 5/1/2012 | 9/4/2012 |
| **SOUTH** | | | | |
| Concrete Substructure | 6/13/2012 | 10/16/2012 | 8/30/2012 | 12/11/2012 |
| Concrete Superstructure | 10/24/2012 | 2/25/2013 | 12/6/2012 | 5/1/2013 |
| Façade & Roof | 1/11/2013 | 5/13/2013 | 3/25/2013 | 6/14/2013 |
| Core MEP / Finishes | 5/13/2013 | 8/29/2013 | 5/2/2013 | 10/1/2013 |
| Elevators | 4/22/2013 | 9/25/2013 | 5/8/2013 | 10/15/2013 |
| **NORTH** | | | | |
| Concrete Substructure | 6/28/2012 | 11/14/2012 | 9/6/2012 | 1/29/2013 |
| Concrete Superstructure | 11/15/2012 | 3/7/2013 | 1/18/2013 | 5/3/2013 |
| Façade & Roof | 2/8/2013 | 5/17/2013 | 3/13/2013 | 6/10/2013 |
| Core MEP / Finishes | 5/29/2013 | 9/11/2013 | 4/12/2013 | 10/2/2013 |
| Elevators | 3/8/2013 | 8/15/2013 | 5/10/2013 | 10/16/2013 |
| **LOBBY** | | | | |
| Core MEP / Finishes | 4/2/2013 | 8/5/2013 | 6/17/2013 | 10/2/2013 |
| **SITEWORK / INSPECTIONS** | | | | |
| Sitework | 3/14/2013 | 6/19/2013 | 4/19/2013 | 8/29/2013 |
| Substantial Completion | 6/4/2013 | 8/27/2013 | 7/19/2013 | 10/30/2013 |
| Punchlist | 8/28/2013 | 10/2/2013 | 10/31/2013 | 1/6/2014 |
| Base Building Final Completion | | 10/2/2013 | | 1/6/2014 |

After reviewing the two schedules visually in the Excel document, it was apparent that the two base building final completion dates for the actual and the proposed schedules varied by a total of 68 work days. The projected schedule had a base building final completion date set in mid-October of 2013, but the actual date the base building construction was set to be completed was early January of 2014. With a 68 work day difference, this meant that the project would be completed nearly 14 work weeks late.

The turn over date for project was crucial, due to the fact once the base building was completed, the interior fit out was to be bid and completed. If the base building construction were to take longer, the interior construction would be delayed and the tenants of the building would have to wait longer than anticipated to occupy the building. The difference in time from the two completion dates can visibly be seen in the overlay of each schedule below in figure 9.

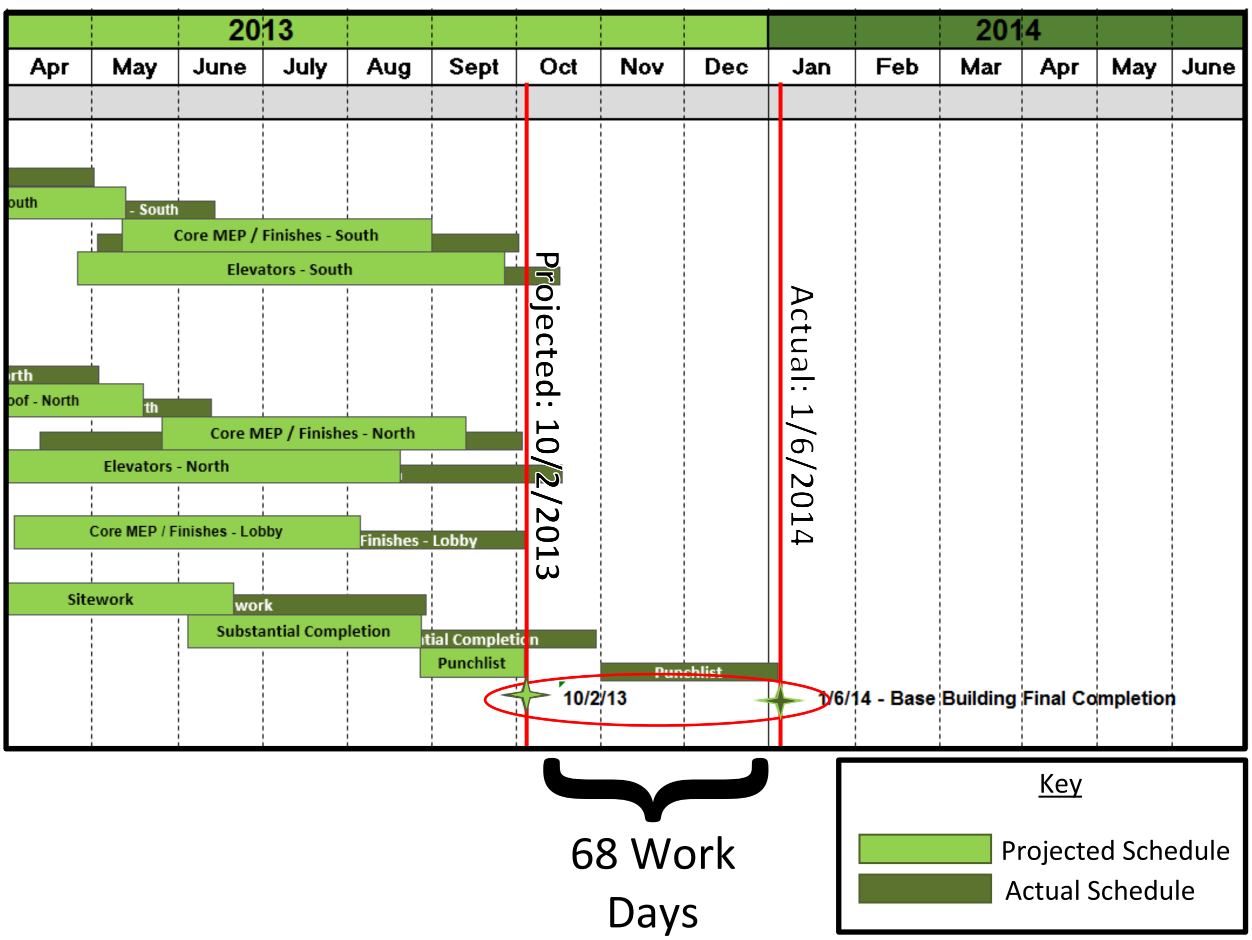



Figure 9 – Visual Representation of the Difference between the Projected and Actual Schedule Final Completion Dates

In the end, it was apparent that something must be done to accelerate the schedule in some fashion to get the job back on track to the original projected completion date of October 2nd, 2013. Although it may not be possible to get all 68 work days back, SIPS will be used to reduce a portion of time after the utility relocation significantly extended the schedule.

*Façade Breakdown*

After reviewing the schedule of both the estimated durations and the actual time it took to complete the project tasks, it was found that SIPS could possibly be implemented somewhere in the building, but in an area that had repeatable activities. The activity must be repeatable to allow a linear flow of work through or across the building, depending on the action that would be undertaken. Knowing that the interior fit out of the project was not in the scope of Davis's contract, the façade was looked at to see if there was any repetition that could be studied to accelerate the assembly of the building's enclosure. All four elevations were meticulously looked at to find whether or not the floors were enclosed in similar materials. The following two figures, figures 10 and 11, show the breakdown of the façade in a color coded format. Each new color represents a different type of enclosure that affixes to the building. Larger visual breakdowns of the façade can be seen in Appendix B towards the end of the report.

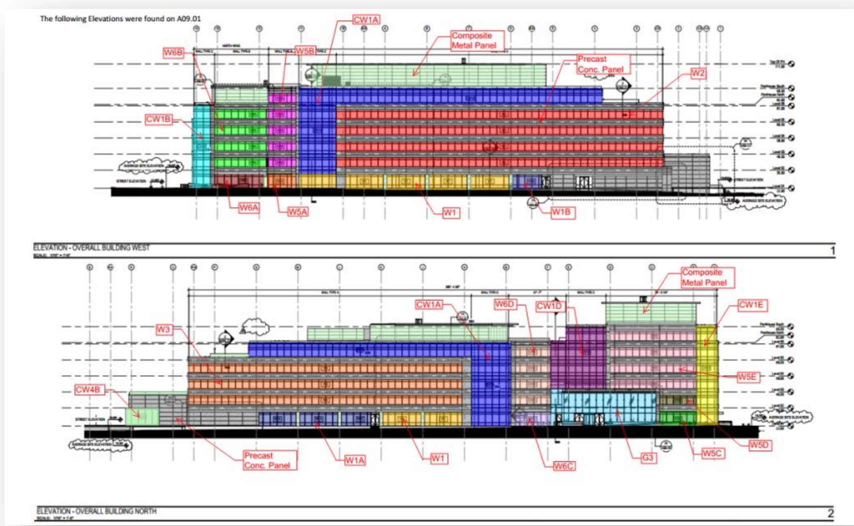



Figure 10 –Façade Material Breakdown of West (Top) and North (Bottom) Elevations from sheet A12.02

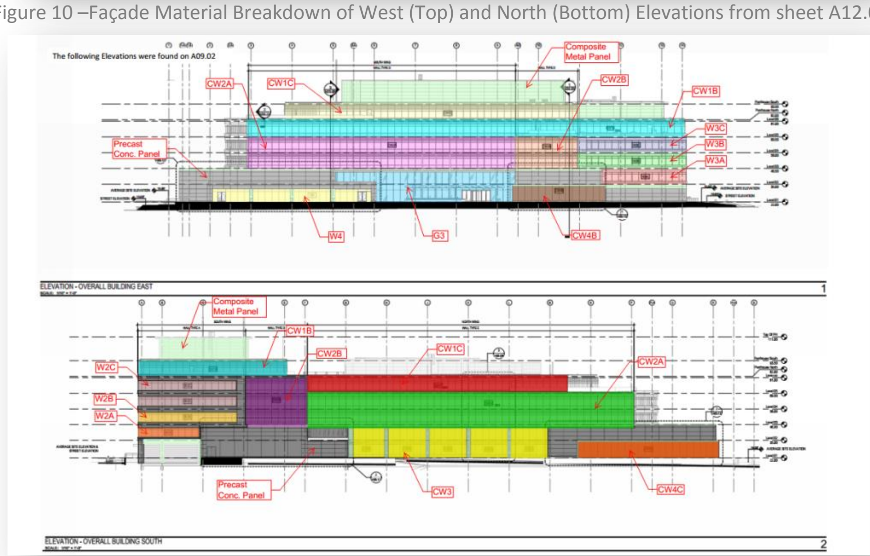



Figure 11 –Façade Material Breakdown of East (Top) and South (Bottom) Elevations from Sheet A12.03

After reviewing the enclosure analysis on the previous page, it is apparent that the first floor varies too much from the make-up of the rest of the building. This is due to the fact that it is oriented with ornate entrances and storefront glass complemented with both concrete and metal panels. Since it varies so significantly from that of the façade of the other floors above it, the floor cannot be considered in this SIPS process of the façade of the building. Where the primary reason that this floor is ruled out on the analysis is due to the fact that the work is simply not repetitive enough.

The other levels that have facades that do not resemble any of the other floors of the building (as a whole) are the sixth floor of the south wing and fifth floor of the north wing. These are both the highest floors of each wing, where the south wing stands 76’ 2” feet above grade at 6 stories tall and the north wing is only 5 stories at 62’ 8” tall. The restrictions in height are a result of air restrictions in the area. The delineation of which wing is north and which is south can be seen in figure 12 below.

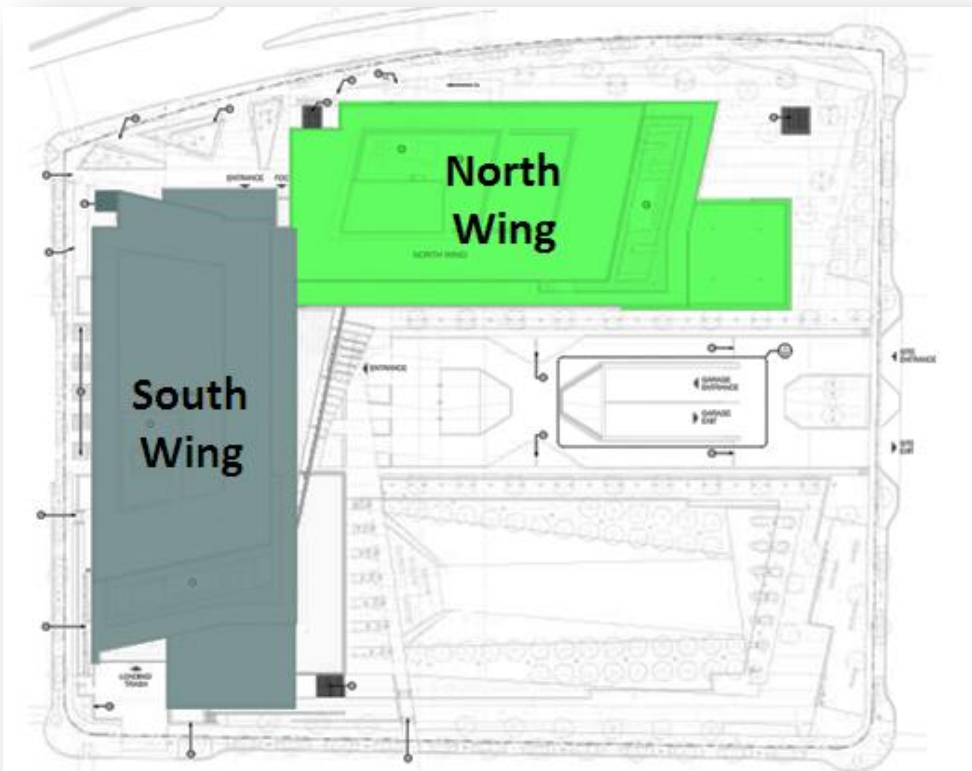



Figure 12 –Depiction of North & South Wing – Drawing Courtesy of Gensler Sheet A1.01

In addition, each of these top floors is known as the executive floors, where the floor plans of each are drastically different than those of the other levels below. That being said, floors two though five of the south wing and floors two though four of the north wing are virtually the same and could benefit immensely if SIPS was applied to the façade structures of these levels. These will be the floors focused on for this analysis.

*Building Zones*

Before looking at breaking the building into zones to complete the short interval production schedule, the layout of the building had to be looked at, along with the logistics of the site. The work for installing the building's enclosure is reliant on numerous things over the duration of a project, but the main dependencies are the labor and equipment needed to complete the façade. This means that the tower cranes for this project must be strategically placed to allow all aspects of the project to be accessible. The façade will need to be installed through the use of these tower cranes, and also through the use of scaffolding. Since scaffolding is not stationary (for the most part) throughout an entire project, then the tower cranes must be placed in such a fashion that the zones associated with the SIPS analysis are easily accessible by the respective tower cranes. It is important to look at the placement of these cranes because they will be used to hoist the façade panels into place. If there was a single crane, the sequencing and building zones would have to be thought out completely different. The horizontal and vertical crane layout of the actual project can be seen below in figures 13 and 14, where it is obvious that each crane can accommodate the separate wings as different zones.

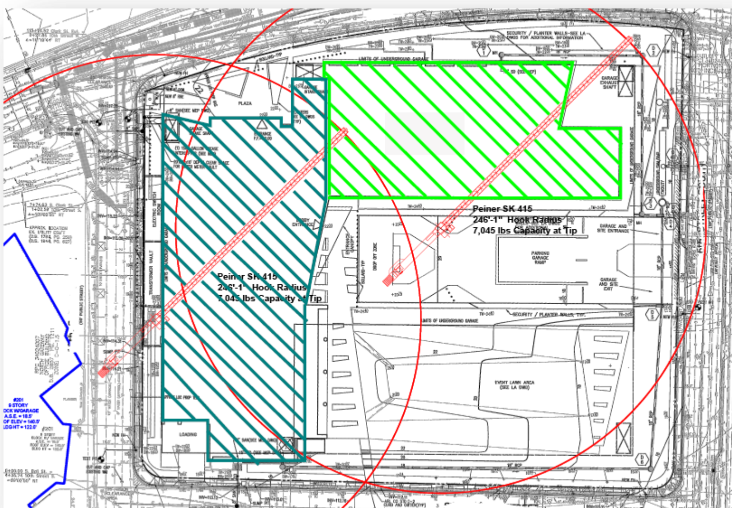



Figure 13 –Horizontal Crane Plan Courtesy of Facchina Construction Company

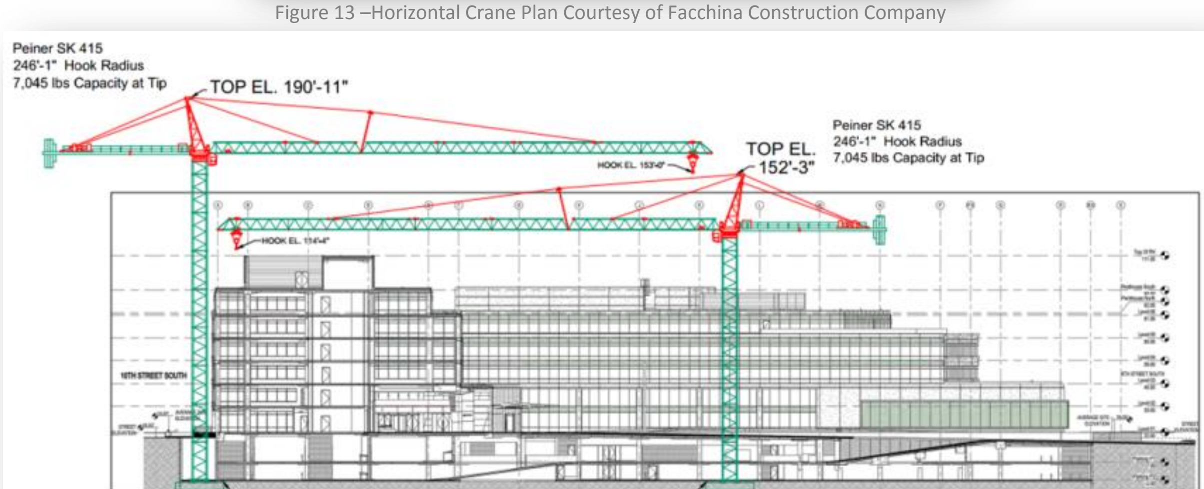



Figure 14 – Vertical Crane Plan Courtesy of Facchina Construction Company

From this, it can be seen that the zones of the building can be broken up into their respective wings due to the fact that each crane is able to access its respectable wing.

Work can then be broken into each floor to keep the work moving. Each floor of each wing will be completed and then the team of workers will move on to the next zone to create a flow of work in a linear scheduling format. By moving the work form one zone to the next as the building is constructed, there is limited down time to ensure an accelerated schedule. The following figure shows the breakdown of the building's zones, where it can be seen that the first zone is in the south wing, the second in the north wing, and then alternation between the two wings as the building goes up. The south wing was chosen first due to the fact that the utility relocation took place in the area of the north wing. By starting in the south wing, the foundation work can be started before the utility relocations are totally completed, where the north win will follow shortly after the south wing is completed and the relocation process is complete.

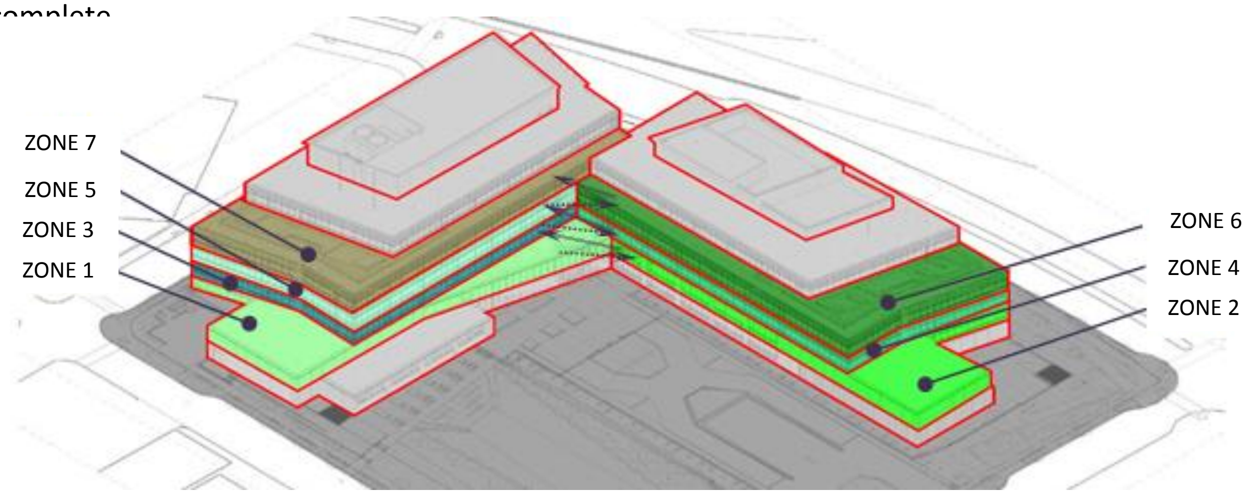



Figure 15 – Building Zones Breakdown – Drawing Courtesy of Gensler

The building areas that are in the green hues are the ones that will be undergoing the short interval production scheduling process, whereas the grey areas (as discussed earlier in the Façade Break down section) are not being studied due to their irregularity and uniqueness. To aid the viewer in distinguishing the floors in the above figure, they have been outlined in red.

After the façade study and zone distinguishing process was completed, it was determined that the third floor of the south wing would be best to study for the SIPS analysis for the building. This was due to the fact that it had a centralized floor plan and façade make-up similar to the other floors that were to be looked at.

The south wing of the third floor was specifically chosen due to the fact it had an average number of window panels when being compared to each of the other zones, and used the typical enclosure components found throughout the building. Once the SIPS analysis would be completed on this floor, the data could be interpolated for the other levels of the south wing and then over to the north wing to determine the overall duration for the façade assembly. The end goal being that the building enclosure would be less than the actual time the activity took.

*Durations*

To find the durations of each activity that takes place to install the facade, the overall duration for each wing had to be found. Figure 16, below, is an excerpt from the actual project schedule that shows the overall duration of each wing.

| Activity ID | Activity Name | Orig Dur | Start | Finish | Total Float |
|---|---|---|---|---|---|
| **Facade** | SOUTH WING | 101 | 02-15-13 | 07-26-13 | 87 |
| | | 101 | 02-15-13 | 07-26-13 | 87 |
| 4200000 | Begin Facade - South | 0 | 02-15-13 | | 101 |
| 4200010 | SOUTH TOWER FACADE SUMMARY | 101 | 02-15-13 | 07-26-13 | 87 |
| 4299000 | Facade Complete - South | 0 | | 07-26-13 | 87 |
| **Facade** | NORTH WING | 66 | 03-14-13 | 06-26-13 | 106 |
| | | 66 | 03-14-13 | 06-26-13 | 106 |
| 5200000 | Begin Facade - North | 0 | 03-14-13 | | 87 |
| 5200010 | NORTH TOWER FACADE SUMMARY | 66 | 03-14-13 | 06-26-13 | 106 |
| 5299000 | Facade Complete - North | 0 | | 06-26-13 | 106 |

Figure 16 – Excerpt of Project Schedule for Façade Durations Courtesy of DAVIS

The schedule that the above figure was taken from did not break the façade installation down into floor by floor sequencing, but rather by the material that was being installed throughout each face of the building. In other words, the activities were broken into line items that were specific to precast panels, glazing, and metal panels that were to attach to specific faces of the building rather than floors. From these line items, the activities were then split into specific levels of installation. This leads to a confusing schedule and miscommunication on when exactly materials had to be on site or when the activities had to be completed on what floor. To remove this misunderstanding, it was determined that the overall durations would be looked at for each wing and then the durations would be broken down by floor. These breakdowns can be seen in the work below.

South Wing = 6 Stories
North Wing = 5 Stories

(101 Work Days) / (6 Stories) = 16.833 Work Days per Floor (South Wing)
(66 Work Days) / (5 Stories) = 13.2 Work Days per Floor (North Wing)

Therefore one floor of the building is to take around 30.033 days. This number was found using the overall duration of each wing and adding them together. In the end, it was believed that duration of the whole façade would be best used to figure out how long each floor took to install the façade system, rather than breaking the components up into their respective orientations and faces, as done so in the actual project schedule. By doing this, the possibility of double counting façade components is nearly eliminated.

The overall reason for obtaining the duration of the building enclosure installation was to see the time frame that SIPS had to come under in order to be a successful analysis.

Since this SIPS analysis is purely focused on the third floor of the south building enclosure, the 16.83 day duration will be the main target. From this value, the rest of the durations will be interpolated out to find the total duration of installation for the building's enclosure systems. For the analysis to be successful, the duration of the south wing of the third floor must be less than this 16.83 time frame.

The next step would be to find the area of the façade that needs to be installed. This will be done to calculate the durations for the installation process. Below is figure 17 showing where the square footage of the building enclosure for the south wing of the third floor is calculated. First the perimeter is found and then multiplied by the height the enclosure component spans to find the square footage of material for this floor around the entire building. The red represents the window glazing; where green is representing the precast concrete panels.

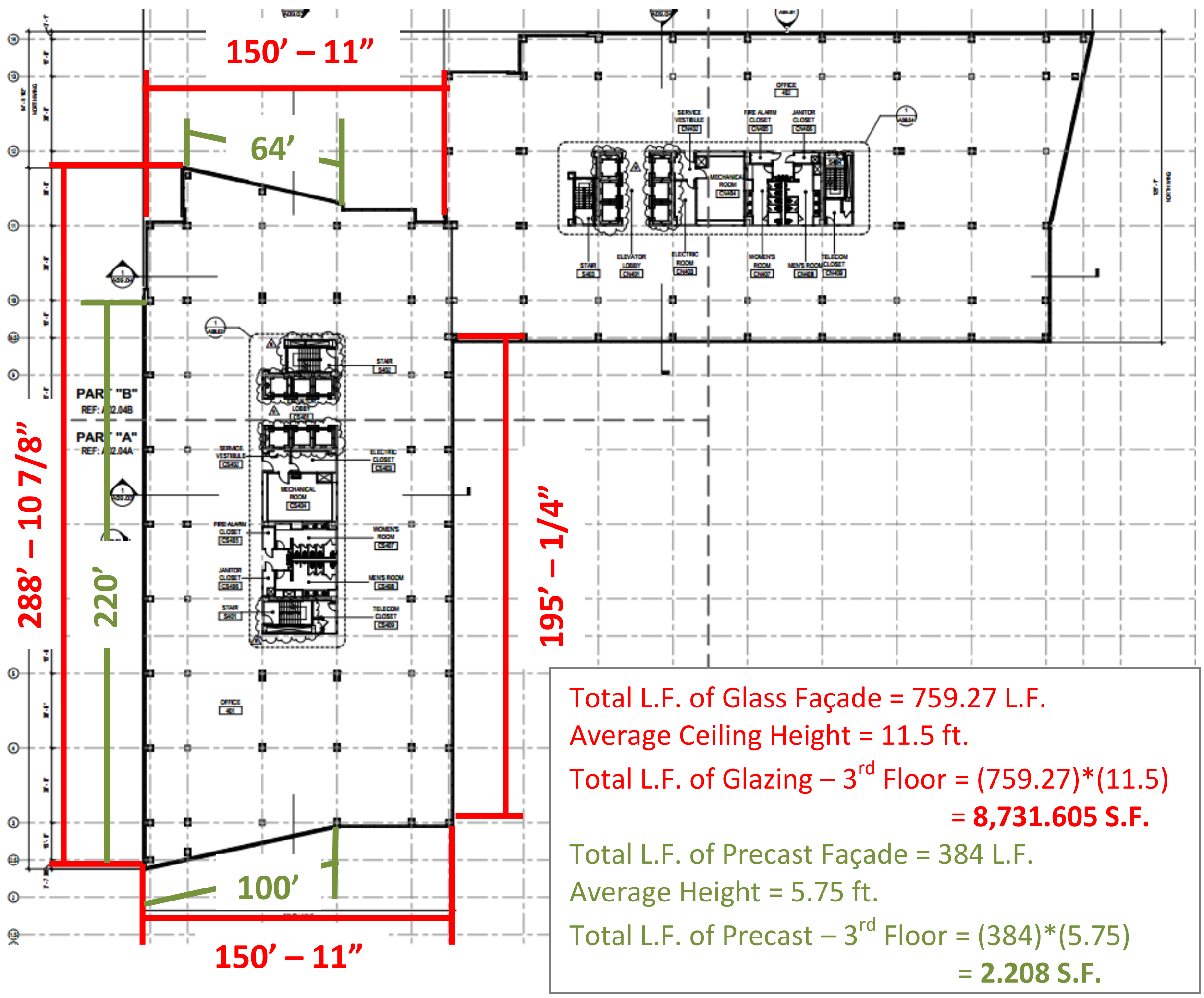



Figure 17 – Square Footage Calculations for South Wing of 3rd Floor

RED = Glazing
(8731.605 S.F.) / 160 = 54.573
Where 160 the Daily Output value from R.S. Means that can be seen in Appendix C
54.573 / 6 hrs. = **9.095 Days/ floor wing**

Note that 6 hours are used as an average work day to take into account two hours of the day for delays, mobilization of scaffolding, and crane hoisting times.

GREEN = Precast Concrete Panels
(2208 S.F.) / 320 = 6.9
Where 320 is the Daily Output value from R.S. Means that can be seen in Appendix C
5.403 / 6 hrs. = **1.15 Days / floor wing**

Note that 6 hours are used as an average work day to take into account two hours of the day for delays, mobilization of scaffolding, and crane hoisting times.

**9.095 + 1.15 = 10.245 days**

Since there are more than likely going to be some form of weather delays or delayed material deliveries, it will be assumed that each floor will be completed in **11 days per floor** [as opposed to 16.833 days/ floor above].

By doing these calculations, it can already be seen that the schedule will be shortened by a little more than 5 days for this level of the south wing alone. It is important to remember that the SIPS analysis will not be applied to all floors, but rather floors two through five of the south wing and floors two through four of the north wing, which was discussed earlier in the report. This results to seven total zones that will be studied in the hope that the schedule is accelerated from the actual durations.

*Façade Components*

In the end, the components of the third floor were counted using Autodesk Quantity Takeoff 2013. The façade can be broken down into 4 main materials – vision glass, spandrel glass, precast concrete panels, and metal panels. The typical vision glass, signified by GL1 in the drawings, and the typical spandrel glass, signified by GL2 in the drawings, is manufactured by Viracon. The precast concrete panels and metal panels are broken up into various increments when they are delivered to the site, depending on their final location on the building. The primary location for the metal paneling is around the storefront on the first floor. A breakdown of the work can be seen below in only the third wing of the south wing of the building.

Gl1 = Typical Vision Glass = 305 Panes
GL2 = Typical Spandrel Glass = 66 Panes
Precast Concrete Panels = 384 L.F. (22 Panels)

This means there are a total of 152 panels around the 3rd floor of the south wing with 393 pieces (excluding frames/mullions).

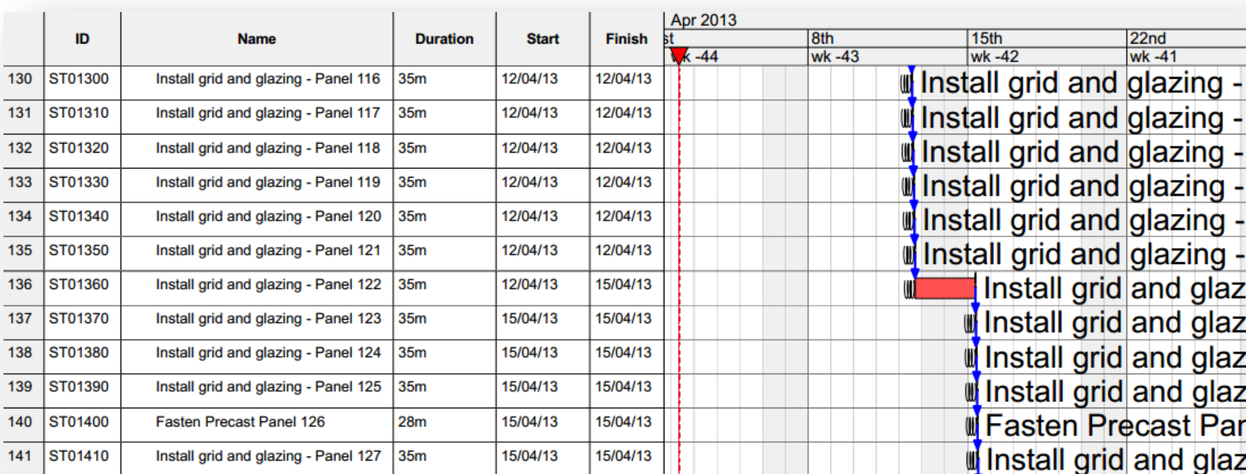
*Duration per Panel Installed*

11 days to construct a floor (Where there are 8 work hours/day) = 88 work hours per floor wing
(88 hours) / (152 Panels) = 34.73 minutes per panel – Installation

This value takes into account crane operation or hoisting material to the proper bay.

Therefore:
It takes 34.73 minutes on average to complete one panel around the perimeter of the building.
There are 130 panels of glazing.
There are 22 precast pieces.

It is assumed that precast panels will to take less time to hang since they are directly welded or bolted to the structure and no framing is necessary. Therefore, 28 minutes is assigned for the precast panels. This allows the left over 6.73 minutes of each of the concrete panels (or 148.06 minutes total) to be divided amongst the glazing panels that require the frame to be installed and then put in place. Each of the 130 glazing panels of the third floor facade then gain 1.13 minutes of additional installation time, yielding a total installation time to be 35.86 minutes. This can be seen in the snip of the project schedule below, in figure 18.



| | ID | Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 130 | ST01300 | Install grid and glazing - Panel 116 | 35m | 12/04/13 | 12/04/13 |
| 131 | ST01310 | Install grid and glazing - Panel 117 | 35m | 12/04/13 | 12/04/13 |
| 132 | ST01320 | Install grid and glazing - Panel 118 | 35m | 12/04/13 | 12/04/13 |
| 133 | ST01330 | Install grid and glazing - Panel 119 | 35m | 12/04/13 | 12/04/13 |
| 134 | ST01340 | Install grid and glazing - Panel 120 | 35m | 12/04/13 | 12/04/13 |
| 135 | ST01350 | Install grid and glazing - Panel 121 | 35m | 12/04/13 | 12/04/13 |
| 136 | ST01360 | Install grid and glazing - Panel 122 | 35m | 12/04/13 | 15/04/13 |
| 137 | ST01370 | Install grid and glazing - Panel 123 | 35m | 15/04/13 | 15/04/13 |
| 138 | ST01380 | Install grid and glazing - Panel 124 | 35m | 15/04/13 | 15/04/13 |
| 139 | ST01390 | Install grid and glazing - Panel 125 | 35m | 15/04/13 | 15/04/13 |
| 140 | ST01400 | Fasten Precast Panel 126 | 28m | 15/04/13 | 15/04/13 |
| 141 | ST01410 | Install grid and glazing - Panel 127 | 35m | 15/04/13 | 15/04/13 |



Figure 18 – Synchro Schedule of 3rd Floor of South Wing

The full project schedule can be seen in Appendix D, were all components and durations of the elements of the third floor of the south wing are visibly mapped out. It is important to note that when looking at the schedule, some of the durations seem a little longer than the other durations, even though the duration imputed into the schedule is the same. This is because extra time is shown in the schedule for the night hours where work is not taking place, and also during the weekends (seen above in red extended bar, line item 136).

Each component in this schedule is also broken down into the panels that are installed, instead of individual panes of glazing and the mullions associated. The reason for this was to allow the 4D model to be more accurately portrayed.

The overall result of the scheduling process of the third floor of the south wing is that the installation process takes 11 days 4 hours and 35 minutes to complete. This data was then taken and implemented into Synchro Pro. Here, the schedule and model were linked to create a 4-D schedule. A view of the 3-D portion of 4-D model can be seen below, in figure 19. Here, one face of the individual panels have been installed and the pattern will be to continue in a clockwise format if an aerial view was the viewing angle.

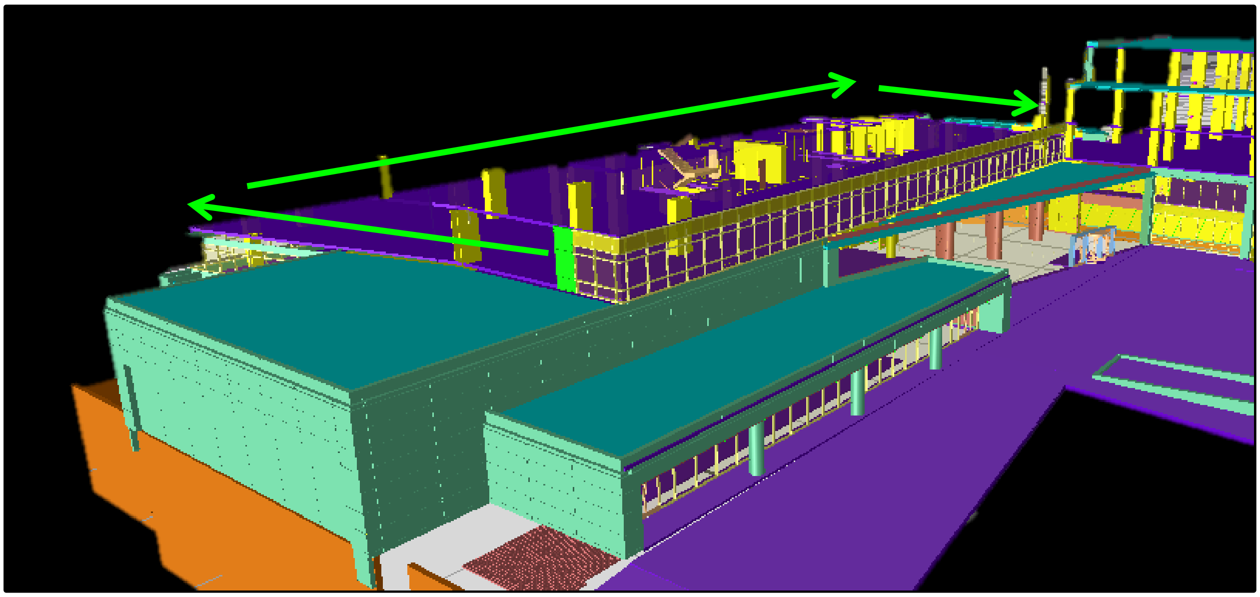


Figure 19 – Synchro 4D Model Representation of 3rd Floor of South Wing

In figure 19, it can be seen that the façade installation is to be initiated on the northeast point of the south wing. This is to ensure that the installation of the building façade spirals its way up the building as the work zones bounce back and forth from the north wing to the south wing. By creating this spiral sequencing pattern, the work and productivity will be able to be run smoother. Hoists and scaffolding will be able to be taken down and moved slightly, rather than relocating to the other side of the building. In the end, this will save enormous amounts of time in the project schedule, and hopefully bring the project closer to the original projected base building completion date.

## Results

After completing the analysis on the façade of the third floor of the south wing, the schedule created had a final duration of 11 days, 4 hours, and 35 minutes. This is equivalent to 11.575 days, where each work day is 8 hours long. This means that floors two though five of the south wing all take 11.573 days to complete the façade, but the façade for the north wing is a little smaller, so linear interpretation is needed. This work can be seen below.

$$\frac{S.Wing}{N.Wing} = \frac{16.833\,\frac{\text{days}}{\text{floor}}\ (original\ duratation)}{13.2\,\frac{\text{days}}{\text{floor}}\,(original\ duration)} = \frac{11.573\,\frac{days}{floor}\,(calculated\ duration)}{X\ (duration\ for\ North\ Wing)}$$

$$Where\ X = 9.075\ days/floor$$

This means that floors two through five of the south wing take 11.573 days/floor, and floors 2 through 4 of the north wing take 9.075 days/floor.

Now the total duration of the floors that underwent the SIPS simulation must be calculated and compared to the original duration to see how much time, if any at all, was saved in the overall project schedule.

South Wing

- Floors being taken into account: 2, 3, 4, & 5 (4 floors total)
- Actual duration to do these floors = (16.833 days/floor)*(4 floors) = 67.332 days
- SIPS duration = (11.573 days/floor)*(4 floors) = 46.292 days
  - Difference of 21.04 days ~~ 21 days

North Wing

- Floors being taken into account: 2, 3, 4, & 5 (3 floors total)
- Actual duration to do these floors = (13.2 days/floor)*(3 floors) = 39.6 days
- SIPS duration = (9.075 days/floor)*(3 floors) = 27.225 days
  - Difference of 12.375 days ~~ 12 days

Adding the two differences will give the total time that the SIPS analysis was able to save in the project schedule. This value yields around 33 days. That means a little more than a total month was saved in the short interval production process. To show this impact not only on the overall project duration, the next page has a quick breakdown on the cost savings for the budget for the general conditions for Memorial Vista.

If thirty-three days were saved in the project's overall schedule, the project would be under construction for around one less month than the actual project's duration was. This would mean about 4 weeks total would be saved in labor costs and general conditions costs.

If the total general conditions cost for Memorial Vista came to $2,878,060 for a project that was to take place for 163 weeks from the start of demolition to the final stages of the building's final completion and occupancy, than the general conditions cost would result in being about $17,657 per week. Since this SIPS analysis saved around 4 weeks, the owner would be able to save $70,627 on the projects general conditions cost. This is around a 2% savings for general conditions alone, which seems small, but this savings can be used in the unforeseen cost of the utility relocations.

## Recommendations

Per the results of this analysis, it is suggested that the proposed phasing plan and short interval production schedule analysis be implemented to the façade of Memorial Vista. This proposed schedule that was used to make the 4-D model and show the SIPS analysis does not comprise any additional expenses to any parties on the project, but rather shares a way of performing the work more efficiently. If the workers follow through with this certain schedule, the durations will be shortened, and the general condition fees will be reduced $70,627, which is a 2% decrease.

By implementing this analysis, the project will not only have a lower general conditions cost, but will allow the project to be completed close to a month sooner. By completing Memorial Vista a month sooner than the actual schedule, the project will be closer to the original projected completion date before the utility relocation mishap, and will allow the interior fit out of the building to take place closer to the time it was originally planned in the preliminary schedule. This will deliver the building to the aviation tenant quicker, where lease payments will be made sooner for the building owner.

To further this study, one could study the time it would take to lift the individual elements of the façade to lead to a clearer and more accurate outcome. This will allow for almost an exact time frame to perform the task of enclosing the building, if everything flows correctly and there is no weather, injury, or unexpected delays. Although a situation like this would be rare, it would allow the schedule and project team to figure out almost exactly how much time they can make up through this analysis to allow the schedule to become closer to becoming on track with the original schedule from the beginning of the project.

## Analysis II – Prefabrication & Study of Photovoltaic Windows

### Problem Identification

The main problem for the construction of this building, as stated in Analysis I, is the under estimated length of the utility relocations. This resulted in extended project durations for Memorial Vista, when being compared to the original schedule. Based on the unforeseen conditions, the project was extended around another two months than originally projected. To help get the construction of Memorial Vista back on schedule, the team at Davis looked at every aspect of the future activities in the schedule after the utility relocation to see what could be combined or done more efficiently.

One thing that could have had the potential to hasten installation durations would have been the use of prefabrication. Since the building is simply a core and shell construction, and will be turned over to another team to perform the interior fit-out, the most logical items to prefabricate would be the façade, specifically the glazing. This structure is erected with seven different types of glass all of which are directly mounted to the structure of the building in small sections, where each pain or unit is fastened with the help or a crane or hoist. The installation process then flows across the building on each floor and progresses up the structure. This is heavily time intensive and could be expedited through the use of prefabrication. If the window units were to be attached to the structure in a way that more than one is attached at a time, this could hasten the schedule. If the window units were pre-manufactured into panel like structures, the sealant between each window has the potential to be a tighter seal than those done in the field allowing for the quality control of the item to increase.

### Analysis Goals

The problem of having the project completed significantly after its targeted completion date still exists. Although Analysis I caught the project up to only be 33 ahead of schedule and closer to the preliminary schedule, there are still 26 to be made up. To get back on schedule, the analysis will once again strive to obtain the goal of accelerating the project schedule to get the project closer to the original completion date. To accelerate the schedule, but remain consistent with quality, the analysis will focus on prefabrication of individual panels, and also prefabrication of photovoltaic glass in certain areas. If the glass is pre-manufactured in a plant off site, the panels have the potential to be delivered on the exact date they are needed and then immediately fastened to the structure. This will save time and capital, and when the photovoltaic glass is prefabricated it has the potential to save the money throughout the building's life span. In the end, it is believed that a total of around one to two days can be saved per floor if the building enclosure is prefabricated and installed in a logical method. This duration is less than average due to the fact that the installation times have already been looked at in analysis I so it will be determined if and additional installation time will be saved through prefabrication.

## Process

*Original Study*

On most projects, after the design phase takes place of the building's façade, it sits around until the building it to be enclosed and the glazing and mullions are installed one piece at a time. This can be done, but the process can sometimes be tedious and increase the construction process for the overall schedule. To limit the length of this construction process, and sometimes even shorten the project schedule, prefabrication can be performed. This practice takes place between the design and construction phase, where the element – in this case, the glazing of the building's façade – can be prefabricated to allow a safer construction process and a shorter duration to construct because they are being constructed on the ground and at an external location. As a result, the prefabrication process allows the building's enclosure components to be constructed in an assembly line manner, where efficiencies can be introduced to save large durations of time on the project. On the Trimble Westminster Project in Westminster, Colorado, the team decided to implement this prefabrication process on multiple aspects of the buildings components, but specifically the window systems.

To prefabricate these ribbon windows and curtain wall, it was decided that they were to be manufactured in the glazing subcontractor's shop to enhance on-site efficiency and safety by minimizing material and worker exposure to site conditions and other trades (Trimble 2013). The only problem that resulted from this was that a few panels were broken in the transportation and installation process, other than that the process was flawless and saved copious amounts of surplus installation time. When the panels were being manufactured off site, the workers could easily access all of their tools in a close proximity. The prefabrication crews were also did not have to work around other project activity, and when the panels arrived, the installation time where the might have been above workers was significantly reduced. In addition, the workers were constructing the panels out of the brutality of the fierce Colorado wind which could have delayed work (Trimble 2013). In the end, the schedule was shortened for the entire façade by a total of 4.5 weeks. By looking closer at this case study, there are numerous similarities between the Trimble building and Memorial Vista. The only large differences are location and the fact that some of the windows that would be prefabricated have the potential of being photovoltaic glazing units.

The next step was to look into a case study where photovoltaic glass was being implemented. After researching various case studies, the most informative was the pilot project on the 56th floor of the Willis Tower. Here, the south facing windows were replaced with Pythagoras Solar's transparent solar windows. By doing this, it was hoped that the solar gain and cooling costs would be cut down due to the increased power

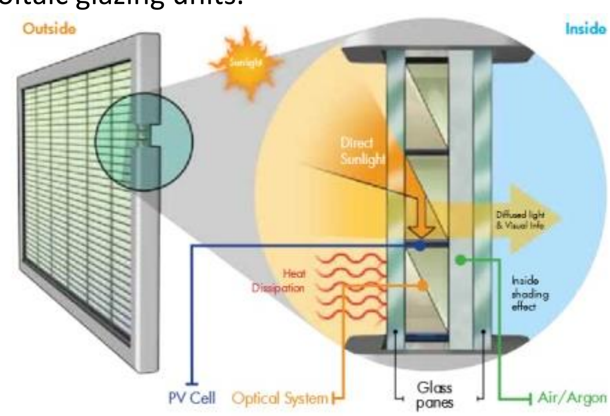


Figure 20 – PV Glass Breakdown Courtesy of http://www.solarpowerworldonline.com

harnessed from the suns energy. These windows allow diffuse light to pass through, but use a prism to reflect sunlight down onto horizontal photovoltaic cell along the bottom of the unit (reference figure 20 on the previous page). If the pilot project proves successful, Pythagoras Solar windows could be expanded beyond the fifth floor to cover enough surface area to provide over two megawatts of solar power (Quick 2011). Since the photovoltaic glass is a relatively new field of study, it has been hesitant by owners to install on their buildings. Its high initial cost is not always rapidly returned in savings, leading to some obvious hesitation.

*Possibility of the Prefabrication of Photovoltaic Glazing Units*

To relate the case study of the Trimble building to Memorial Vista fully, the process of photovoltaic glazing units must be looked in to in order to see if prefabrication is even possible. After further research, it was discovered the photovoltaic glass units are prefabricated in a similar manner to that of a traditional glazing unit. The only difference is that the electrician is needed to hook up the collector to the invertor once on site to change the power generated from DC current to AC. This is done in order for the building to be able to use the power generated since most systems run off of AC current within a building (Miroslav 2007). This whole phenomenon where sunlight is changed from light to power can be described in a few steps. Within sunlight are photons, or particles of sunlight, and these hit the photovoltaic glazing units. The PV units convert those photons into electrons of direct current electricity, and they then flow out of the units to an inverter. Here, the electrons change from direct current power to alternating current power, which can then be used to power various systems within the building (California Energy 2013).

*Pros and Cons of Photovoltaic Glass*

With photovoltaic glass units in the state of Virginia, numerous incentives and advantages can be a result of their installation. One of the main ones is that the use of these glazing units can result in up to 12 credits and 39 points in the Leadership in Energy and Environmental Design (LEED) scoring system. Some of the main points that could be applied to the LEED tracking list can be seen in figure 21 below. Some of these may already be used to give Memorial Vista's 60 points to become LEED Gold, but the addition of these points could push the building into the LEED Platinum category. By doing this, the building can now be granted an additional floor area ratio of 0.45, which could be used in the future it the tenant does choose to add an additional wing to expand the building size to accompany more employees. The other incentive is that the additional height could also be rewarded for meeting the Platinum level (Virginia Economic 2014). This may not be as crucial for Memorial Vista, due to the fact that it has air restriction based on its location to a nearby air strip, but the floor area ratio may be important to note.

Figure 21 – LEED Credentials Courtesy of Onyx Solar (http://www.onyxsolar.com/)

Some of the other aspects of photovoltaic glass that yields them to being extremely beneficial is the fact that the fuel that they run on is free and natural sunlight. The system is also quiet and requires minimal maintenance throughout their lifetime.

The down side to the photovoltaic glazing units is that they have an extremely high cost, when being compared to conventional glass facades. The high cost is also not compensated for in a short payback time, but can sometimes be extremely long. In some instances, the pay-back period could take longer than the life of an average building. If cost was not a main concern, the next issue would be that the photovoltaic units create direct electric current that needs to be converted to alternating current before it can be used to power the building. One of the other large disadvantages it that the photovoltaic glazing units relatively low efficiency levels that range between 12 to 20%, and they are significantly limited based on the availability of the sun (Green 2012).

*Prefabrication of Glazing Units*

The glazing for this façade was originally purchased through Viracon Glass, where the three different types of glazing for the building's enclosure were all delivered directly to the site. Form here, Harmon Inc. was the exterior glazing subcontractor and supplied frames and manufactured the panels on the job site. This was done out of the way of most of the work being done on a plot of land adjacent to the site. This neighboring parcel can be seen in the figure below in light green next to the soccer fields. The reason why this site was accessible for assembly was due to the fact that the original contract with government officials states that the design of the surrounding landscape was to be improved. The contractors used this clause to their advantage by using the space as assembly and laydown areas prior to improving the landscape.


Figure 22 – Assembly location courtesy of Davis and Google Maps

Due to the fact that the assembly point was across the street from most of the construction, the crew working on fabrication of the panels could work safer and more efficiently. The crew could easily access all tools and could work through most weather that may not have been possible if the windows were framed as they were being hung. By framing on site and a good distance from construction, work was not slowed down due to crane work or delayed due to work not able to be completed under the lifts. The only problem with this was that the work was dependent on the weather. It may have been more efficient to prefabricate the glazing panels in an enclosed and easily controlled environment. By doing this, both safety and efficiency could be more strictly followed and ensure the activity of enclosing the building was completed on time.

If Harmon Inc. was to continue supplying the manpower to fabricate the glazing, they could have the Viracon glass panels delivered to a manufacturing plant to prefabricate panels in one of their controlled environments. The closest manufacturing plant that Harmon Inc. has to the project site, while keeping the transportation path in mind, would be their Cincinnati Fabrication Center in West Chester, Ohio. Figure 23 below shows the duration and distance the glass would be transported if the panes of glass were fabricated on site and traveled from Owatonna, Minnesota to northern Virginia. Figure 24 shows the same start and finish points as figure 23, but adds an additional stop in West Chester, Ohio for the prefabrication process. The result is that the total duration and distance traveled is only approximately 2 hours longer than the original path with around an additional cost of $70 in fuel. By being prefabricate in a shop, the panels to be manufactured safer and with more stringent quality control.

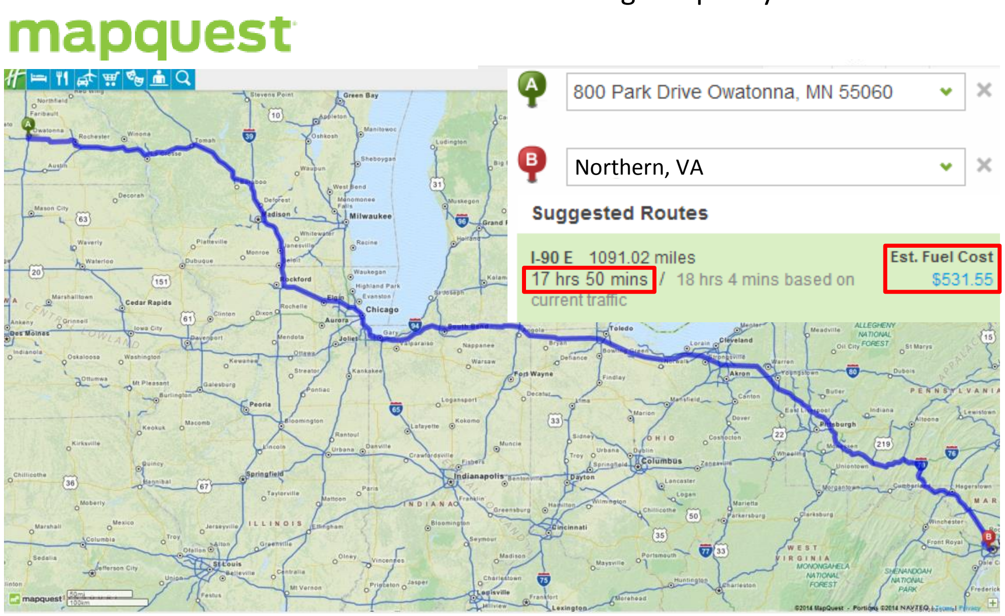



Figure 23– Travel Path from Viracon Glass to Site courtesy of Mapquest

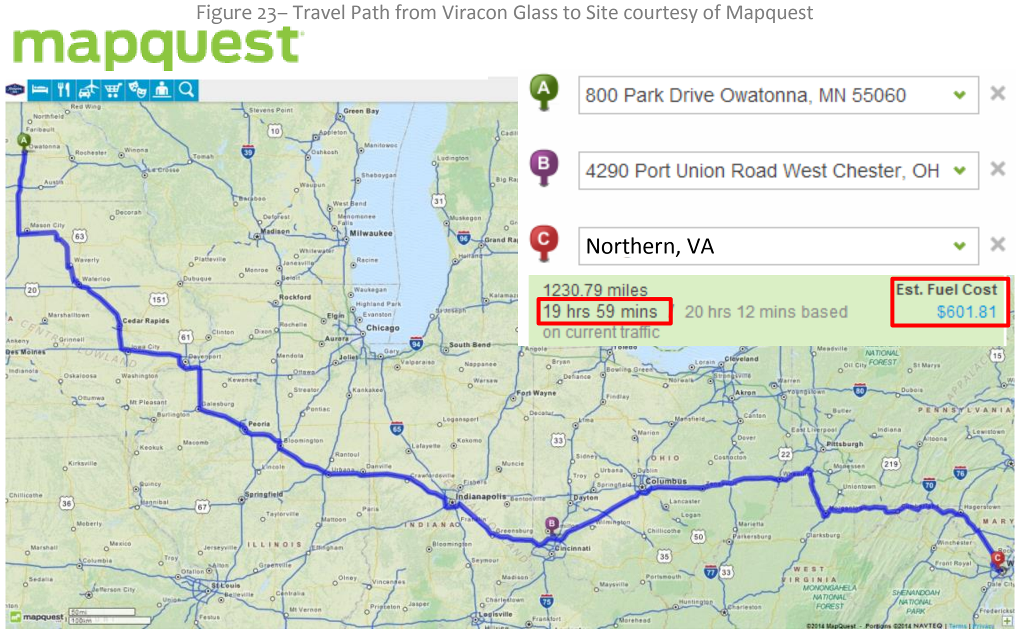



Figure 24 – Travel Path from Viracon Glass to Harmon Inc., and then to Site courtesy of Mapquest

The stop in West Chester, Ohio would be the first stop that the Viracon glass panels would make. A glass transport tractor trailers would be loaded with the glass and drive from the Viracon manufacturing plant to the Harmon Inc. prefabrication plant in Westchester, Ohio. This first leg of transportation would be made in one of Viracon's glass transport trailer, as seen in figure 25 below. The trailer consists of compartments for safely housing the glass for shipping to allow minimal damage as the distance is covered. This type of trailer is similar to the one in figure 26. The truck used to transport this glass within the marked distance was assumed to be a Volvo VNL 300 tractor trailer with a gas mileage of 7.1 miles to the gallon. With this information, the trip cost was calculated on MapQuest with an average diesel price of $3.36 per gallon along the route. Each of the costs for the duration of the trip directly to the site and with the additional stop can be seen outlines in red in figures 23 and 24 on the previous page.


Figure 25 – Viracon Glass Transportation Truck Courtesy of Google Images

Figure 26 –Glass Transportation Trailer Courtesy of Google Images

The next step would be to figure out how much lead time needs to be given to Harmon Inc. to complete the prefabrication in time to get the glazing panels to the site by April 1st, 2013. The abbreviated schedules where this information was found can be seen in Appendix E. For this to take place, 10 to 12 weeks would need to be given in advance for approval, and 8 weeks from the start of fabrication until enough cache is built to start in the field. This unit production in the shop continues after the building enclosure start date in the field until all the units are completed and installed. The shop generally has to stay 2 weeks ahead of the field, so the workers do not run out of units to set, according to Patrick Hartford of Harmon Inc. (Hartford 2014).

This being said, the order must be put in around 12 weeks in advance, where the order will start to be processed in around 8 weeks before the glazing panels are needed on site. That means that the order would have to be made during the week of January 7th, 2013. The order then would have been processed on February 4th, 2013 and the panels would have begun to be prefabricated. With the panels the typical panels that accompany this building being approximately 11.5' x 5', Harmon Inc. can manufacture the panel in 12 hours, where approximately 20 panels are made a day. These values would not be taken into account to formulate the schedule later in this analysis, due to the fact the delivery date will be assumed to be on time. By having the panels prefabricated off site, the safety concerns and scheduling become easier for Davis, and they would be able to supply a better product as a result. As the panels would be prefabricated, they would then be stored in a warehouse according to both Viracon and Harmon's standards, until the day they are to be shipped to the site.

The panels would have then been delivered from the prefabrication plant in West Chester, Ohio to the northern Virginia site on March 29th, 2013. Although the windows are needed on April 1st, which is a Monday, the panels would have been delivered on a Friday to ensure the work would not be held up, and work could smoothly and efficiently flow. The material laydown area would be the same location that the previous on-site prefabrication location was (as seen previously in figure 22). The delivery of these panels would be unique in the fact that they would be coming preassembled to the site and would have to fit on a flatbed tractor trailer. The orientation of these panels can be seen in figure 27 below. This trailer is different than the Viracon one that dropped the glass panes off at Harmon Inc.'s prefabrication plant, due to the fact it is a flatbed style. The truck pulling the load is still assumed to be the Volvo VNL 300 to keep with consistent rates for miles per gallon, but now a flatbed model.

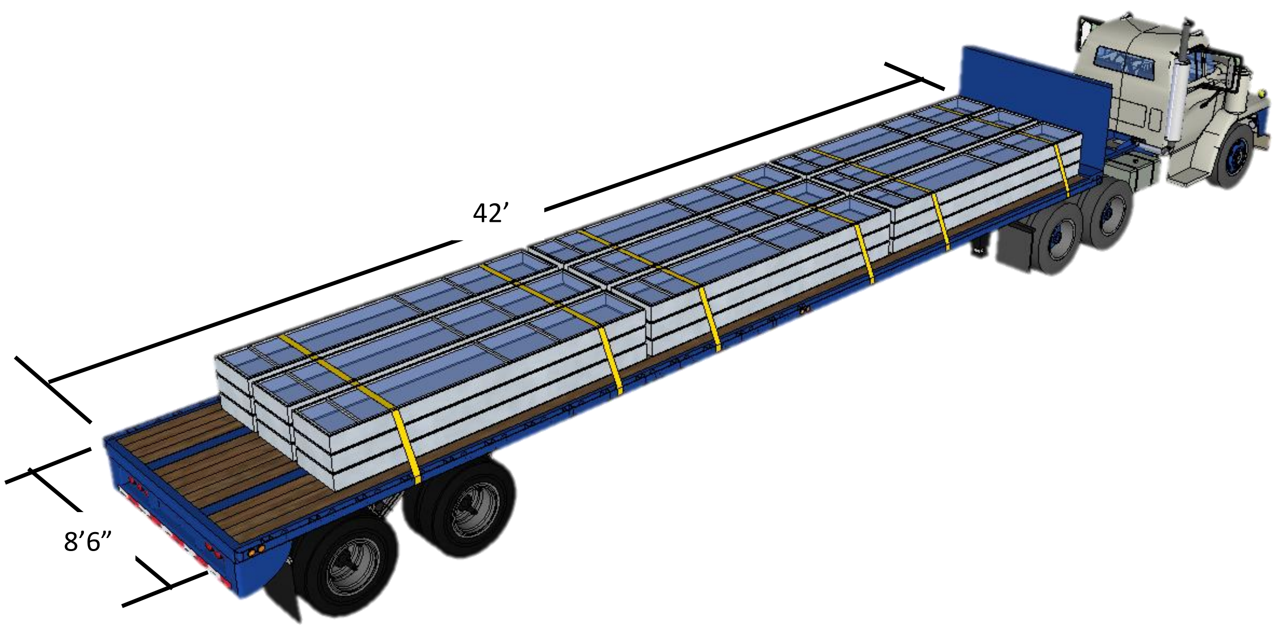



Figure 27 – SketchUp Model of Panel Transportation from Prefab Shop to Site

As the panels are transported, it can be seen in the figure above that 27 panels come at one time. These 27 panels are under the Virginian maximum load capacity of 24,000 pounds.

Once at the site, the panels are laid in the assembly area and then moved to the perimeter of the building with the help of a telescoping fork lift. As the prefabricated panels arrived on site, they would be staged in a manner that they would be assembled. The unloading process can be seen in figure 28. Then, once the panels are laid down and brought to the construction site, the panels are lifted into place through the use of the crane, as needed.

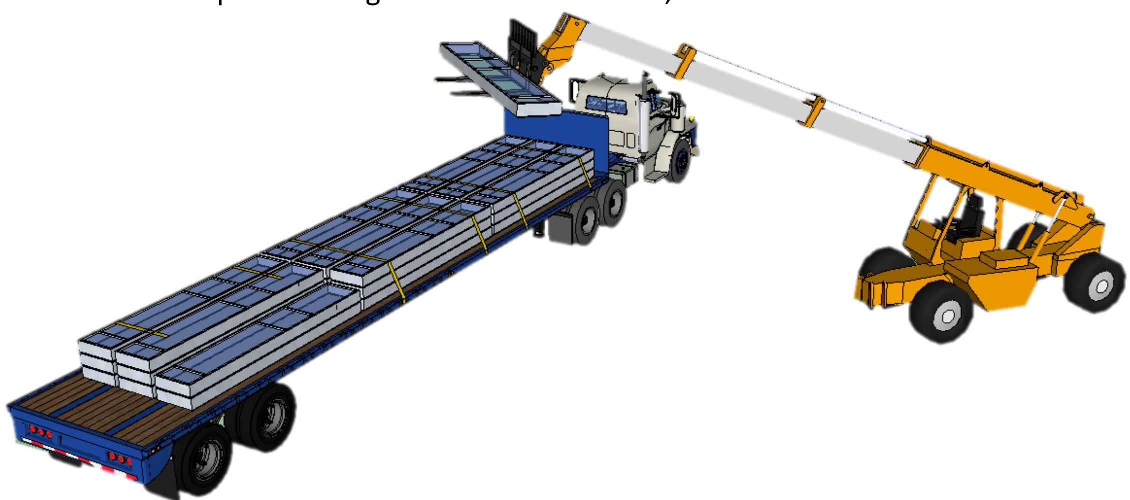


Figure 28 – SketchUp Model of Telescoping Fork Lift Unloading Panels

To determine what prefabricated portions of the glazing was to be photovoltaic, a solar study had to be completed to share what face of the building would yield the most natural sunlight for the longest duration. By finding this face, the pay off period would presumably be the quickest.

*Solar & Shading Study (Breadth 1)*

The first step was to look at Revit 2014 to perform a shadow study to share where the largest shadows would be casted on the building using the buildings orientation and location. In these locations, photovoltaic glass would be deemed inefficient due to the fact that no direct sunlight is hitting the units. The figures below show the Revit model and the location of the sun for the winter and summer solstice and autumnal and vernal equinox.

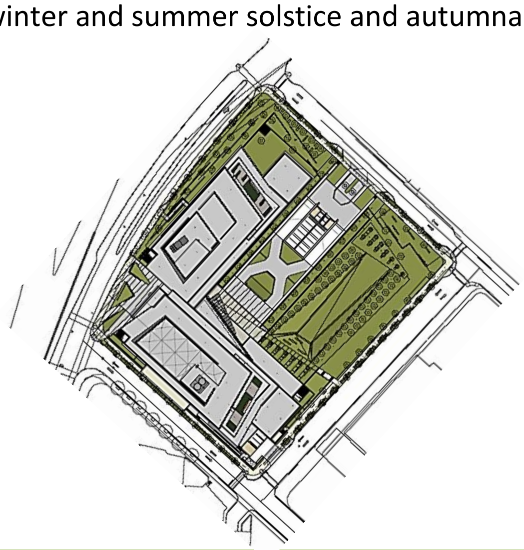


Figure 29 – Revit Model of Memorial Vista

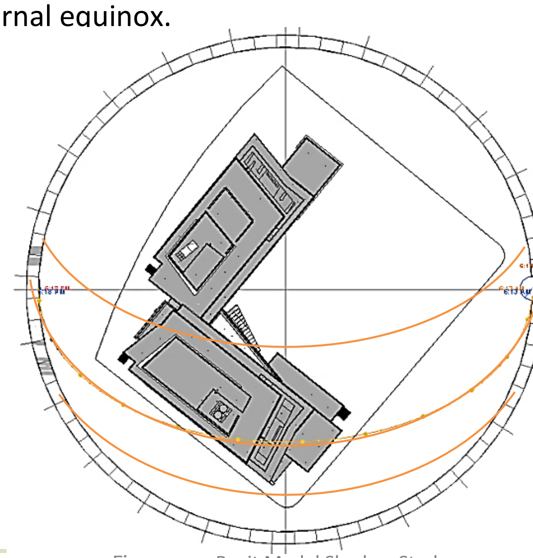



Figure 30 – Revit Model Shadow Study

The four times of the year shown in figure 30 are most important of a study of this kind due to the fact that these are the extremes for the entire year. On June 21st, which is the summer solstice, the sun is at its highest point in the sky for the entire year. Contrary to the summer solstice is the winter solstice, which is on December 21st, and this is where the sun is at its lowest point in the sky. The other two locations are directly in the middle and these times are known as the vernal and autumnal equinox, which fall on March 21st and September 21st respectively. With these times, an animation was produced in Revit to show where the shadows of the building are cast throughout the four critical days to clearly show the spectrum of possibilities.

After completing the shading study, it was determined that a solar study would have to be completed to actually show which surface obtained the most sunlight. This was done with the help of Autodesk Ecotect. Here, a simple model was produced in the program and oriented to the proper direction and location to perform an accurate study. This then produced a 3-D graphic that showed the watt-hours per meter squared for each of the four main dates listed in the shadow study. These figures can be seen below in figures 31 through 34.

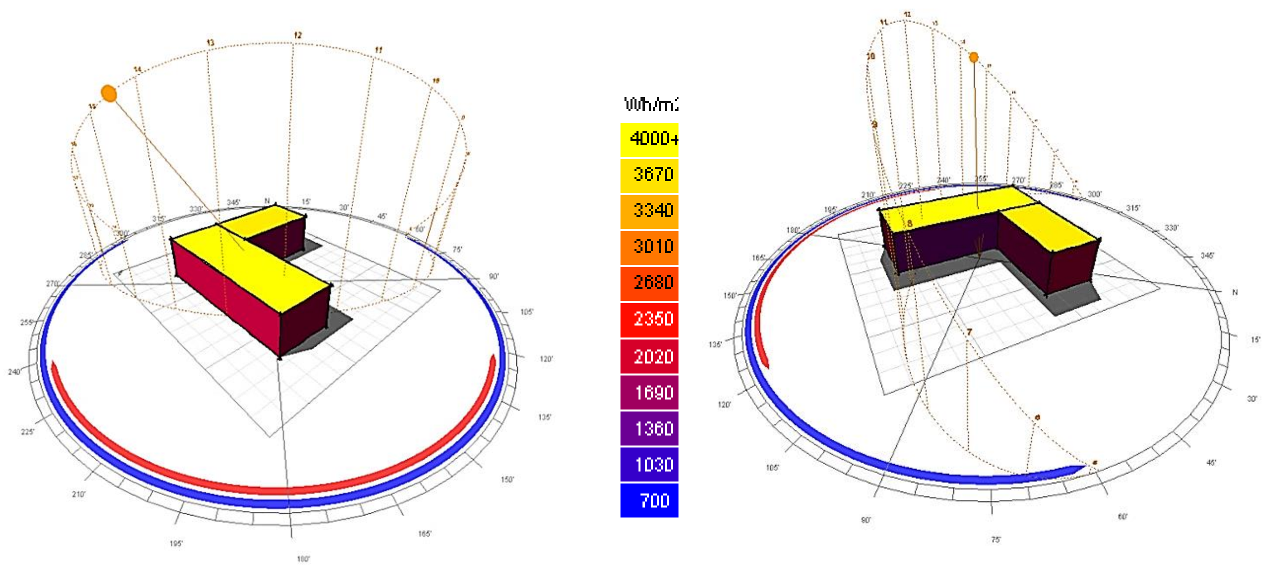



Figure 31 – Autodesk Ecotect Model of Summer Solstice (June 21st)

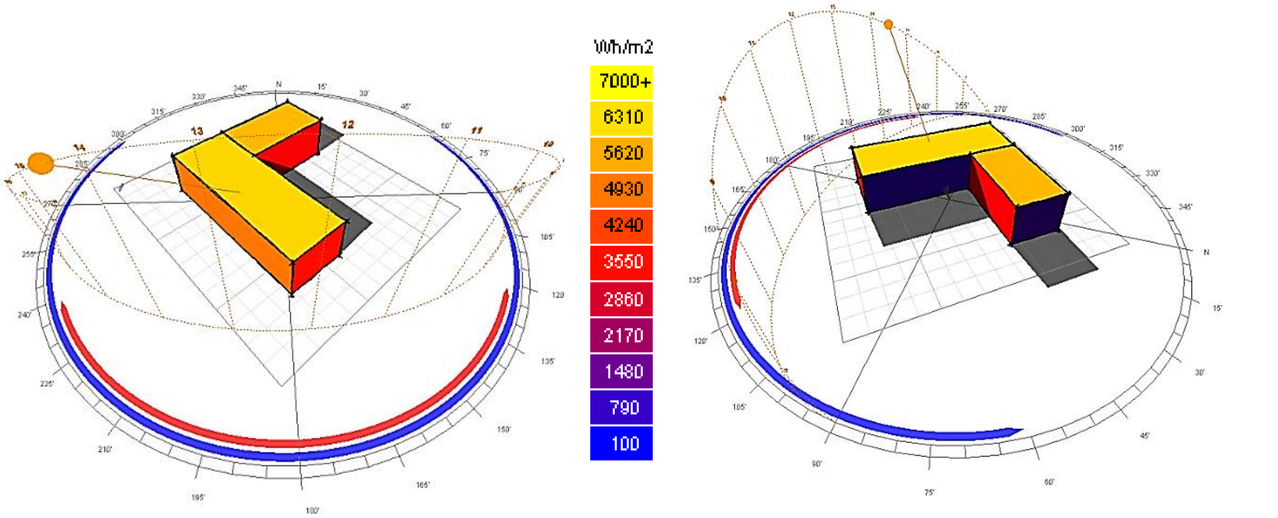



Figure 32 – Autodesk Ecotect Model of Spring Equinox (March 21st)

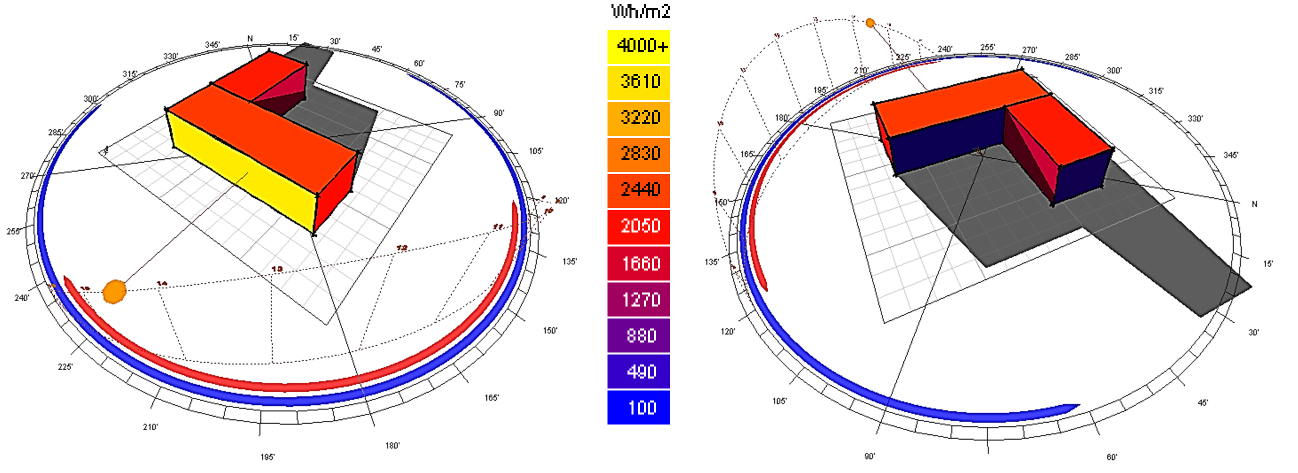



Figure 33 – Autodesk Ecotect Model of Winter Solstice (December 21st)

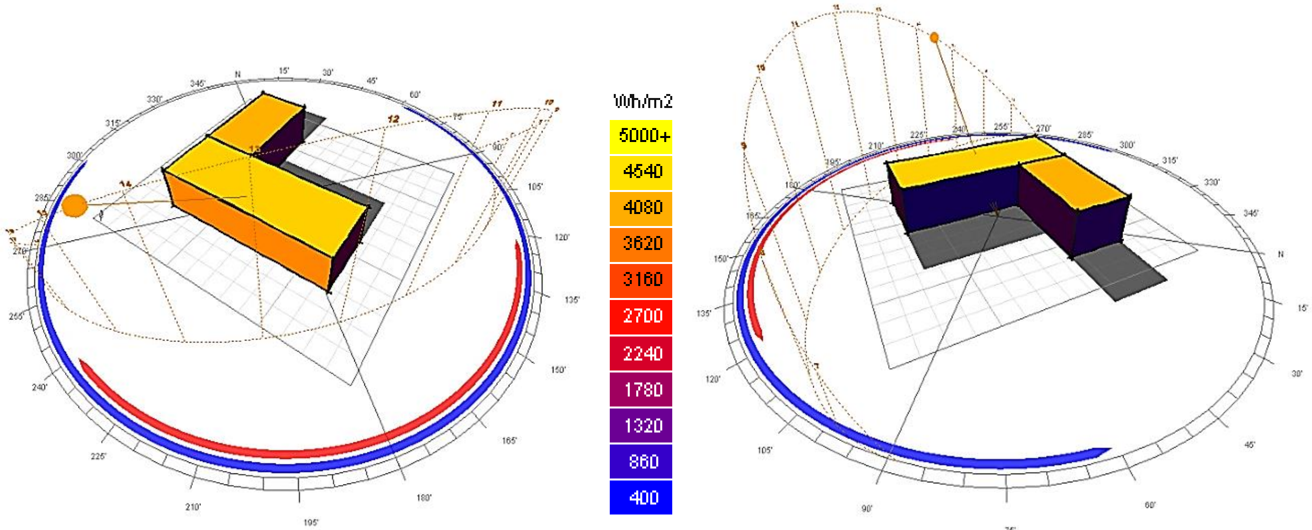



Figure 34 – Autodesk Ecotect Model of Autumn Equinox (September 21st)

In addition, Ecotect was able to generate another shadow study for the entire year in sequential shading, which can be seen in figure 35 below.

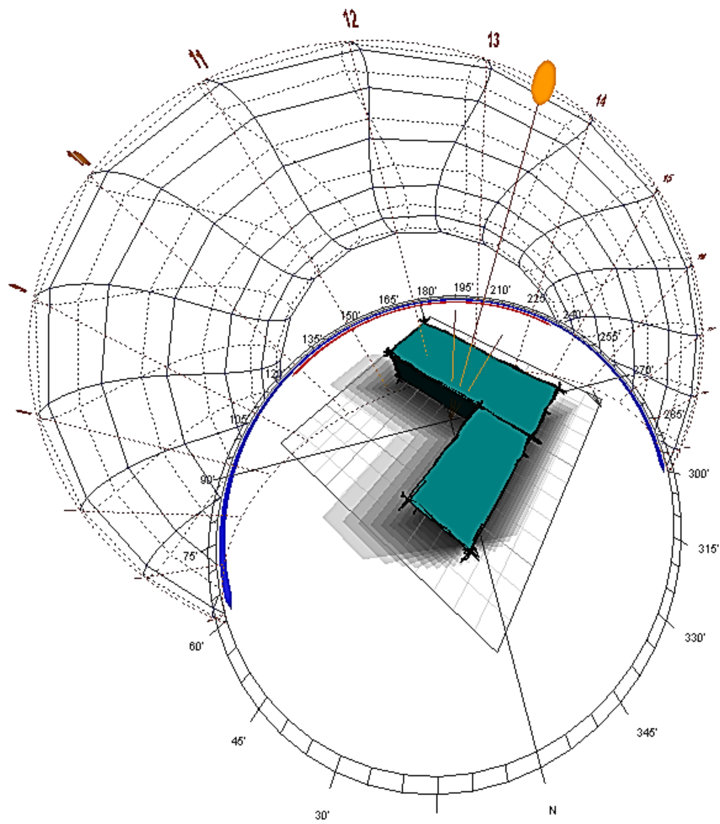


Figure 35 – Ecotect Generation of Shadow Range for Year in Northern Virginia

After doing both the solar and shadow study in Revit and Autodesk Ecotect, it was determined that the southwest façade of the building's south wing would best be suited for the photovoltaic glass because of the fact that the sun allows this face to gather the most watt-hours per meter squared. This exterior face is also the rear of the building in the layout; therefore the photovoltaic glass will not be seen by guests pulling up to the structure.

It was determined to do all of the glass for the southwest face of the south wing because the more glass that could be redesigned to be photovoltaic; the larger collection surface there was for the sun's rays. The only concern was that the first floor is a very high end lobby that may clash with the look of photovoltaic glass, but in the end, it was determined that the glass would not affect the feel of this space. This was because the elevator bank in the lobby blocks the view from the front of the building to the back, so it would most likely be seen to a minimal scale. By reviewing the location and keeping the modern open look of the lobby, all while implementing the photovoltaic glass, the building is able to keep the aesthetic feel that the architect was trying to portray, all while generating electricity for the buildings internal systems.

*Photovoltaic Layout & Breakdown*

Below is a breakdown of the southwest façade of the south wing, where the area of the glass panels was taken off in Autodesk Quantity Takeoff 2013.

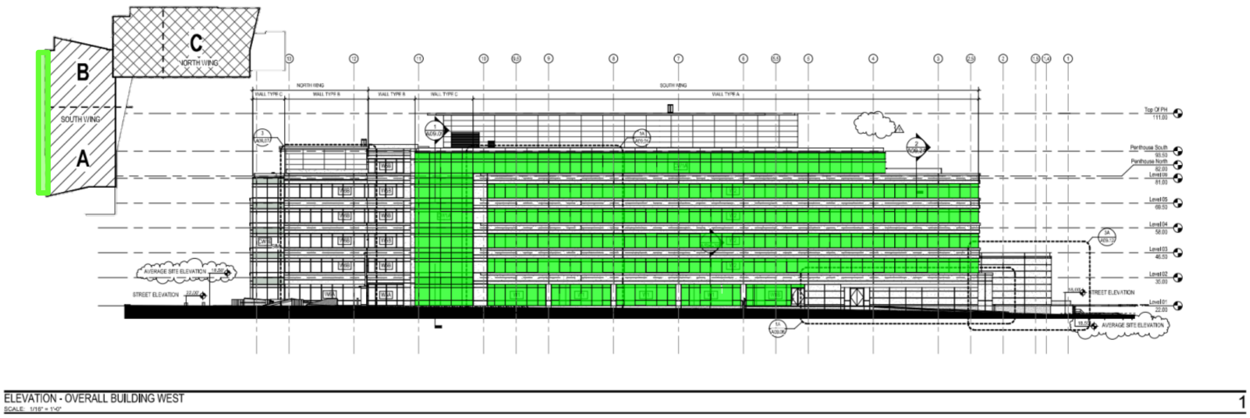



Figure 36 – Area Where Photovoltaic Glass Will be Hung for Optimum Efficiency (Drawing Courtesy of Gensler)

After performing this takeoff in Autodesk Quantity Takeoff 2013, it was determined that a total of 9,553 square feet of glazing has the capability to become glazing for PV Glass. Knowing this, a calculation had to be done to calculate the output of an area this size of photovoltaic glass. That can be seen in table 2.

Table 2 – Cost Savings per Year of PV Glazing Units

| Watts/Panel | Width (ft.) | Height (ft.) | SF/Panel | Watts/SF | Total SF of Glazing | Total Watts | Total kW | Days/Yr | Hrs/Day of Sunlight in VA (kWh/day) | Hrs/Yr | Total kWh/Yr | Cost/kWh in VA | Cost Savings/Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 252.8 | 5.00 | 5.00 | 25.00 | 10.11 | 9553.00 | 96599.94 | 96.60 | 365 | 2.3 | 839.5 | 81,096 | $0.08 | $6,649.84 |

Appendix F shares where the kilowatt hours per day in northern Virginia were found, along with the specification sheet for the photovoltaic glazing unit used. The watts per panel were taken from Appendix F, as was the dimensions. This then allowed the watts per square foot to be calculated. With the total square footage of glass calculated to be 9,553 from the figure 36, the total kilowatts that the photovoltaic glazing units would produce was found. The next step was to find the average hours of daylight in Virginia per day to determine the total kilowatt-hours per year. The result was that the photovoltaic glazing units could produce just over 81 thousand kilowatts per year. With an average of eight cents per kilowatt in the Virginia area, the total cost savings that this system could produce resulted in $6.6 thousand (U.S. Energy 2014). This cost does not take into account installation costs or incentives associated with the product.

To compare this cost, reference Appendix G. Here an online cost generator that takes into place location and orientation calculated the cost savings to be $6,115.64. This is extremely close to the cost that was hand generated; being that it is around 8% less than the value found in table 1.

*Prefabricated Panel Layout*

Now that the cost savings and the location of the photovoltaic glazing have been determined, the units can be prefabricated. There will be two types of prefabricated units, those being full floor to floor glazing panels with their frames, and strip windows that are smaller and don't include the precast concrete panels at the plenum areas. Knowing this and that each delivery is 27 panels total, the sequencing diagram can be fabricated.

The following figures (figure 37 and 38) show how the work that would be conducted. Piece by piece, the façade would come together and eventually lead to the milestone of building being completely enclosed. This leads to a total of 611 prefabricated panels delivered to the site, but does not take into account all of the photovoltaic strip windows.

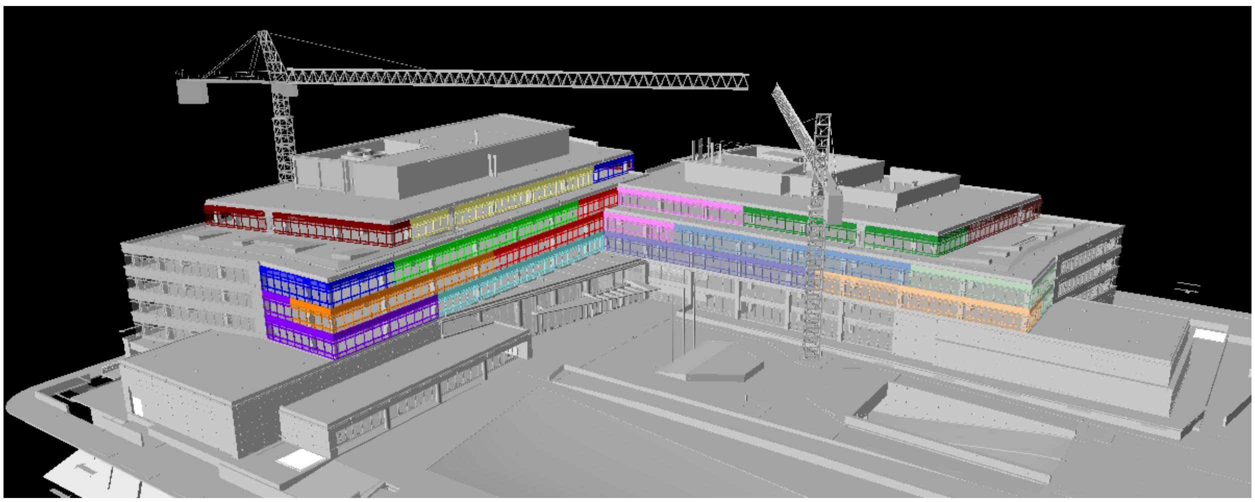


Figure 37 – Location of Prefab Glazing Panels per Delivery

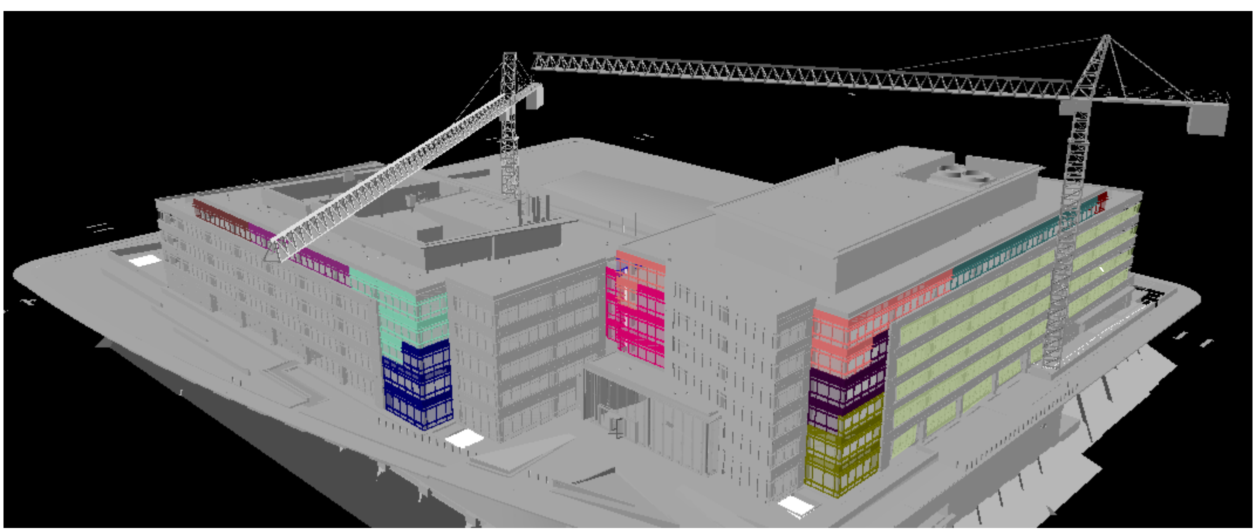


Figure 38 – Location of Prefab Glazing Panels per Delivery opposite Side

The photovoltaic strip windows are represented through the light green color on the south façade in figure 38. There strip windows will require an additional 222 units. With the 611 floor to floor glazing panels and the 222 strip windows that don't include the precast concrete pales, a grand total of 833 panels to be prefabricated for Memorial Vista is the result. If each truck carries 27 panels, a total of 31 trucks will roll in and out of the site and will need to be continuously staged for installation.

The installation would start on the south wing, due to the fact the foundation of the south wing was started first, leading to the levels of the south wing to be completed prior to those of the north wing. To eliminate the probability of workers constrained due to space or other work going on in their surroundings, the entire third floor of the prefabricated installation will be completed for the south wing before the third floor of the north wing begins. Both wings will be constructed simultaneously after the third floor of the south wing is completed, in order to save time in the installation process and lead to the building being fully enclosed quicker. Prior to the third floor installation taking place, the few photovoltaic panels being installed on the first and second floor will take place simultaneously. One thing that must be kept in mind is that the south facing façade will take significantly longer in the prefabricated installation process due to the entire wall becoming prefabricated photovoltaic glazing.

The zone that this analysis did not take into account would be the installation of the precast concrete panels, but the same durations will be used of those calculated from analysis I to provide a schedule of the façade installation with prefabricated panels. Since Harmon Inc. only provides prefabrication of the glass and frame, the precast concrete subcontractor for the job (Arban & Carosi) were responsible for the installation of the precast façade once the strip windows were installed to their correct location. The schedule also does not take into account the cost of the converters needed to allow the suns energy to be used in the building or the wiring associated.

*Schedule Outline*

The next step was to organize the 27 panel regions in figures 37 and 38 into a schedule format. The actual schedule can be found in Appendix H, but figure 39 below sows a breakdown of each line item. The colors that are associated with each line item coordinate back to figures 37 and 38 to help show the location of the line item. The items are broken up into a North Wing and a South Wing, where work takes place simultaneously.

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **South Wing** | **35.19 days** | **Fri 2/15/13** | **Fri 4/5/13** |
| 2 | Install panels 1-27 (S Wing - SW corner) | 13.5 hrs | Fri 2/15/13 | Mon 2/18/13 |
| 3 | Install Strip Windows 28 - 54 (S Façade) | 13.5 hrs | Mon 2/18/13 | Wed 2/20/13 |
| 4 | Install Strip Windows 55 - 81 (S Façade) | 13.5 hrs | Wed 2/20/13 | Fri 2/22/13 |
| 5 | Install Strip Windows 82 - 108 (S Façade) | 13.5 hrs | Fri 2/22/13 | Mon 2/25/13 |
| 6 | Install Strip Windows 109 - 135 (S Façade) | 13.5 hrs | Mon 2/25/13 | Wed 2/27/13 |
| 7 | Install Strip Windows 136 - 162 (S Façade) | 13.5 hrs | Wed 2/27/13 | Fri 3/1/13 |
| 8 | Install Strip Windows 163 - 189 (S Façade) | 13.5 hrs | Fri 3/1/13 | Mon 3/4/13 |
| 9 | Install panels 190 -216 (SW corner) | 13.5 hrs | Mon 3/4/13 | Wed 3/6/13 |
| 10 | Install Strip Windows 217 - 243 (S Façade) | 13.5 hrs | Wed 3/6/13 | Fri 3/8/13 |
| 11 | Install Strip Windows 244 - 266 (S Façade) | 11.5 hrs | Fri 3/8/13 | Mon 3/11/13 |
| 12 | Install panels 267 -293 (NE Facade) | 13.5 hrs | Mon 3/11/13 | Wed 3/13/13 |
| 13 | Install panels 294 -320 (E Corner) | 13.5 hrs | Wed 3/13/13 | Thu 3/14/13 |
| 14 | Install panels 321 -347 (NE Façade) | 13.5 hrs | Fri 3/15/13 | Mon 3/18/13 |
| 15 | Install panels 348 -374 (N Façade) | 13.5 hrs | Mon 3/18/13 | Wed 3/20/13 |
| 16 | Install panels 375 -401 (N corner) | 13.5 hrs | Wed 3/20/13 | Fri 3/22/13 |
| 17 | Install panels 402 -428 (N Façade) | 13.5 hrs | Fri 3/22/13 | Mon 3/25/13 |
| 18 | Install panels 429 -455 (N Façade) | 13.5 hrs | Mon 3/25/13 | Wed 3/27/13 |
| 19 | Install panels 456 -482 (N Façade) | 13.5 hrs | Wed 3/27/13 | Fri 3/29/13 |
| 20 | Install panels 483 -509 (SE Façade) | 13.5 hrs | Fri 3/29/13 | Mon 4/1/13 |
| 21 | Install panels 510 -536 (S Façade) | 13.5 hrs | Mon 4/1/13 | Wed 4/3/13 |
| 22 | Install panels 537 -563 (NW Façade) | 13.5 hrs | Wed 4/3/13 | Fri 4/5/13 |
| 23 | **North Wing** | **16.88 days** | **Wed 3/13/13** | **Fri 4/5/13** |
| 24 | Install panels 564 -590 (E Corner) | 13.5 hrs | Wed 3/13/13 | Thu 3/14/13 |
| 25 | Install panels 591 -617 (E Corner) | 13.5 hrs | Fri 3/15/13 | Mon 3/18/13 |
| 26 | Install panels 618 -644 (S Corner) | 13.5 hrs | Mon 3/18/13 | Wed 3/20/13 |
| 27 | Install panels 645 -671 (E Corner) | 13.5 hrs | Wed 3/20/13 | Fri 3/22/13 |
| 28 | Install panels 672 -698 (E Corner) | 13.5 hrs | Fri 3/22/13 | Mon 3/25/13 |
| 29 | Install panels 699 -725 (SE Facade) | 13.5 hrs | Mon 3/25/13 | Wed 3/27/13 |
| 30 | Install panels 726 -752 (S Corner) | 13.5 hrs | Wed 3/27/13 | Fri 3/29/13 |
| 31 | Install panels 753 -779 (E Corner) | 13.5 hrs | Fri 3/29/13 | Mon 4/1/13 |
| 32 | Install panels 780 -806 (N Corner) | 13.5 hrs | Mon 4/1/13 | Wed 4/3/13 |
| 33 | Install panels 807 -833 (NW Facade) | 8.5 hrs | Wed 4/3/13 | Thu 4/4/13 |
| 34 | Prefabricated Façade Complete | 0 days | Fri 4/5/13 | Fri 4/5/13 |

Figure 39 – Prefab Schedule Line Items and Associated Colors

In the end, the overall duration cannot be looked at to see how much time was saved from the original schedule; due to the fact the SIPS analysis for Breadth 1 studied this information. The duration that can be compared is that for 833 panels of the building, 5.9 minutes was saved during the installation period. That equates to 10.239 days saved in the schedule for the installation of these glazing units. To account for some installation problems, inefficiencies or delays, it will be assumed that 10 days were saved prefabricating the glazing. This includes the prefabrication of the photovoltaic units.

*Photovoltaic Cost Analysis*

Once the schedule is complete, the cost to run the building must be calculated in order to see how influential the prefabricated panels will be. This will also determine the payback period for the photovoltaic units.

Within Memorial Vista are 3 switchboards at 4000 Amps each, where two of them in use and one is purely there for the connection to the future wing of Memorial Vista and is not connected to receive current. The calculations below will show the cost for the building to run its systems for the day, a month (specifically looking at January), and then the cost for an average year.

$$P_{(kW)} = \frac{\left[PF * I_{(A)} * V_{(V)}\right]}{1000} = \frac{[(0.8) * (4000A * 2\ Switchboards) * 480]}{1000} = 3{,}072\ kW$$

$$\frac{Energy}{Day} = (3{,}072\ kW) * (Time\ that\ Building\ is\ in\ Use)$$

For this estimation, an average office building was determined to be in use around 12 hours a day, where 7 A.M. to 7 P.M. would be the typical time frame. This is because the times that employees start and finish their day vary, where the peak load is in the middle of the day, but there is still power requirements to be fulfilled for the employees to get their job done early in the morning and when they stay late after work.

$\frac{Energy}{Day} = (3{,}072\ kW) * (12\ hrs.)$= 36,864 kW - h

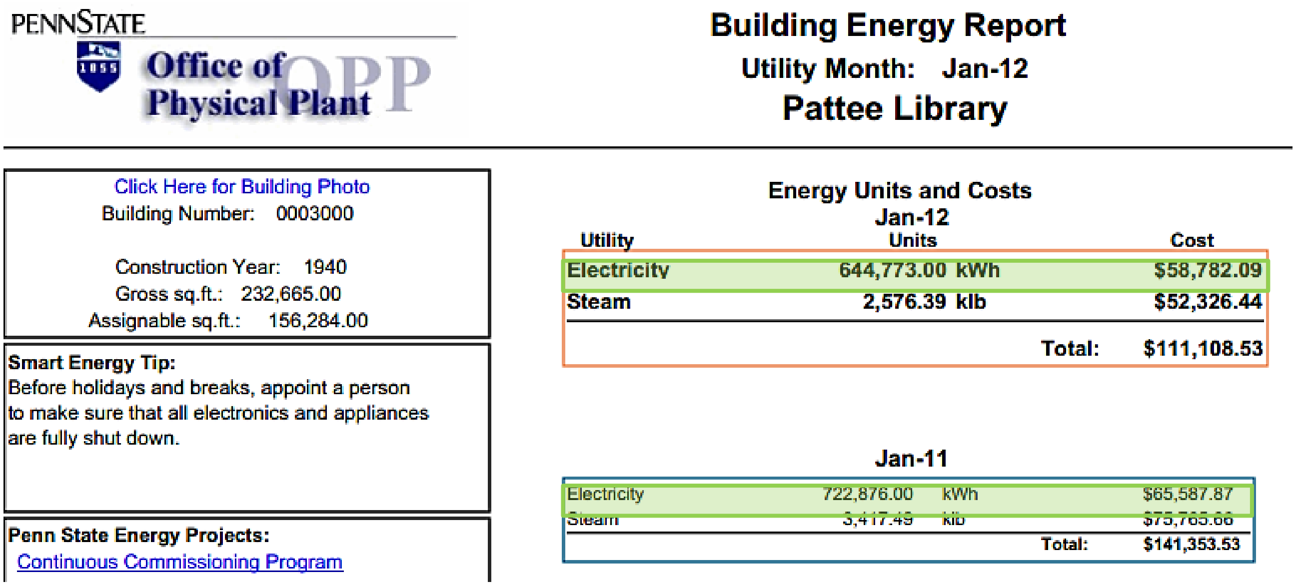
Next, the cost for a kilowatt-hour needed to be found for northern Virginia. This was determined to be an average of 8.20 cents per kilowatt-hour (U.S. Energy 2014).

Knowing this, the total cost for the power necessary to allow the building to perform the task of being an environment for leading aviation pioneers can be seen below.

$$\frac{Cost}{Day} = (36{,}864\ kWh) * \left(8.20\frac{Cents}{kWh}\right) = (302{,}284.8\ cents) * \left(\frac{1dollar}{100cents}\right) = \$3{,}022.85$$

$$\frac{Cost}{Month} = (\ \$3{,}022.85) * (\#of\ days\ in\ January) = (\ \$3{,}022.85) * (31\ days) = \$93{,}708.29$$

Looking at this information during the month of January, it can be compared to the electricity cost to the Pattee Library on the Pennsylvania State University's campus. Since both buildings will have similar loads and number of occupants, they will most likely result in comparative monthly costs. The only thing that must be taken into account is the gross square feet of each building. Memorial Vista has a total of 322,725 gross square feet, whereas the Pattee Library has only 232,665 gross square feet. The total cost for electricity in the month of January in both 2012 and 2011 can be seen on below.


PENNSTATE

Office of Physical Plant OPP

**Building Energy Report**

**Utility Month: Jan-12**

**Pattee Library**

Click Here for Building Photo

Building Number: 0003000

Construction Year: 1940

Gross sq.ft.: 232,665.00

Assignable sq.ft.: 156,284.00

**Smart Energy Tip:**

Before holidays and breaks, appoint a person to make sure that all electronics and appliances are fully shut down.

**Penn State Energy Projects:**

Continuous Commissioning Program

**Energy Units and Costs**

**Jan-12**

| Utility | Units | | Cost |
|---|---|---|---|
| Electricity | 644,773.00 | kWh | $58,782.09 |
| Steam | 2,576.39 | klb | $52,326.44 |
| | | Total: | $111,108.53 |

**Jan-11**

| | | | |
|---|---|---|---|
| Electricity | 722,876.00 | kWh | $65,587.87 |
| Steam | 3,417.49 | klb | $75,765.66 |
| | | Total: | $141,353.53 |

Figure 40 – Data Supplied for Pattee Library courtesy of Penn State's Office of Physical Plant

This figure, although has a smaller gross square footage compared to Memorial Vista, can be used to ensure the monthly cost estimate is on track for a building of its size and use. Although in different states, and varying gross square footages, the fact that the library's electric costs range from fifty-eight thousand to sixty-six thousand in the month of January is linearly interpolated to be comparable to that of Memorial Vista where the monthly cost in January was to be just under ninety-four thousand. The calculation was completed with costs that were most likely now and to date, and also was roughly one-hundred thousand more gross square feet. This was the reason for a higher monthly value for the cost of electricity in the month of January for Memorial Vista.

Lastly, the yearly estimate for power was calculated below.

$$\frac{Cost}{Year} = (\ \$3{,}022.85) * (\#of\ days\ in\ a\ year) = (\ \$3{,}022.85) * (365\ days) = \$1{,}103{,}340.25$$

If the actual cost to run the building is around $1.1 million per year, the cost with the photovoltaic glass can be seen to be reduced below

| | |
|---|---|
| (Actual Total cost of Electricity/ year) | $1,103,340.25 |
| (Cost savings of PV glazing of SW facade of S. Wing) | – $6,649.84 |
| (New Electric Bill with PV Glass Assistance) | $1,096,690.41 |

This means that the photovoltaic glazing units allow for a 1% savings per year.

## Results

Based on these cost savings per year, the payoff period must now be determined. It was found that the panel that was specified in Appendix F was averaged by Pythagoras Solar Assistants to cost $405.00. The façade that is comprised of the photovoltaic glazing units is 9,553 square feet, and the panel size is 25 square feet, than there will be a total of 382 panels necessary to outfit the south facing façade of the south wing of Memorial Vista. The resultant cost can be seen in table 3 below, where the total payoff period for a system of this nature in the location noted is just over 23 years.

Table 3 – Cost and Payoff Durations of PV Windows

| Cost of Each Panel | # of Panels | Total Cost of Panels | Cost Savings/Yr. | # of years until payoff |
|---|---|---|---|---|
| $405.00 | 382 | $154,710.00 | $6,649.84 | **23.26522142** |

The cost for the entire savings is also not entirely accurate. It does not take into account labor for installation or the other equipment costs for a solar powered system to be put back into the building. When the sunlight is turned into power, direct current is produced, but a building uses alternating current, so an inverter is necessary. Incentives were also not discussed, which may have made the photovoltaic glazing units more enticing.

## Recommendations

Per the results of this analysis, it is suggested that the proposed prefabrication process be implemented to reduce installation time, but the photovoltaic windows are not recommended for Memorial Vista. Prefabrication would allow the construction on site to be less congested and there would not need to be a designated area on site for workers to prefabricate the glazing panels on site. Through the process of prefabrication, the project is able to save an additional 10 days making the total duration saved for analysis I and II to be 43 days of the original 68 days that the schedule was behind. That means, if analysis I and II were implemented prior to the completion of the façade, the job may have only been 25 days behind schedule.

The photovoltaic glazing units were proposed and denied due to the payback period that they offer. The photovoltaic panels offer just over $6,600 per year on a $1.1 million dollar power bill, which is only a 1% savings. This minute amount allows the photovoltaic units to be fully paid off in just under 24 years, which is half the life expectancy of an average building. It is recommended that the technology of harnessing sunlight for power within a building be closely watched to see if a more efficient panel is released to the market, but until then, the payoff period it just too far into the future. The only truly positive factors that may sway an owner to accepting photovoltaic glazing units is the fact that there will be reduced property taxes, monetary incentives, and exempt or partial exempt solar energy equipment from local property taxes (Clean Energy 2013). Both spectrums of this technology need to be fully weighed before choosing a solution on whether or not to implement such technology.

To further this study, one could determine the cost of an electrician to wire the photovoltaic glazing units and determine the cost of an inverter. The other aspect that would need to be looked at further is the monetary tax cuts and incentives set forth by the government and/or town to see if any apply to installing photovoltaic glazing units in the specific area. By researching and finding more about these two areas, the payback period for the photovoltaic class could have been more accurate.

# Analysis III – Implementation of an Automated Parking Garage

## Problem Identification

The utility relocation process was a severely influential stage early on in the project and heavily changed the original schedule and sequencing of the job to attempt to make up time in the schedule. Although these setbacks were a result to unforeseen conditions, the time must be made up as much as possible to hand over the job as close to the original base building completion date as possible. Items and sequencing processes on the schedule were studied and performed in the most efficient manor but the schedule remained around two months behind the original schedule.

One of the main reasons that the schedule could not be fully shortened was due to the fact that the entire site of 4.7 acres needed to be dug to the lowest footer depth in search of contaminated soil. The original twenty-five test bores over the 204,966 square feet of the lot showed some minor contamination in the soil, so the land was assumed to be contaminated as a whole. This site can be seen in figure 41 below, where it is important to note that since the entire site was to be excavated there was no one area that could be used as an assembly point, staging area, or location for job trailers. These specific areas crucial for a job site were to be sequenced and changed based on the work taking place and the schedule of future events on the project. During excavation, if the soil was found to be contaminated, the proper techniques were to be used to dispose of the toxins. As the excavation process was undergone, it was found that the soil was not contaminated in a majority of the lot, but rather small and erratic in nature. In the locations where the soil was contaminated, the soil was quickly and efficiently removed and disposed of through excavation and transportation to burning plants off site.

In the end, the 4.7 acre site was dug to a depth of around 29.17 feet equating to a volume of just over 221,000 cubic yards looking for contaminated soils. If the site did not have to be dug this deep or there was something that could have been done to eliminate contaminated soil, the schedule would have a better possibility of getting back on its original path. Figure 41 shows the surface of the 4.7 acres that needed to be decontaminated.


Figure 41 – Site to be excavated courtesy of Google Maps

## Analysis Goals

After Analysis I and II, the project schedule has been shortened 43 days of the 68 total work days that the schedule was extended after the utility relocations. For this final analysis, the goal will be to get the project completely back on schedule or as close to the original scheduled completion date. The result of this third analysis will be to present an alternative that will keep the quality that the owner and architect desire, but accelerate the schedule in a way to perform the job and complete it to the proposed completion date. To do this, the soil contaminant mitigation will be studied closely before the analysis begins. The goal will be to remove all contaminants in the soil without excavating the entire site. This process must be monitored in the duration that it would take to install and remove the contaminants and hopefully result in the duration to be fewer days than completely excavating the site. The next step will be to take the traditional multi-story parking deck and transform it into an automated parking garage. By doing this, the total depth and area that needed to be excavated will be significantly reduced, and should further reduce the duration of the schedule to bring it back on schedule. In the end, it is believed that a total of around ten to twelve days can be saved if the soil contaminant mitigation is performed in a schedule effective manner, and a proper design is established for an automated parking garage.

## Process

For Memorial Vista, the soil contaminant mitigation process was thought to be extensive due to its past, but resulted in minor amounts of contaminated soil to be pulled from the earth and removed from the site. The reasoning behind the large excavation and remediation process was due to the fact that there was a junk yard and scrap metal recycling facility from 1934 to 1988 across the street from the sites property. It is known that high concentrations of lead, arsenic, and polychlorinated biphenyls (PCBs) are below grade on this adjacent lot and capped with a layer of asphalt to prevent distribution of the toxins in fresh water. It was presumed that these contaminates could possibly travel to Monument View's site and pollute the soil.

The other factor that led to the belief that there would be significant contamination levels in the soil below grade was the fact that one of the past uses of the property was an auto body repair shop and repair facilities. To accompany these facilities were several 55-gallon and 25-gallon toxic drums that could have led to contamination, along with the numerous scrap car parts lying around.

*Soil Contaminant Mitigation Alternative*

To look further into the sites soil condition a geotechnical report was compiled, where test bore samples were conducted to determine the soil type, water table, conditions, and contamination level. In the end, twenty-four test bores were completed in a combination of the years 2005 and 2010. The map of these approximate locations can be seen in figure 42 on the following page.

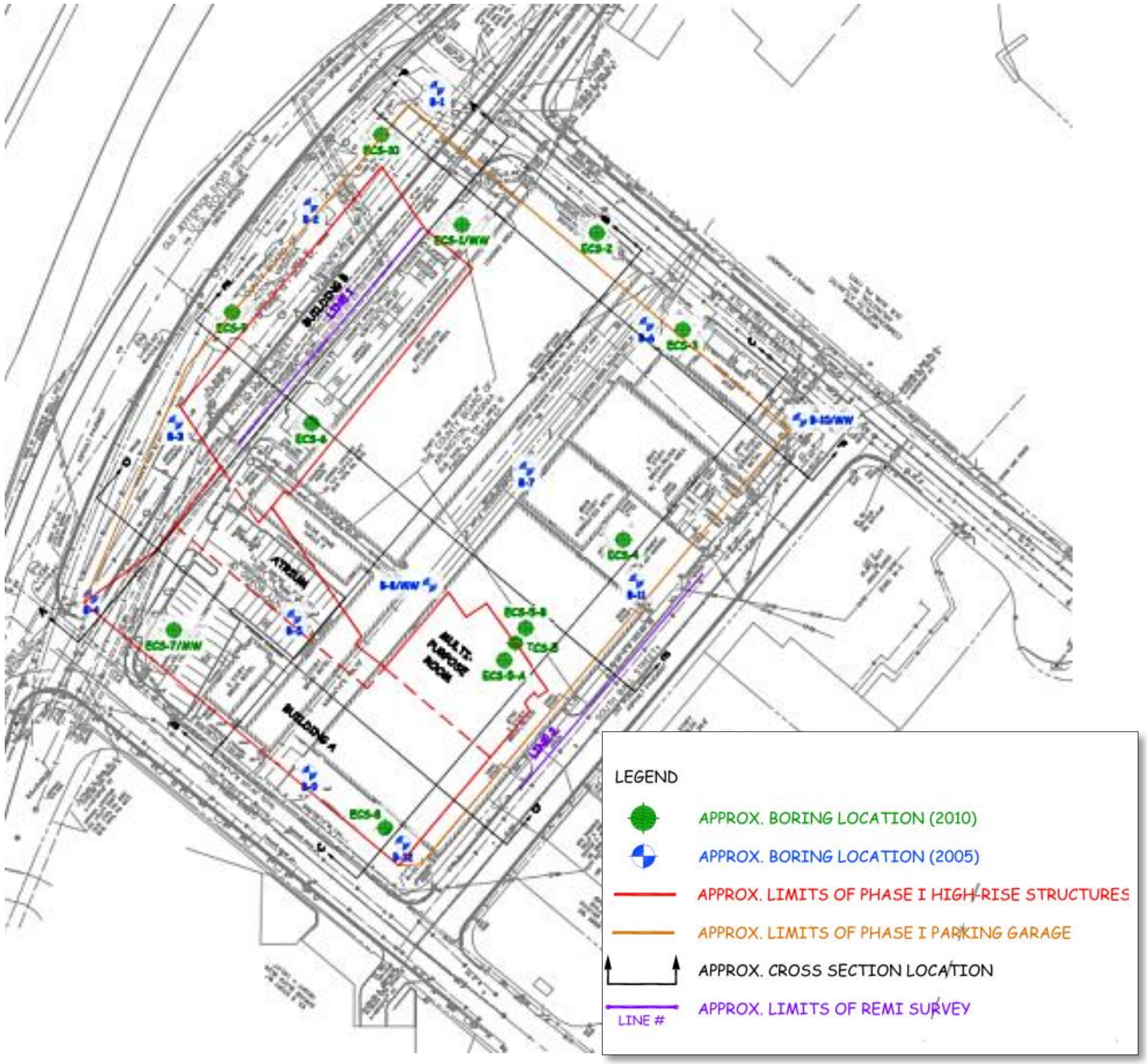



Figure 42 – Test Bore Locations Courtesy of Davis

The samples (especially in the northern plot of the site) showed some contamination in the samples that were pulled during the test bores, but not nearly as much as anticipated. The owner of the building wanted to take no chances and stated that they wanted the entire site to be excavated and undergo contaminant mitigation regardless of the cost and schedule impact put on the project. This meant that the entire 4.7 acre site was excavated to the lowest footer depth of 29.17 feet. That being said, and average dump truck holds 15 cubic yards, and the entire site contains about 47,061 cubic yards of soil. This results in the possibility of 4,471 truckloads of contaminated soil leaving the site.

If the owner allowed the team to mitigate the contaminated soil in a different fashion that suited the concentration of saturation and the soil consistency, numerous weeks could be saved due to the fact the entire site would not have to be excavated in search of the contaminated particles.

According to the Department of Environmental Quality, there are many methods for excreting the toxins in its original place, or "in-situ" (Scheel 2011). The various methods for removing these toxins range from soil removal, landfill disposal, above ground biological treatment, thermal treatment, and soil aeration. All of these treatments take the soil and expunge the out the pollutants, weather that is on site or off. Typically, in-situ treatment can be expensive but becomes more cost effective when large amounts of contamination are present or would be difficult to remove. To ensure that there is significant contaminated soil below grade on the project site, there needs to be numerous subsurface investigations to inform the owner, general contractor, and subcontractor performing the mitigation what is happening below the surface.

In the end, if soil mitigation is necessary, no matter what the process must be to remove the toxins, a solid waste permit for treatment will be required. This type of permit is called a Solid Waste Letter Authorization and requires the payment of a $500.00 permit fee (Scheel 2011). If this process was to take place, it would have been most effective to obtain this permit in the procurement stages of the project and this cost would have to be added to the overall cost of the project.

After looking at the test boring logs, the soil type is primarily silty-sand and silty-gravel. The full geotechnical report for a single test bore can be seen in Appendix I. Based on this data discovered and the soil types that are dominant in the area, it would be suggested that in-situ thermal treatment should take place. This type of soil contaminant mitigation is extremely effective in soil similar to the consistency found at Memorial Vista, which would further accelerate the process. The only down side to this specific soil mitigation procedure is the monetary value associated with it. The reason for an increased cost is primarily due to the cost of the equipment used and the operations and maintenance costs.

In-situ thermal treatment was chosen over the other alternatives due to the types of contaminants in the ground, the soil types, and how rapidly the contaminants can be purged. Soil aeration was not chosen due to the fact that the contamination would be transferring from the soil to the air and creating further problems with the surrounding locations. The next choice to remove the toxins would have been through advanced chemical oxidation. This process would take place through direct and immediate contact with chemical oxidant, where the soil and the contaminants within the soil would undergo rapid oxidation reactions. The only issue with the Redox reaction method is that not all the contaminants are degraded quickly or completely, and predicting the final treatment concentrations from previous studies is virtually impossible (United States 2006). In other words, this method could either take place rapidly or take and uncharted amount of time, but either way it would be nearly impossible to put a date into the schedule for the activity.

As a result, the best method for the site of Memorial Vista was in-situ electrical thermal treatment. This method is known for increasing the temperature of the soil below grade, all while decreasing the viscosity. This then results in increased solubility and decreased absorption. The ground is heated to these high temperatures through the use of three-phase power in triangular electrode arrays. The electrodes on this equipment can be thought of as wells that are equipped to deliver electric power at selected depths and also act as vapor recovery wells. When ground-water flow rates are high, the semi-volatile hydrocarbons are to be recovered as the liquids are retracted from the ground. The vapor that contains the contaminants from the soil is then taken to an onsite vapor treatment building where it is to be treated. The horizontal spacing between electrodes is usually between 14 and 24 feet (United States 2006). The result is the closer the spacing between the electrodes; the quicker the soil is heated, but the more expensive. On the other hand, fewer electrodes mean heating the soil for a much longer period of time. The layout for a typical thermal treatment process can be seen in the figure to the right.

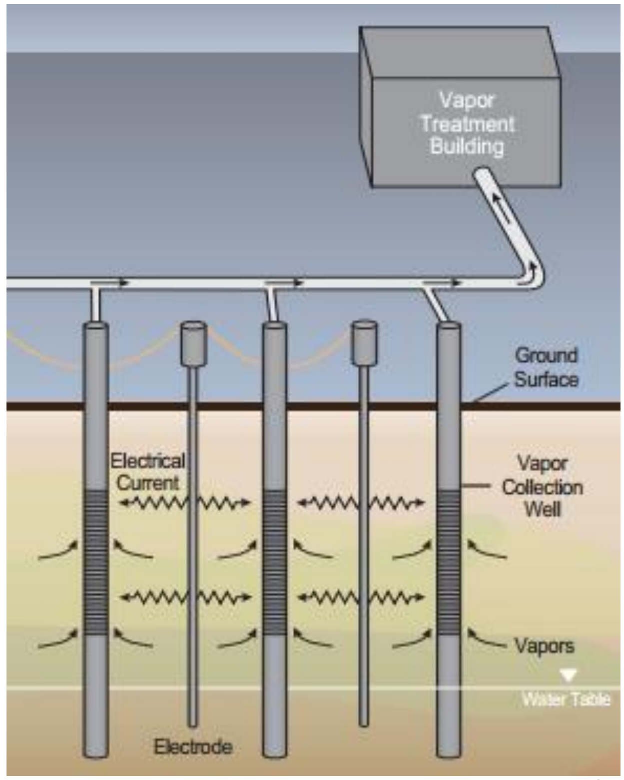


Figure 43 – In-Situ Electrical Thermal Treatment Setup Courtesy of http://www.epa.gov/tio/download/citizens/a_citizens_guide_to_in_situ_thermal_treatment.pdf

The electrodes may be installed using conventional drilling rigs, both through vertical or angular drilling techniques. When staging these drill holes, caution should be taken to ensure that the potential for stray currents is accounted for in the design. Care should also be taken in designing the systems to ensure that all plumbing, including monitoring wells, are capable of withstanding high heat. In the presence of clay, vadose zone heating by resistivity, conductance, or radio frequency may result in some settlement of the treatment area due to the drying of the clay (United States 2006).

The electrodes can be deployed to any depth that the drill rig can go and used in both vadose and saturated zones. If the system is deployed only in the vadose zone, water should be added at the electrodes to maintain the moisture content and thus, the flow of electricity (United States 2006). That is the case for Memorial Vista, since the soil is silty sands and clay. Although water is known for not rapidly permeating silts, the electrodes heat the more conductive silt and clay. Temperatures over 100°C can be generated in the saturated zone and these temperatures produce steam and steam stripping, which is especially beneficial for the silts and clays as contaminant movement in them is usually diffusion limited (United States 2006).

This is crucial for Memorial Vista since the soil type is exactly what heats up the fastest, resulting in soil mitigation promptly taking place. As the soil is heated, the steam is produced and contaminants are recovered via vacuum extraction and processed in the vapor treatment building at the surface. The figure below shows a potential layout for the wells of the nodes. There are 2,124 wells, which results in 1,062 electrodes and 1,062 vapor collection wells. The wells are space ten feet apart from each other, which allow the electrodes to heat the earth much quicker. This will result in a shorter contaminant mitigation time.

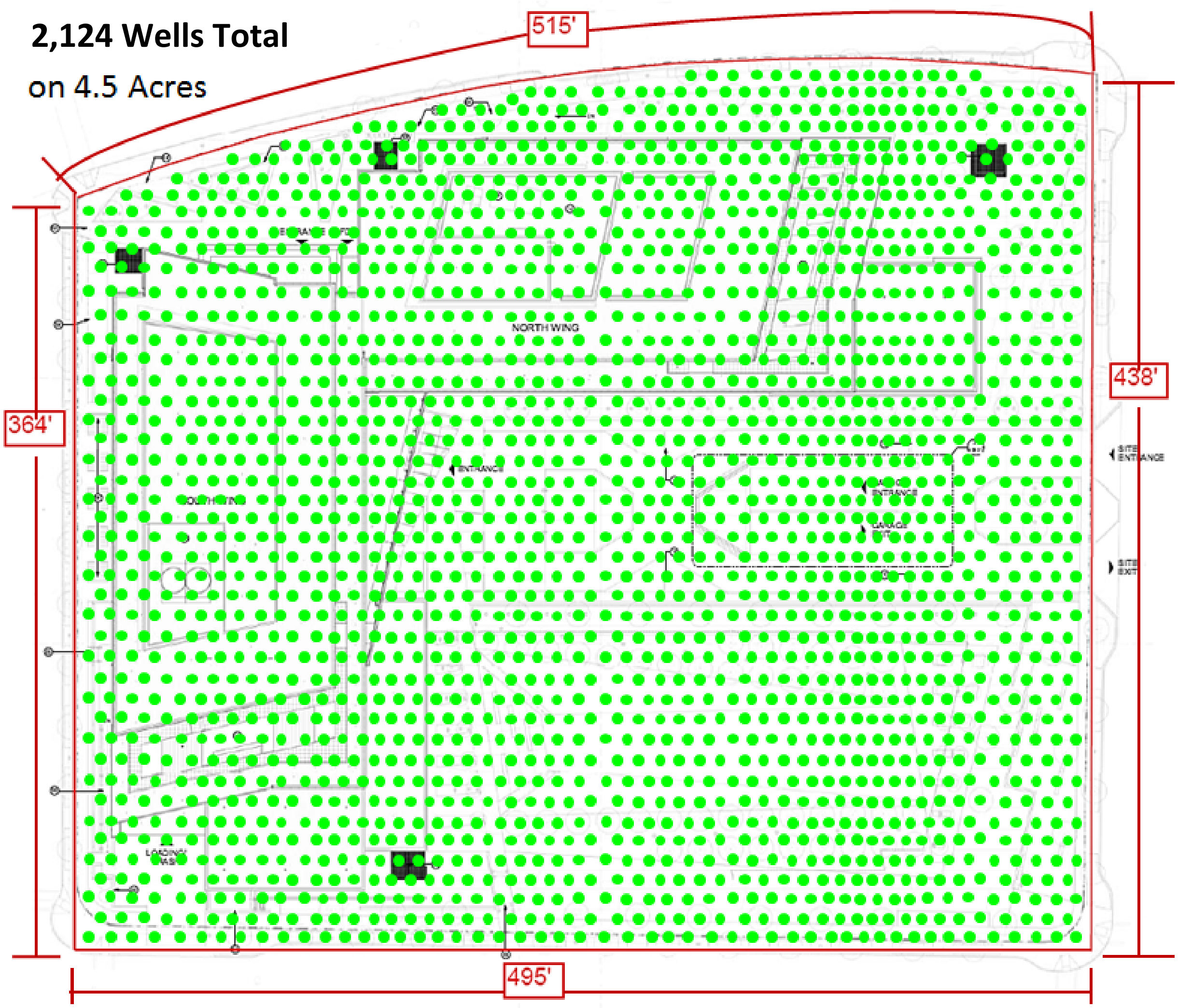



Figure 44 – Electrical Thermal Treatment Layout

The U.S. EPA (2004) provides remediation cost estimates of $32 and $73 per cubic yard at two full-scale sites; whereas Beyke and Fleming (2005) estimate that the contaminant removal costs $200,000, plus $40 to $70 per cubic yard. In the end, the technology is proven and has been used at a number of sites, but the number of vendors offering the technology is limited (United States 2006). That being said, if Memorial Vista is to undergo thermal treatment for 4.7 acres and 29.17 foot depth minimum, there would be 47,061 cubic yards of soil. The U.S EPA (2004) would estimate the cost of this soil mitigation to be between $1,505,952 and $3,435,453.

This is comparable to Beyke and Fleming (2005) where a total would range between $2,082,440 and $3,494,270. An average of these estimates would most likely be taken and input into the original total cost for site work for this project which was $11.1 million. That number could easily grow to 12 or 15 million if thermal treatment was chosen, which would be a 14 to 24% increase in cost for the site work alone, but this would be counteracted where general conditions, labor, and equipment costs could all be saved in the new treatment plan.

The next step was to look at the duration to use electrodes to thermally remove toxins from Memorial Vista's Site. A case study was found in Fort Lewis, Washington on the East Gate Disposal Yard. Although the location of the project is on the other side of the country, the aspects are primarily the same. Non-aqueous phase liquid contaminants similar to the ones found below Memorial Vista's site, and electrical resistance heating was used to remedy the situation. The East Gate Disposal Yard had an area of 25,400 square feet, where 106 electrodes were placed. This means that each electrode was to cover around 240 square feet of surface at varying depths (Beyke 2005). Memorial Vista has 4.7 acres of space, which is equivalent to 204,732 square feet. The example layout of the wells found previously stated that the wells for this site would be placed at about 10 feet. This means the area that these electrodes are responsible for on the Monument View site only need to treat around 97 square feet of area at varying depths. In the end, this would result in a high cost to drill and operate so many wells for electrodes, but the time to remove the contaminants form Memorial Vista's soil would be about half of that of the case study found. This is due to the fact the electrodes are much closer to one another. If the case study of the East Gate Disposal yard took 60 days to purge the contaminants form the soil, Memorial Vista could take about 30 days. This is extremely accelerated, seeing that the original soil mitigation process that was actually done was completed through the process of excavation and treating the soil at an external plant. This process was to take 115 days for original excavation for entire site. This process started on November 29th, 2011. Although this method is more efficient in the contaminant mitigation, it is important to remember the duration to drill the wells for the system. If an auger is used, it is estimated to drill 65 wells a day, leading to an additional 32 days for drilling. These 32 days don't have to be scheduled in a start-to finish manner; because the electrodes can be installed as the auger makes its way across the site. In the end, it is estimated that the electrical thermal treatment will take a total of around 45 days. This process results in being about half of that of the excavation process that was actually completed on the project to mitigate the soil.

After completing this alternate study on how the soil can be decontaminated, the schedule is minimized by 70 work days, which allows the actual excavation for the building's foundation to start on February 8th, 2012. This value of days saved does not take into account that while the contaminants were being mitigated, the excavation process was taking place. The original excavation included the mitigation of the soil and the duration was set to be 115 days total. If the excavation of the new automated parking garage can be completed in less than 70 work days, the scheduled duration will result in a shorter time frame. This is possible since the excavation process will be dug to a significantly shorter depth when being compared to a traditional parking garage.

*Automate Parking Structure Design (Breadth 2)*

The previous underground parking garage was two levels where P1 is the first level below grade and P2 is the second level below grade. The plans of both of these levels can be seen below in figure 45. Here, the circulation within each level of the original parking garage can also be noted.

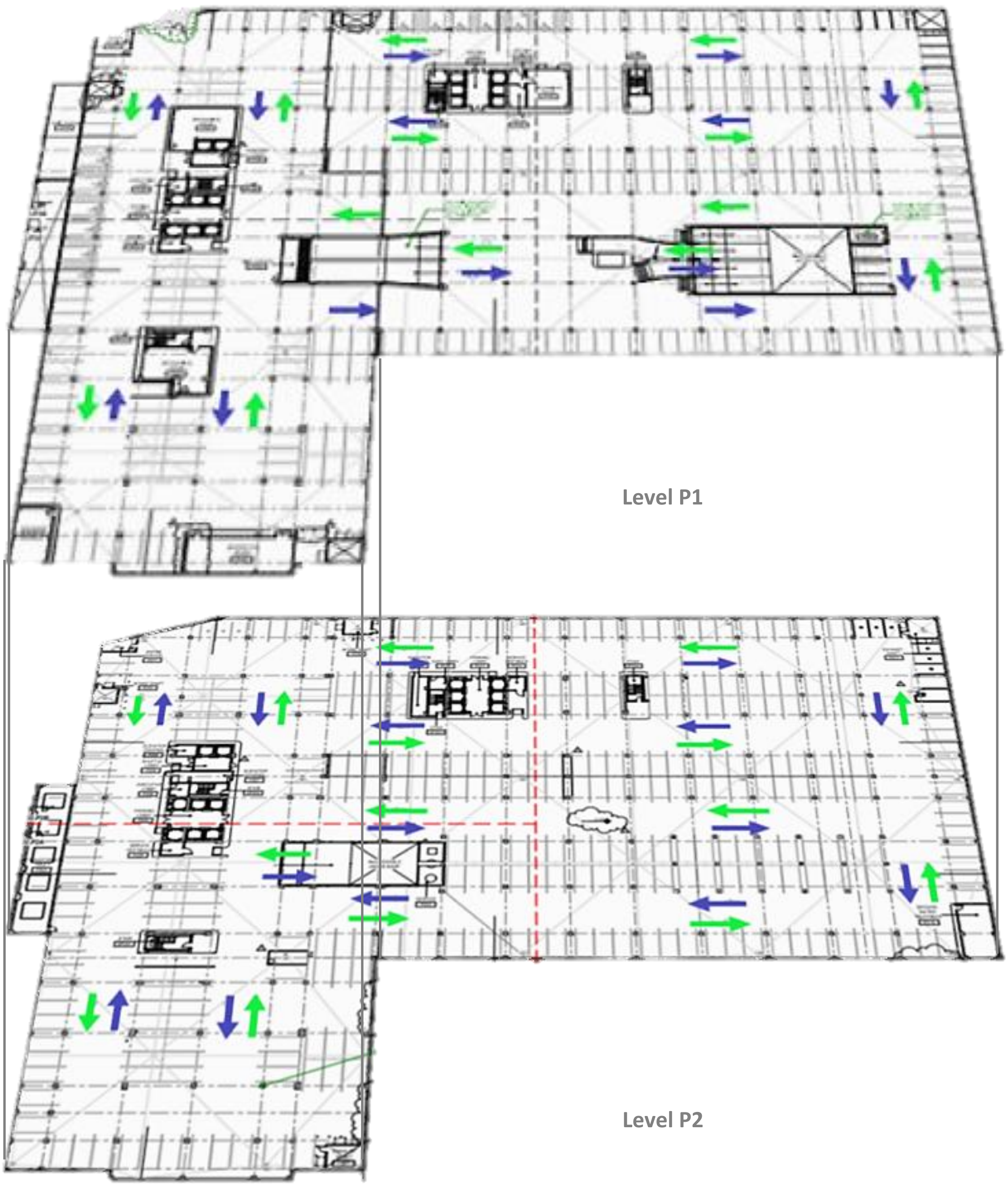



Figure 45 – Original Parking Garage Layout

The important thing to note from the original garage is that the layout allows the driver to drive throughout the structure and eventually park their car when a space is found. A typical car could travel in a similar pattern to the car in the figure below, where time is taken to find a spot within the structure and eventually exit the structure by foot.

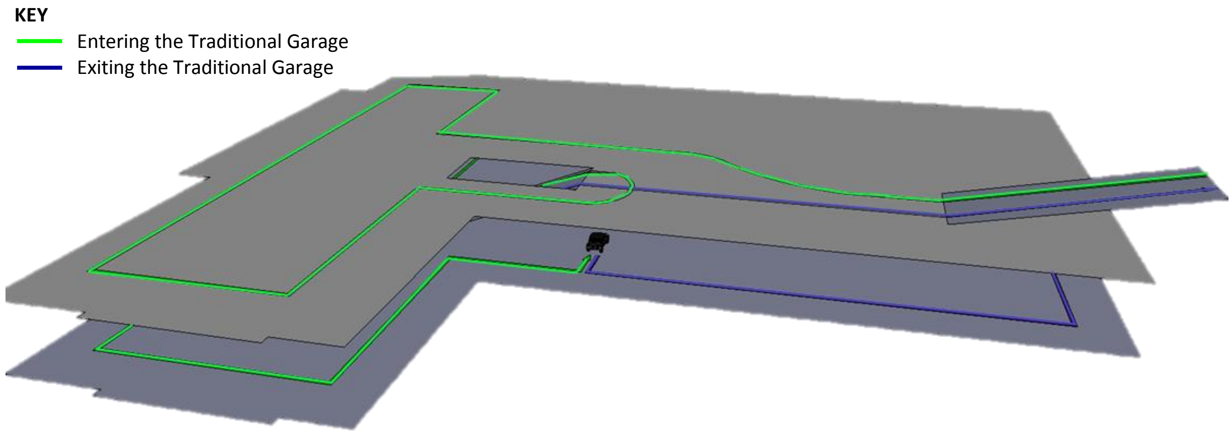



Figure 46 – Original Parking Garage Travel Path

This garage is composed of two levels of 123,765 gross square feet each, leading to a total of 247,530 gross square feet for the entire underground parking garage. Taking this into account, and the fact that the original garage has 556 total spaces, each space allows for a little over 430 square feet per space. This total amount takes the area that is necessary to drive around the garage and distributes it into the parking space areas.

To reduce this large amount of space, an automated parking garage will be designed to see is space and time can be saved. Prior to design, the benefits and disadvantages must be weighed to see if the garage will have the potential to produce a garage better and quicker than the previous one.

According to Fred Gorove of Unitronics, the benefits of an automated vehicle storage retrieval system are greater parking capacity, lower overall costs with similar capital investments to conventional parking, reduced pollution, and increased safety and personal security (Gorove, 2013). This automated garage, compared to a traditional ramp-style garage, also allows for a shallower excavation since the floor to floor heights are significantly less than a traditional garage. By having a shallower excavation, the schedule has the potential to be accelerated and the job could become fully back on track. The final major benefit is that the power consumption is significantly reduced. Since no human activity will take place in the garage where the cars are stored (other than maintenance), the garage does not need mechanical equipment supplying fresh air suitable for human occupancy or electricity for lighting the space. This will lead to reduced costs over the life cycle of the building. The only system that must remain in the garage is the pneumatic lifts for picking up the cars and putting them in various locations. Lighting and ventilation will only need to be done in the vehicular and pedestrian traffic areas.

The only real disadvantage is that there can potentially be a line waiting for the machine to retrieve ones vehicle from the garage. This concern is addressed over time as the computer detects patterns in the time that the employees typically leave the building, and then arranges the cars in a strategic fashion. This leads to efficiency and allows the user to obtain their vehicle in a fairly quick manner.

Although the user experience in obtaining their car from the automated garage may result in waiting in a line, that would be no different than waiting in a car as a line of employees exits through the gate at the entrance and exit one at a time. Unitronics performed a study comparing the conventional time it takes to park and retrieve a car as compared to an automated one. The diagram below shows the comparison in a graphical form.

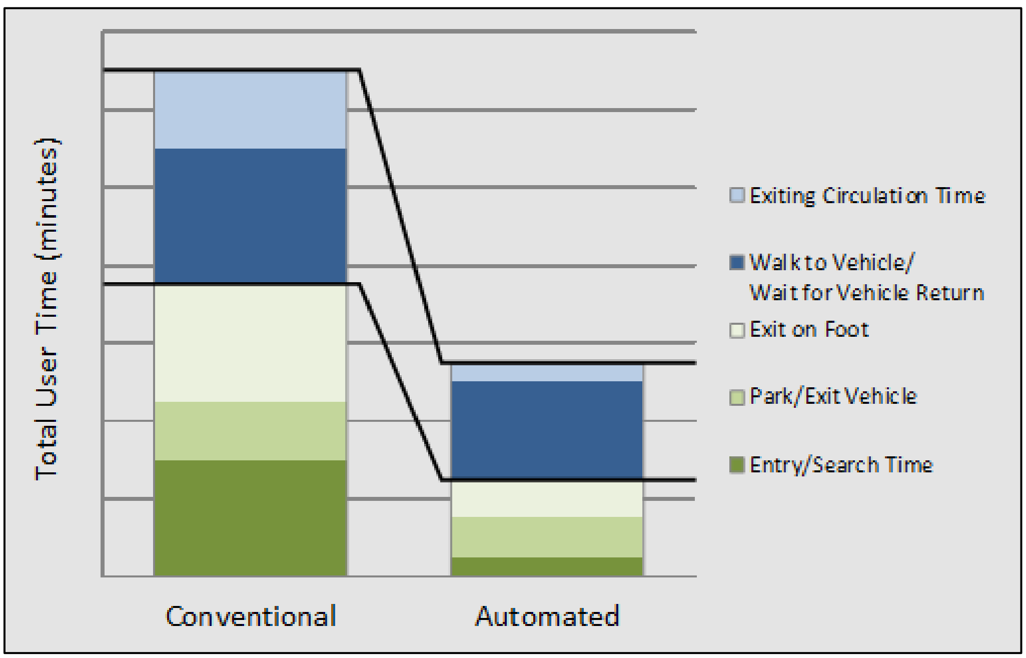



Figure 47 – Time comparison between Conventional and Automated Garage Courtesy of Unitronics

The figure shows that automated garage virtually takes half the time of that of a conventional garage when a vehicle is being retrieved.

The way these automated garage works is a simple manner. Once the driver pulls the car into the garage, they then pull into individual structures that look like individual box like structures. The floor of this smaller garage is actually a pallet that can rotate and move. Once the car is in the correct location and has been indicated to the driver though visual signals and sounds, the vehicle is turned off. The driver then exits the one-car garage and everything else is automatic. A brief safety check follows. Next, the car, on the pallet, is transported vertically and horizontally until it is brought to a vacant parking space (Gorove 2013).

The next step was to find a case study to base the excavation and area of the garage off of. This was found to be the Dubai International Finance Centre in the United Arab Emirates. This building, according to Fred Gorove, is a multi-use building comprised of office space, hotel rooms, residential units, and retail spaces. To accommodate all of these people that could potentially be occupying the building, a plan had to be set forth to park the highest amount of cars in the smallest amount of space. This is where the automated parking garage was implemented into the planning phase of the project. As the building was being excavated, it was determined that the depth excavated was half of that of a traditional garage that would have been put in place. The garage also used 60% of the volume compared to conventional parking, where ramps and drive isles were eliminated. This then allowed the vehicles to be parked closer together both horizontally and vertically.

If this information is transposed to an automated parking garage for Memorial Vista, where the depth excavated could be around 14.6 feet with an overall area of about 74,259 square feet. This was found due to the excavation being half of the original 29.17 feet and sixty percent of the volumetric area of the 123,765 gross square feet for one level. The volumetric area of what the new automated parking garage will be constrained to will be seen below, but the design and parking locations still must be determined, due to the fact that these values are simply estimates as of now. The second figure below shows the actual size comparison that the garage resulted in, after code and dimensions were finalized.

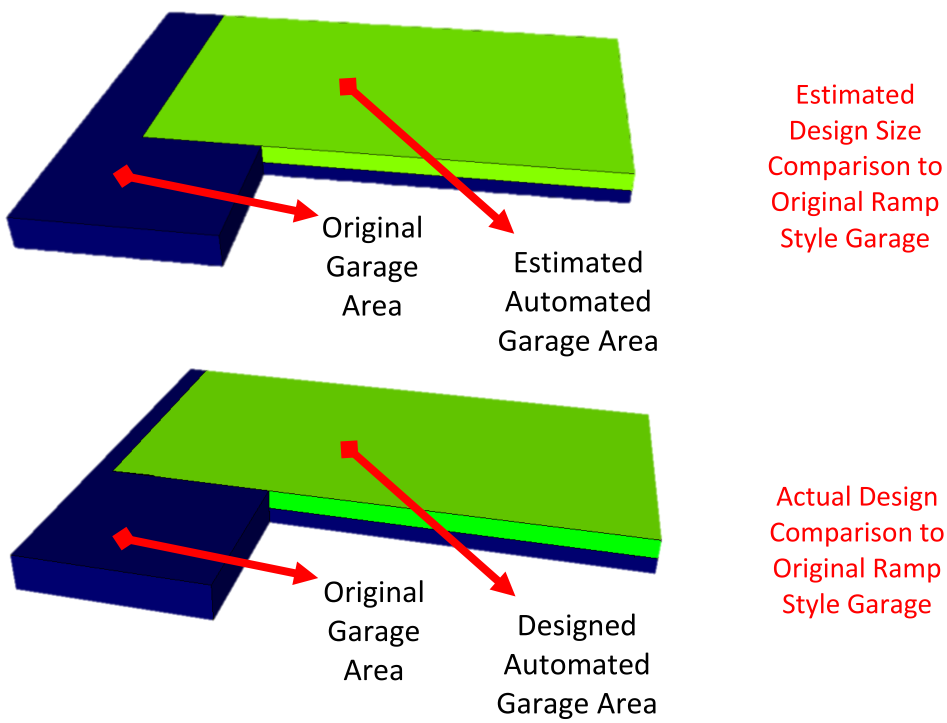



Figure 48 – Area Comparison between an Estimated Automated and a Traditional Garage along with Actual Design Comparison

In comparison, the figure 48 on the previous page shows the actual garage to be a little more area than the typical estimate and a little deeper than anticipated. These dimensions and circulation code were outlined by Fred Gorove of Unitronics to be specialized to this building.

A model of the new automated parking design can be seen below,

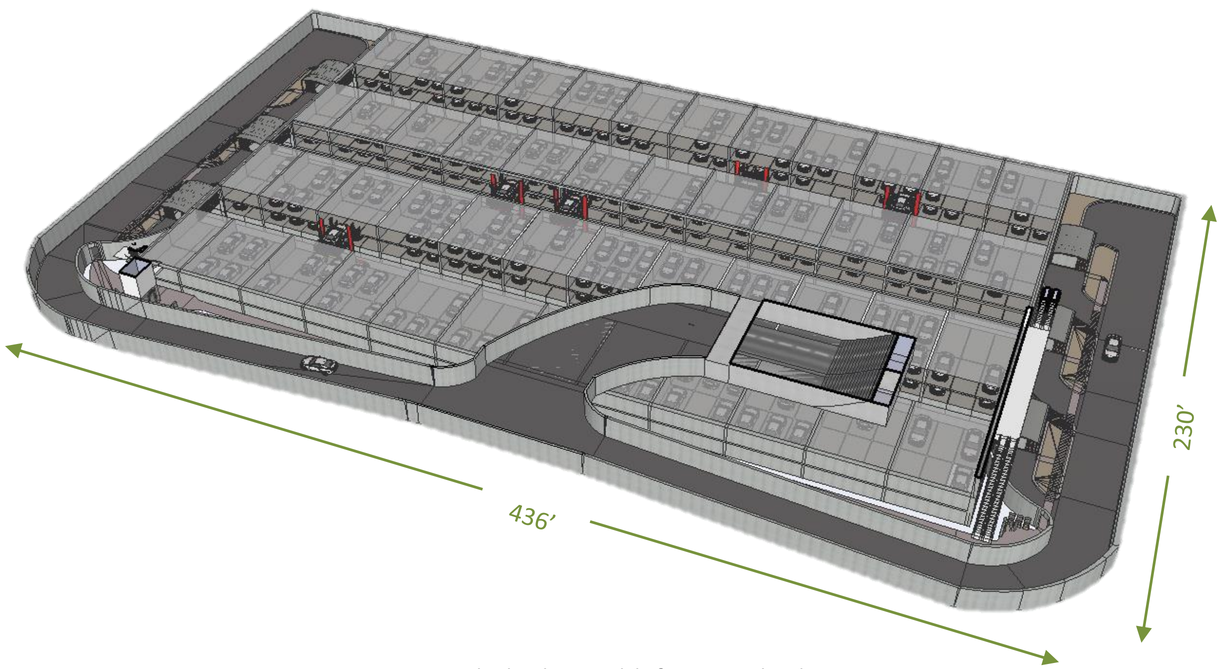
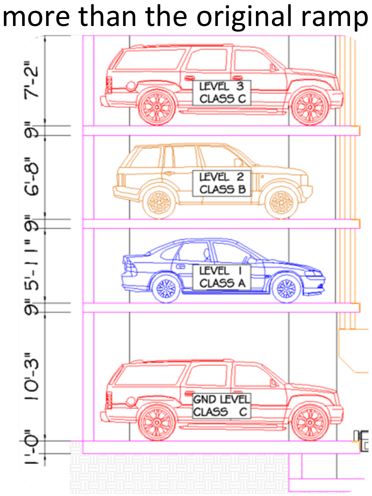



Figure 49– Google SketchUp Model of Automated Parking Structure

This design yields a length of 436 feet and a width of 230 feet. The garage will need to be excavated a depth of 16 feet. The reason for this is the top layer on parking is a floor to ceiling height of 7'2" and the level below that is 6'10". The remaining height is for the space below the levels to allow the pneumatic lift to run on a track to move the cars. Figure 50 shows the standard elevations associated with each car class. This garage for Memorial Vista was designed with the largest cars in size, where class B and C can easily fit, along with the smaller class A cars. It is also important to note that the number of parking spaces this structure holds is 560, which are 4 more than the original ramp structure.




| Dimensions | Class A | Class B | Class C |
|---|---|---|---|
| Length | 197" | 212" | 228" |
| Width | 86" | 86" | 86" |
| Height | 63" | 72" | 78" |
| Weight | 6,600 lbs | 6,600 lbs | 6,600 lbs |

Figure 50 – Area Comparison between an Automated and a Traditional Garage

To further show the design of the automated parking structure, the vehicular circulation plan can be seen below.

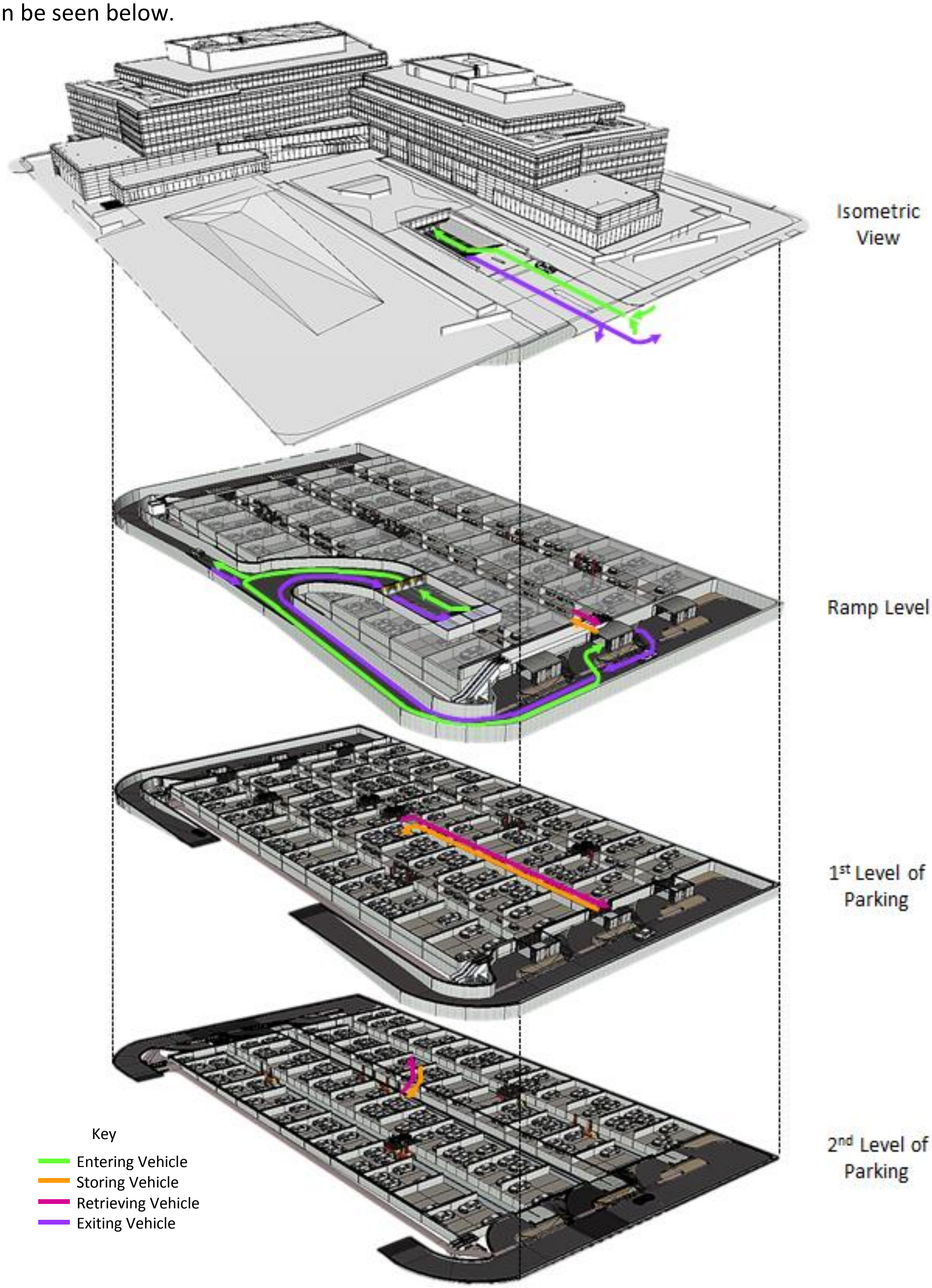



Figure 51 – Vehicular Circulation within Automated Parking Garage

The green in the following diagram is traffic going into the parking structure. Once in the single car garages, the automated lift picks up the car, only keeping in contact with the car's rubber wheels and never making contact with the car's body. The orange represents the automated system putting the car into a parking spot, where pink is the car being retrieved. The purple is then the vehicle exiting the parking structure.

To accompany the vehicular circulation plan, a pedestrian traffic plan was also completed. The numbered pictures surrounding the image show snips from the Google SketchUp model.

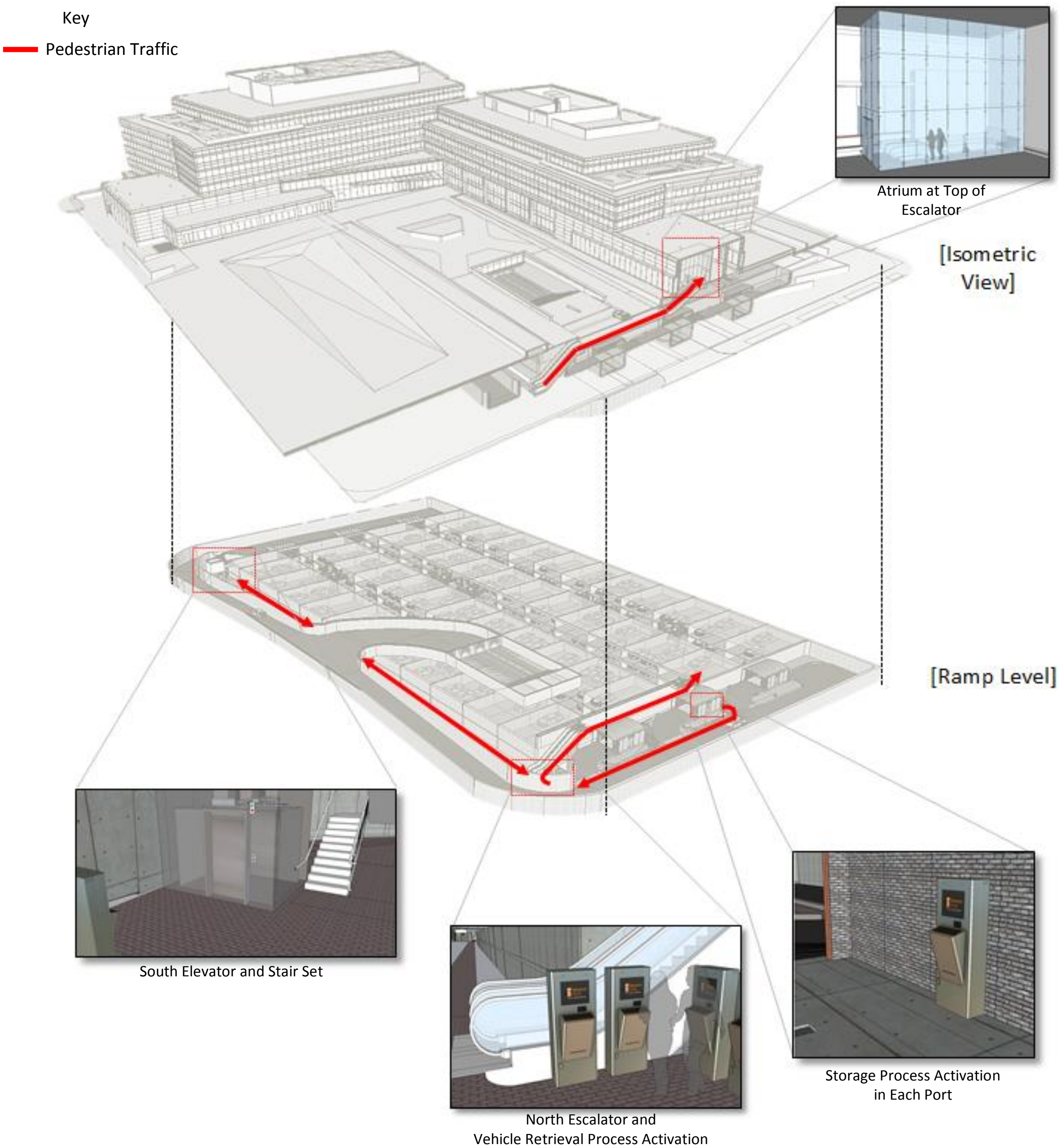



Figure 52 – Pedestrian Circulation within Automated Parking Garage

*Vehicle Storage*

To take a closer look at how the automated garage actually works, the figures below show sequentially how the car is stored once in the car port. This process is fairly simple and is completed in little time, where only a few questions and checks are asked at the kiosk prior to the vehicle being stored. To speed up this process, the system can be accompanied with an electronic pass system that is associated with the car where the pass is simply touched to the sensor and all the data is collected and the car is stored immediately.

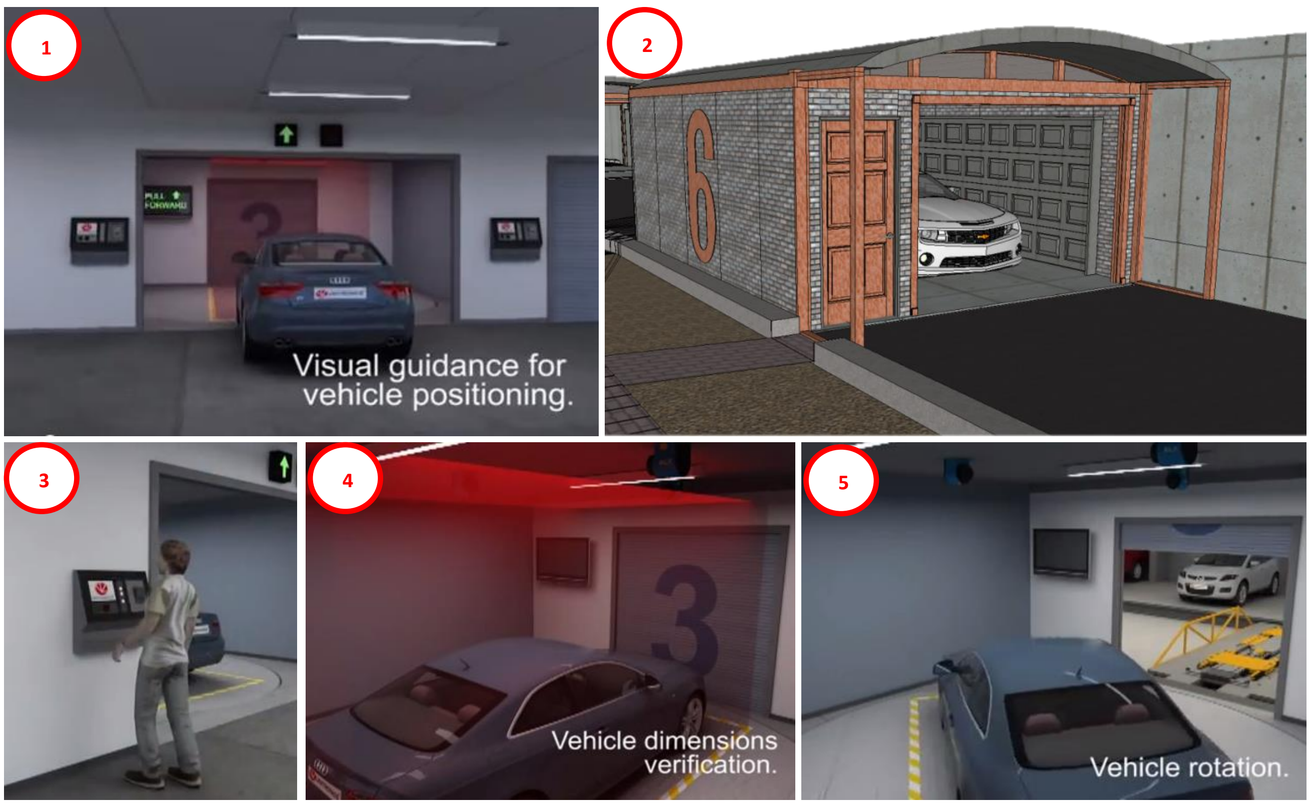



Figure 53 – Sequential Steps of Car Storage in Car Port

1. The driver pulls into the individual car port, head first. To aid the driver in their positioning, there is visual and automated guidance.
2. The car is now in the car port and the user is then instructed to turn the car off and to exit the vehicle.
3. The driver heads to the storage process activation kiosks. Here, the car type and owner are taken into account.
4. As this is taking place, the vehicle dimensions and position are being verified.
5. If necessary, the vehicle can be rotated and then undergoes the storage process.

*Vehicle Retrieval*

After the work day has been completed, the vehicles need to be retrieved. This is simple and can be done either at the vehicle retrieval kiosks or there is a call or text ahead feature to request ones vehicle.


Figure 54– Vehicle Retrieval Process

Just like a typical ramp style garage where a ticket for parking would be paid, there is a kiosk that one would request their vehicle. Accompanying this space would be a monitor sharing the order in which the vehicles are being picked and along with the status of each bay.

If the call or text ahead option is used, the user will get a notification when their car will be ready and in which port.

*Duration of Automated Garage Excavation*

The next step was to look at the duration to excavate this new structure in comparison to the old ramp style garage. These new dimensions and depths led to new excavation durations. As stated previously on page 52 of this report, if the soil mitigation is completed using in-situ electrical thermal treatment, there would be 70 days left to complete the excavation for the duration of the mitigation process and excavation to remain the same as originally planned. If the excavation was to take less time than the 70 remaining days, the project's schedule would become accelerated to be back on track to the original completion date after the utility relocations extended the project duration.

The mitigation of the contaminated soil was to be the entire 4.7 acre site down a distance of around 29 feet in some areas and shallower in other areas. In the end, the old excavation process resulted in a total of 132,650 cubic yards. To remove this soil and get the site to the necessary elevation, 115 days were required in the projects overall duration.

The new automated parking garage is shallower and the amount of soil that needs to be excavated is significantly less due to the fact the soil contamination problem has been resolved with the use of the electrical thermal treatment. The total amount of soil that needs to be removed for the new automated garage is only 59,426 cubic yards. This is less than half, or 45%, of the soil that was originally removed from the site as compared to the old ramp style garage and excavation of the entire site.

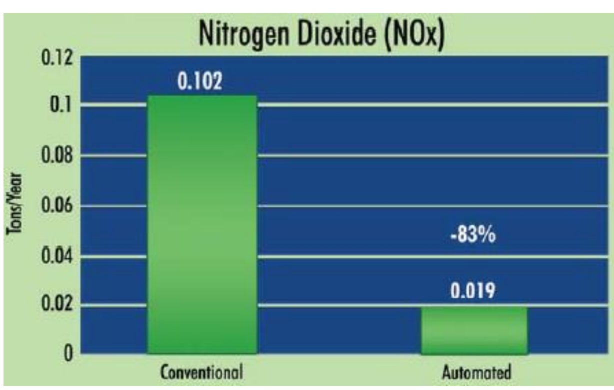
If the same rate of excavation is interpolated to the new automated garage excavation, it would be found that the old excavation of the 132,650 cubic yards and 115 days to excavate this volume would result in the excavation contractor being able to remove 1,153 cubic yards per day. If the new excavation of the shallower and smaller area contains 59,426 cubic yard that need to be removed, and a rate of 1, 153 cubic yards per day is used, than around 52 days would be needed to excavate the new site.

Since the mitigation process took 45 days total, which leave a remaining 70 days for excavation. The calculation above just showed that 52 days would be needed to excavate for the automated parking garage. In other words, the soil mitigation originally took 115 days, whereas now the total for the automated parking garage and electrical thermal treatment are a combined total of 97 days. This saves 18 work days from the project duration.

## Results

In the end, using in-situ electrical thermal treatment along with implementing and automated garage design was able to both fulfill the need of eliminating the contaminants from the site's soil and allowing a garage to fit the necessary number of cars for the office building. Doing both of these tasks in a shorter time frame allowed the schedule to be closer to the date that the base building completion was originally scheduled for before the utility relocation mishap.

Beyond being a reduction to the schedule, this analysis also leads to enormous unforeseen benefits to the users, the environment, and the building owner. According to Fred Gorove of Unitronics, the automated garage offers enhanced security and safety due to the fact that there is no pedestrian traffic, no accidents or damage when maneuvering into parking spaces, and no searching for an empty parking space. All this reduces liability concerns within the garage for the building owner (Gorove 2013). The automated garage also does not require the owner of the vehicle to drive around the garage to find a parking space, by removing this step, fuel consumption is not only saved, but also car emissions such as Nitrogen Dioxide and Carbon Dioxide. The comparison between a conventional garage and an automated garage can be seen below, where a reduction of 83 percent for both nitrogen dioxide and carbon dioxide in the case of an automated garage, when being compared to an automated one (Gorove 2013).



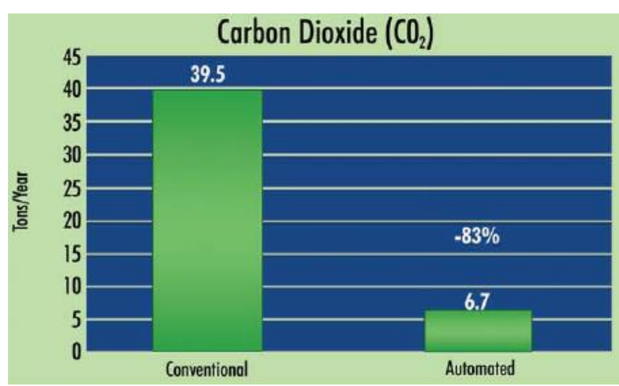




Figure 55 – Emission Reduction Bar Chart

Since the vehicles are not driving around a traditional ramp style garage looking for a parking spot, than the fuel consumption is also reduced (Gorove 2013). This can be seen in the graph below.

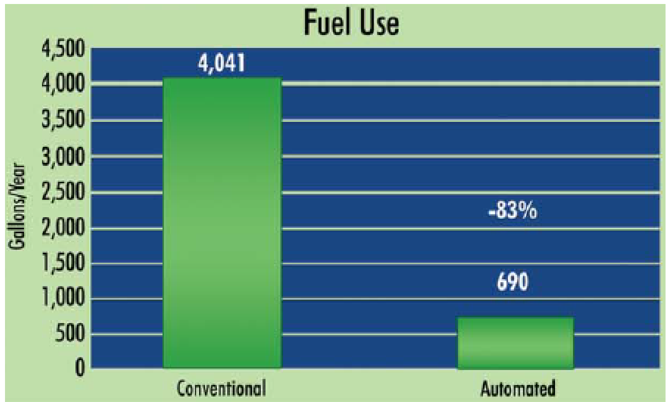



Figure 56 – Fuel Reduction Bar Chart

Finally, the cost is compared of that of a traditional ramp style garage to that of an automated one. The unit costs per area and automated machinery cost were received from Fred Gorove of Unitronics, but all of the other values are specific to the parking garage originally designed and the automated one done for the purpose of this thesis.

Table 4 – Cost Comparison between Automated and Conventional Ramp Garage

| Type | Unit Cost ($/SF) | X | Efficiency (SF/ Stall) | = | Cost Per Stall | + | Automated Machinery Cost($/Stall) | = | Total Cost ($/Stall | X | Number of Stalls | = | Total Garage Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ramp Garage** | $105 | X | 430 | = | $45,150 | + | $0 | = | **$45,150** | X | 556 | = | **$25,103,400** |
| **Automated Garage** | $85 | X | 225 | = | $19,125 | + | $12,000 | = | **$31,125** | X | 560 | = | **$17,430,000** |

In comparison, the automated garage is 36% decrease of that of the estimated cost for a typical ramp style garage. It is important to note that the estimate for the traditional garage came out fairly closely to the actual cost of the traditional garage that was actually on the project. This actual cost associated with the ramp style underground parking deck was $24.8 million, which is only about 5% less than the estimate in the table above.

## Recommendations

Per the results of this analysis, it is suggested that the in-situ electrical thermal treatment be implemented to reduce the soil mitigation time. The parking garage design is suggested to change from a conventional ramp style garage to an automated one in order to save on excavation time. The electrical thermal treatment allows the contaminated soil to be cleansed in a time frame of 45 days, and eliminates the necessity of excavating the entire site in search of contaminated soil. The excavation for the smaller volumetric automated garage can then be undergone. Since it is a smaller area and depth, the process should be significantly shorter, and save time in the long run.

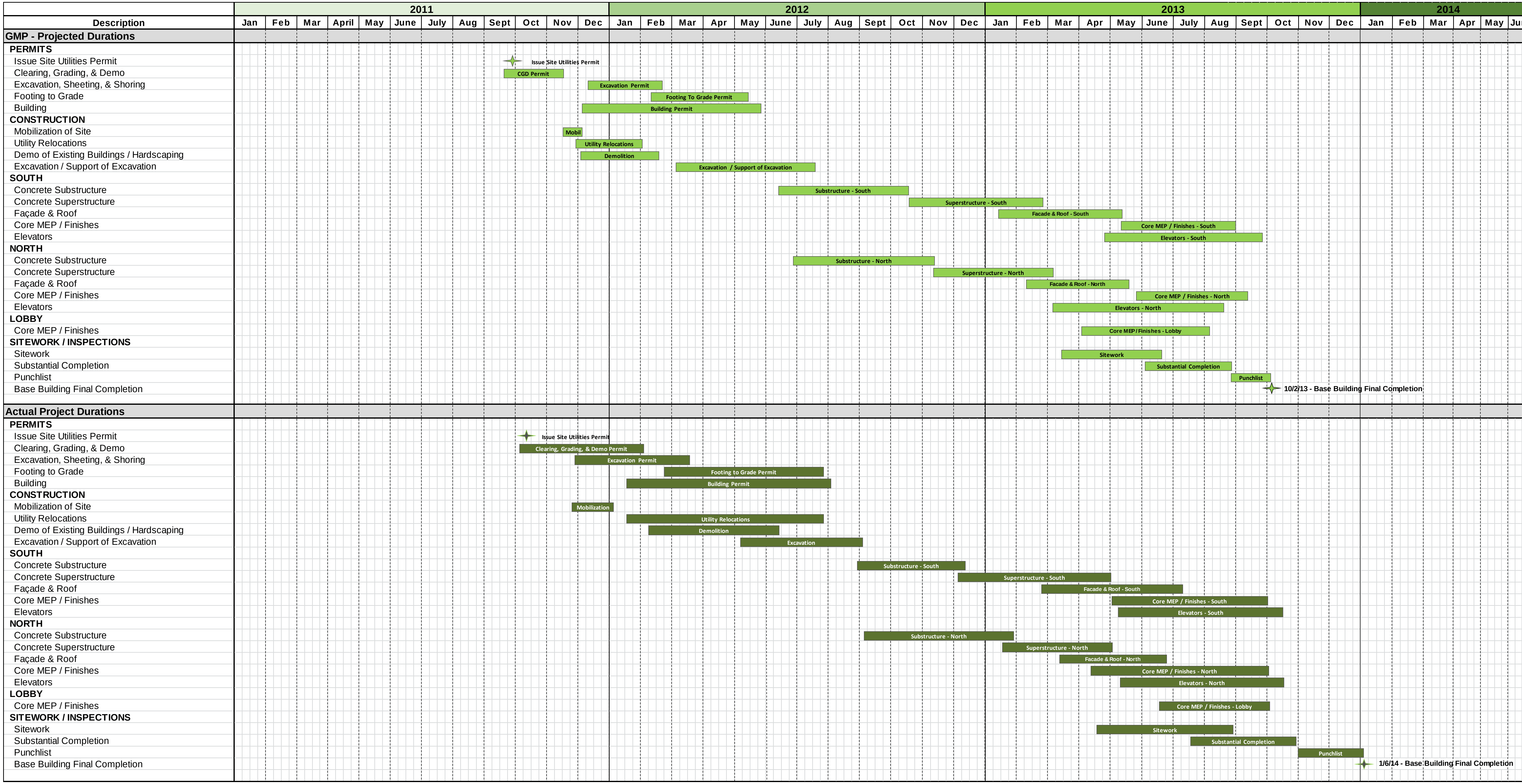
The total time that needed to be saved to allow the project to get back on schedule was 68 days. Analysis I saved 33 days, Analysis II saved 10 days, and finally this analysis was able to save 18 days. This leads to a total of 61 days. In the end, the analyses got the project 7 days off of the original project duration. Time could also be potentially saved even more in the physical construction of the automated garage because it had a smaller footprint and depth, but this was not studied in this analysis.

In the end, this analysis is accepted due to the fact that the soil contamination problem and garage are taken care of and constructed in a time frame that is 18 days less than originally expected. The cost for the contamination removal of the soil is around two to five million more than anticipated in the case if the soil is just excavated and treated. Not disturbing the virgin soil is important because it saves time, money, and man-hours. The excavation for the new automated garage is then smaller and less time consuming, leading to around a 40% decrease in the cost of the construction process when being compared to a traditional ramp style garage. The automated garage also offers LEED potential with reduced emissions and fuel consumption, and holds increased value for the owner and users.

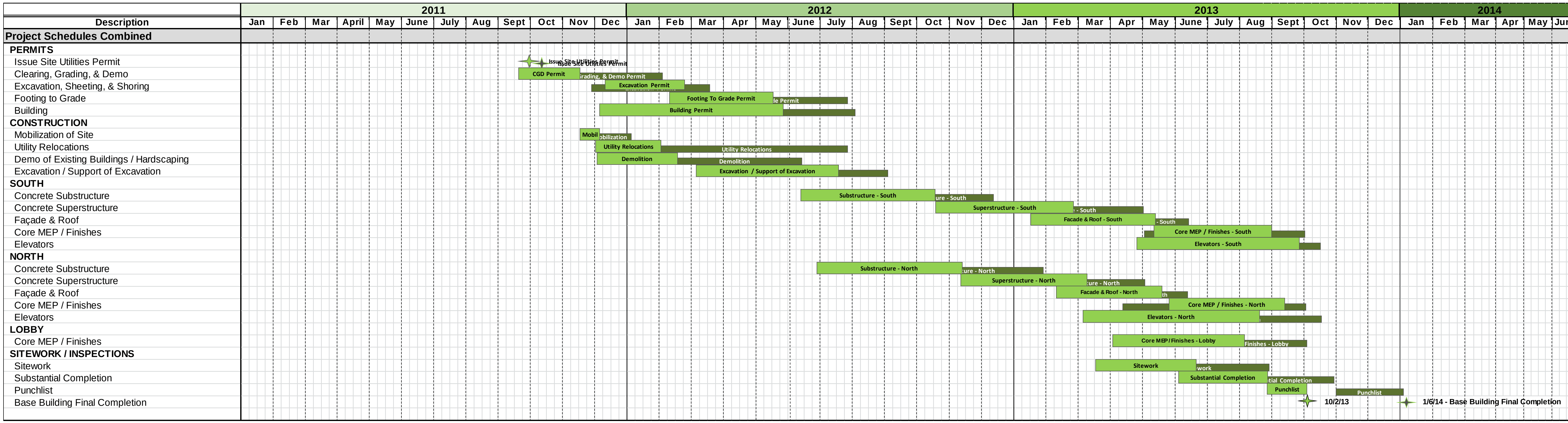
To further this study, one could determine the cost of excavation for a typical site in this geographic area and an actual rate that an excavation contractor can perform. This may result in even less time than the 52 days interpolated to excavate the new automated design. It is felt that time could be saved due to the fact that the excavation rate that was interpolated from the original design most likely scheduled for delays due to the contaminant mitigation process. This would more than likely not be a problem after the in-situ thermal electric treatment, and a shorter excavation time frame may have been a result.

# Appendix A

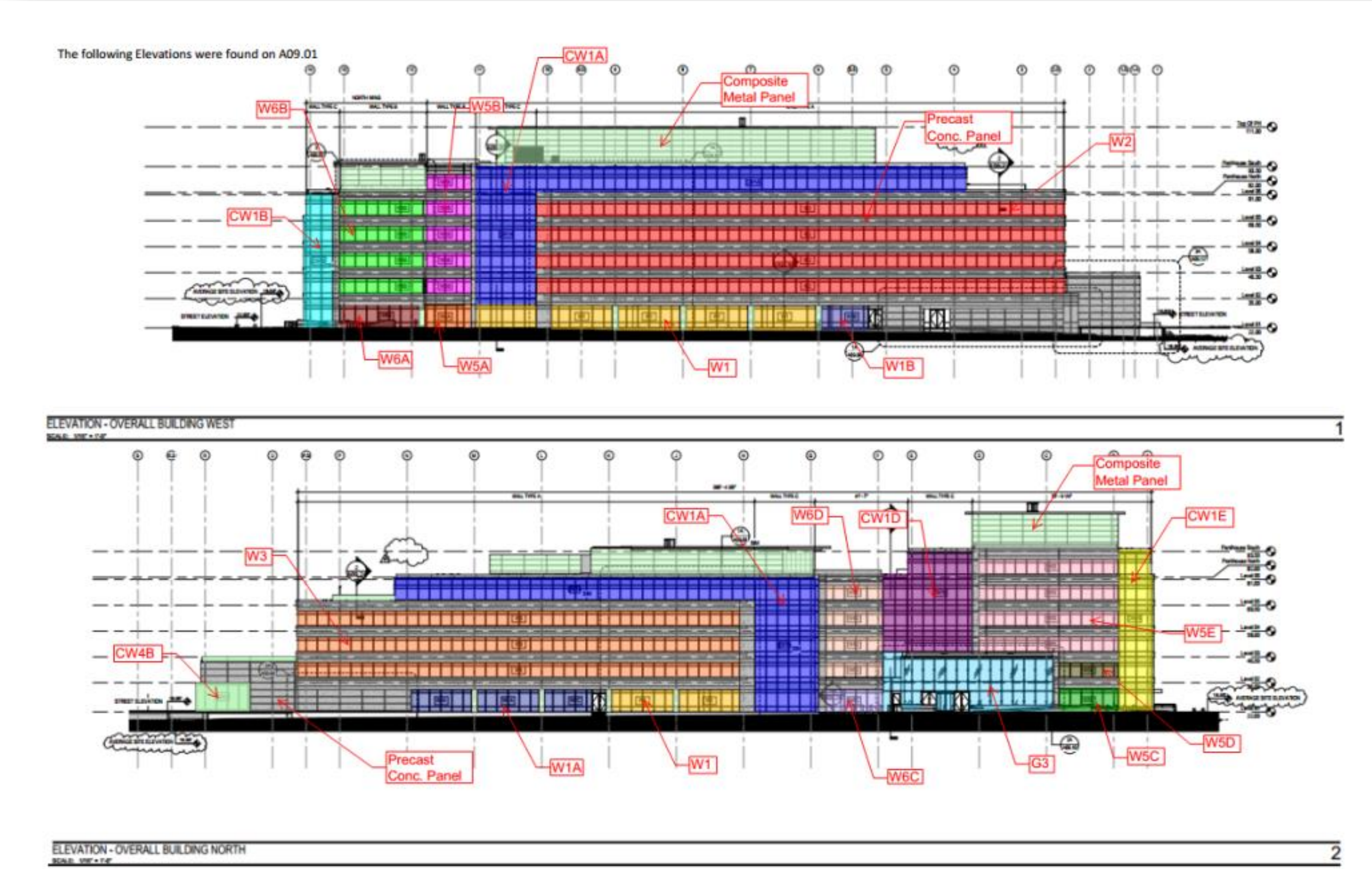
Actual and Projected Schedules for Memorial Vista



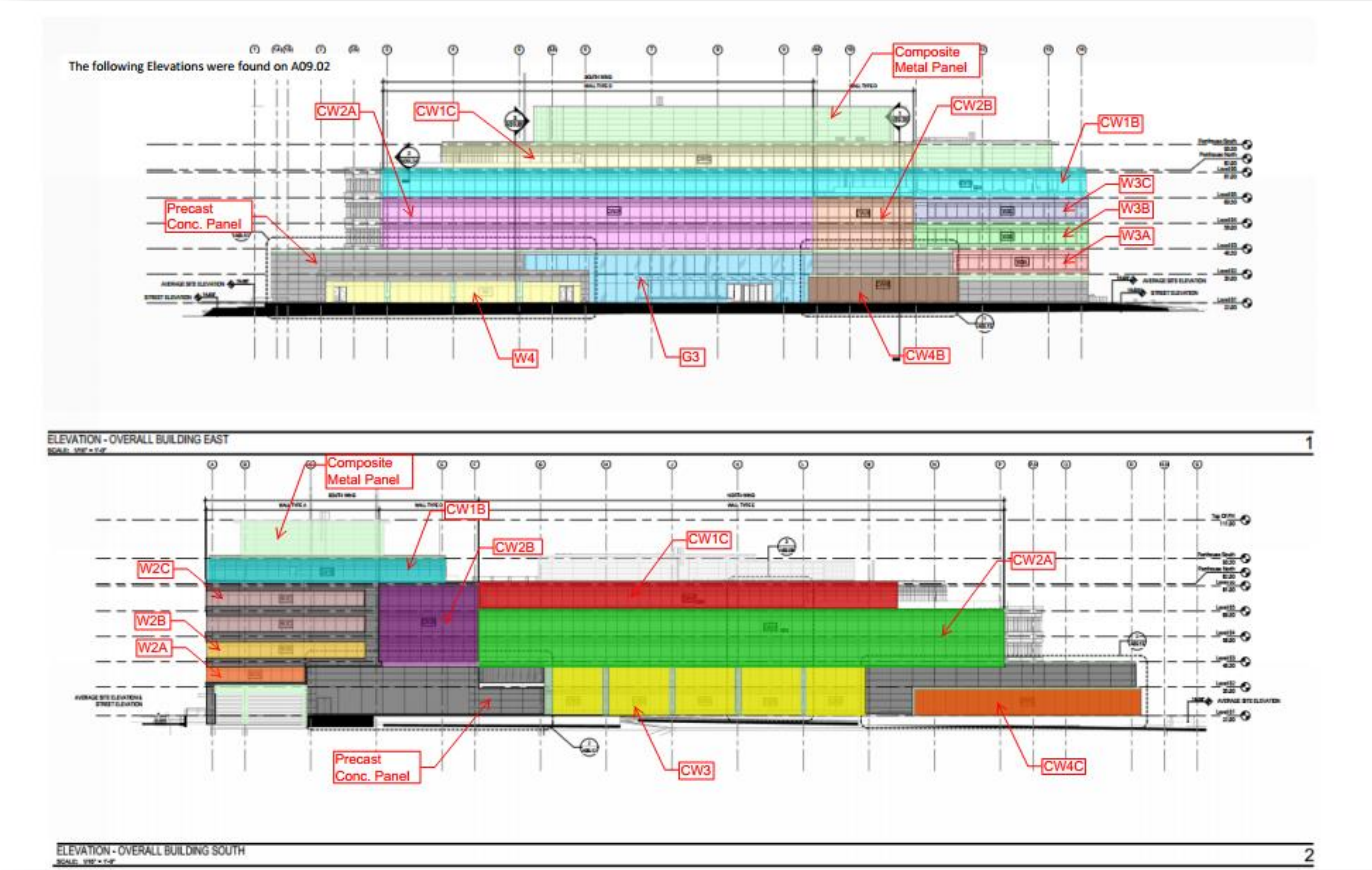
Overlay of Actual and Projected Schedules for Memorial Vista



# Appendix B



The following Elevations were found on A09.01
CW1A
Composite Metal Panel
W6B
W5B
Precast Conc. Panel
W2
CW1B
W6A
W5A
W1
W1B
ELEVATION - OVERALL BUILDING WEST
1
Composite Metal Panel
CW1A
W6D
CW1D
CW1E
W3
W5E
CW4B
Precast Conc. Panel
W1A
W1
W6C
G3
W5C
W5D
ELEVATION - OVERALL BUILDING NORTH
2


The following Elevations were found on A09.02
Composite Metal Panel
CW2A
CW1C
CW2B
CW1B
W3C
W3B
W3A
Precast Conc. Panel
W4
G3
CW4B
ELEVATION - OVERALL BUILDING EAST
1
Composite Metal Panel
CW1B
CW2B
CW1C
CW2A
W2C
W2B
W2A
Precast Conc. Panel
CW3
CW4C
ELEVATION - OVERALL BUILDING SOUTH
2

# Appendix C

## 03 45 Precast Architectural Concrete

### 03 45 13 – Faced Architectural Precast Concrete

**03 45 13.50 Precast Wall Panels**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0010 | **PRECAST WALL PANELS** R034513-10 | | | | | | | | | |
| 0050 | Uninsulated, smooth gray | | | | | | | | | |
| 0150 | Low rise, 4′ x 8′ x 4″ thick | C-11 | 320 | .225 | S.F. | 20.50 | 11.35 | 5.75 | 37.60 | |
| 0210 | 8′ x 8′, 4″ thick | | 576 | .125 | | 20.50 | 6.30 | 3.19 | 29.99 | |
| 0250 | 8′ x 16′ x 4″ thick | | 1024 | .070 | | 20.50 | 3.54 | 1.80 | 25.84 | |
| 0600 | High rise, 4′ x 8′ x 4″ thick | | 288 | .250 | | 20.50 | 12.60 | 6.40 | 39.50 | |
| 0650 | 8′ x 8′ x 4″ thick | | 512 | .141 | | 20.50 | 7.10 | 3.59 | 31.19 | |
| 0700 | 8′ x 16′ x 4″ thick | | 768 | .094 | | 20.50 | 4.72 | 2.39 | 27.61 | |
| 0750 | 10′ x 20′, 6″ thick | | 1400 | .051 | | 34.50 | 2.59 | 1.31 | 38.40 | |
| 0800 | Insulated panel, 2″ polystyrene, add | | | | | 1.05 | | | 1.05 | |
| 0850 | 2″ urethane, add | | | | | .79 | | | .79 | |
| 1200 | Finishes, white, add | | | | | 2.68 | | | 2.68 | |
| 1250 | Exposed aggregate, add | | | | | 2.10 | | | 2.10 | |
| 1300 | Granite faced, domestic, add | | | | | 29.50 | | | 29.50 | |
| 1350 | Brick faced, modular, red, add | | | | | 8.75 | | | 8.75 | |
| 2200 | Fiberglass reinforced cement with urethane core | | | | | | | | | |
| 2210 | R20, 8′ x 8′, 5″ plain finish | E-2 | 750 | .075 | S.F. | 21 | 3.75 | 2.04 | 26.79 | |
| 2220 | Exposed aggregate or brick finish | " | 600 | .093 | " | 32 | 4.68 | 2.55 | 39.23 | |

| **Crew C-11** | **Hr.** | **Daily** | **Hr.** | **Daily** | **Bare Costs** | **Incl. O&P** |
|---|---|---|---|---|---|---|
| 1 Struc. Steel Foreman (outside) | $53.10 | $424.80 | $93.70 | $749.60 | $50.39 | $86.34 |
| 6 Struc. Steel Workers | 51.10 | 2452.80 | 90.20 | 4329.60 | | |
| 1 Equip. Oper. (crane) | 50.25 | 402.00 | 76.20 | 609.60 | | |
| 1 Equip. Oper. (oiler) | 43.55 | 348.40 | 66.00 | 528.00 | | |
| 1 Lattice Boom Crane, 150 Ton | | 1838.00 | | 2021.80 | 25.53 | 28.08 |
| 72 L.H., Daily Totals | | $5466.00 | | $8238.60 | $75.92 | $114.43 |

# 08 44 Curtain Wall and Glazed Assemblies

## 08 44 13 – Glazed Aluminum Curtain Walls

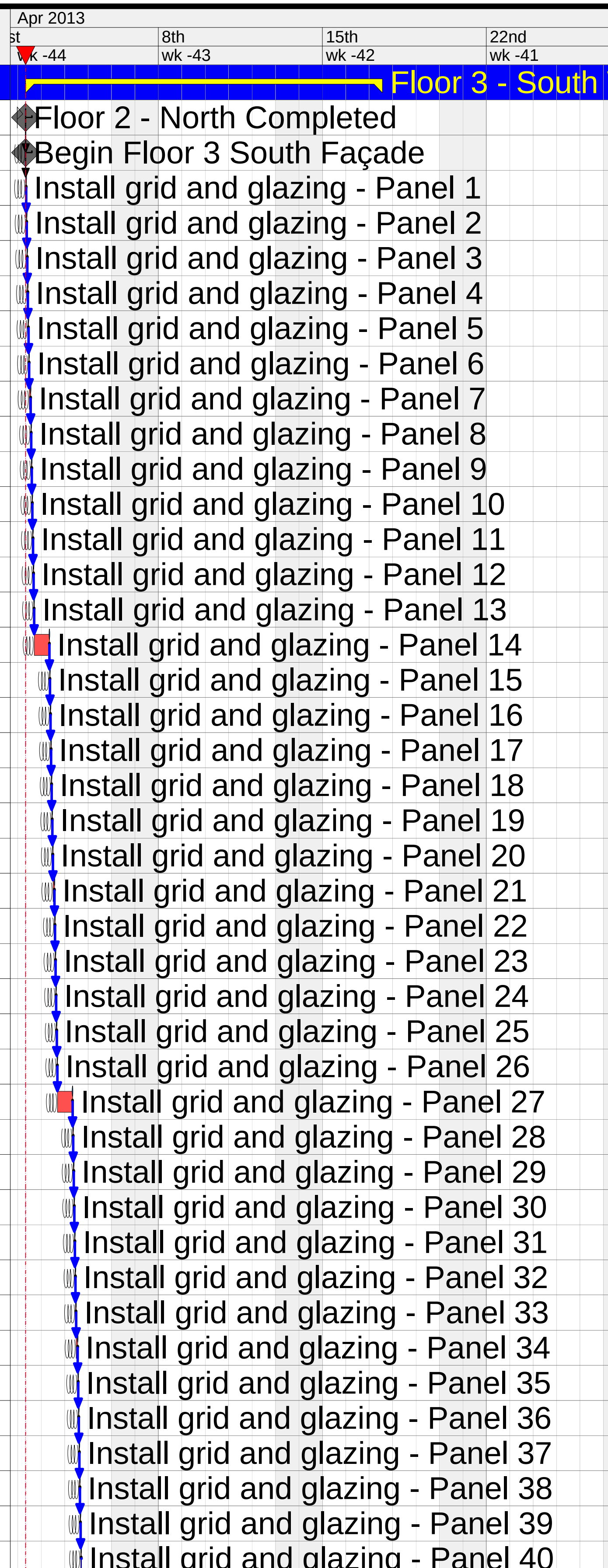
### 08 44 13.10 Glazed Curtain Walls

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0010 | **GLAZED CURTAIN WALLS**, aluminum, stock, including glazing | | | | | | | | | |
| 0020 | Minimum | H-1 | 205 | .156 | S.F. | 35 | 7.45 | | 42.45 | 51 |
| 0050 | Average, single glazed | | 195 | .164 | | 51 | 7.80 | | 58.80 | 69 |
| 0150 | Average, double glazed | | 180 | .178 | | 65.50 | 8.45 | | 73.95 | 86.50 |
| 0200 | Maximum | | 160 | .200 | | 176 | 9.50 | | 185.50 | 209 |

| Crew H-1 | Hr. | Daily | Hr. | Daily | Bare Costs | Incl. O&P |
|---|---|---|---|---|---|---|
| 2 Glaziers | $44.05 | $704.80 | $67.00 | $1072.00 | $47.58 | $78.60 |
| 2 Struc. Steel Workers | 51.10 | 817.60 | 90.20 | 1443.20 | | |
| 32 L.H., Daily Totals | | $1522.40 | | $2515.20 | $47.58 | $78.60 |

# Appendix D

| | ID | Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 1 | | **Floor 3 - South Wing Façade** | **11d, 4h, 35m** | **02/04/13** | **17/04/13** |
| 2 | ST00020 | Floor 2 - North Completed | 0 Days | 02/04/13 (*) | |
| 3 | ST00030 | Begin Floor 3 South Façade | 0 Days | 02/04/13 | |
| 4 | ST00040 | Install grid and glazing - Panel 1 | 35m | 02/04/13 | 02/04/13 |
| 5 | ST00050 | Install grid and glazing - Panel 2 | 35m | 02/04/13 | 02/04/13 |
| 6 | ST00060 | Install grid and glazing - Panel 3 | 35m | 02/04/13 | 02/04/13 |
| 7 | ST00070 | Install grid and glazing - Panel 4 | 35m | 02/04/13 | 02/04/13 |
| 8 | ST00080 | Install grid and glazing - Panel 5 | 35m | 02/04/13 | 02/04/13 |
| 9 | ST00090 | Install grid and glazing - Panel 6 | 35m | 02/04/13 | 02/04/13 |
| 10 | ST00100 | Install grid and glazing - Panel 7 | 35m | 02/04/13 | 02/04/13 |
| 11 | ST00110 | Install grid and glazing - Panel 8 | 35m | 02/04/13 | 02/04/13 |
| 12 | ST00120 | Install grid and glazing - Panel 9 | 35m | 02/04/13 | 02/04/13 |
| 13 | ST00130 | Install grid and glazing - Panel 10 | 35m | 02/04/13 | 02/04/13 |
| 14 | ST00140 | Install grid and glazing - Panel 11 | 35m | 02/04/13 | 02/04/13 |
| 15 | ST00150 | Install grid and glazing - Panel 12 | 35m | 02/04/13 | 02/04/13 |
| 16 | ST00160 | Install grid and glazing - Panel 13 | 35m | 02/04/13 | 02/04/13 |
| 17 | ST00170 | Install grid and glazing - Panel 14 | 35m | 02/04/13 | 03/04/13 |
| 18 | ST00180 | Install grid and glazing - Panel 15 | 35m | 03/04/13 | 03/04/13 |
| 19 | ST00190 | Install grid and glazing - Panel 16 | 35m | 03/04/13 | 03/04/13 |
| 20 | ST00200 | Install grid and glazing - Panel 17 | 35m | 03/04/13 | 03/04/13 |
| 21 | ST00210 | Install grid and glazing - Panel 18 | 35m | 03/04/13 | 03/04/13 |
| 22 | ST00220 | Install grid and glazing - Panel 19 | 35m | 03/04/13 | 03/04/13 |
| 23 | ST00230 | Install grid and glazing - Panel 20 | 35m | 03/04/13 | 03/04/13 |
| 24 | ST00240 | Install grid and glazing - Panel 21 | 35m | 03/04/13 | 03/04/13 |
| 25 | ST00250 | Install grid and glazing - Panel 22 | 35m | 03/04/13 | 03/04/13 |
| 26 | ST00260 | Install grid and glazing - Panel 23 | 35m | 03/04/13 | 03/04/13 |
| 27 | ST00270 | Install grid and glazing - Panel 24 | 35m | 03/04/13 | 03/04/13 |
| 28 | ST00280 | Install grid and glazing - Panel 25 | 35m | 03/04/13 | 03/04/13 |
| 29 | ST00290 | Install grid and glazing - Panel 26 | 35m | 03/04/13 | 03/04/13 |
| 30 | ST00300 | Install grid and glazing - Panel 27 | 35m | 03/04/13 | 04/04/13 |
| 31 | ST00310 | Install grid and glazing - Panel 28 | 35m | 04/04/13 | 04/04/13 |
| 32 | ST00320 | Install grid and glazing - Panel 29 | 35m | 04/04/13 | 04/04/13 |
| 33 | ST00330 | Install grid and glazing - Panel 30 | 35m | 04/04/13 | 04/04/13 |
| 34 | ST00340 | Install grid and glazing - Panel 31 | 35m | 04/04/13 | 04/04/13 |
| 35 | ST00350 | Install grid and glazing - Panel 32 | 35m | 04/04/13 | 04/04/13 |
| 36 | ST00360 | Install grid and glazing - Panel 33 | 35m | 04/04/13 | 04/04/13 |
| 37 | ST00370 | Install grid and glazing - Panel 34 | 35m | 04/04/13 | 04/04/13 |
| 38 | ST00380 | Install grid and glazing - Panel 35 | 35m | 04/04/13 | 04/04/13 |
| 39 | ST00390 | Install grid and glazing - Panel 36 | 35m | 04/04/13 | 04/04/13 |
| 40 | ST00400 | Install grid and glazing - Panel 37 | 35m | 04/04/13 | 04/04/13 |
| 41 | ST00410 | Install grid and glazing - Panel 38 | 35m | 04/04/13 | 04/04/13 |
| 42 | ST00420 | Install grid and glazing - Panel 39 | 35m | 04/04/13 | 04/04/13 |
| 43 | ST00430 | Install grid and glazing - Panel 40 | 35m | 04/04/13 | 04/04/13 |

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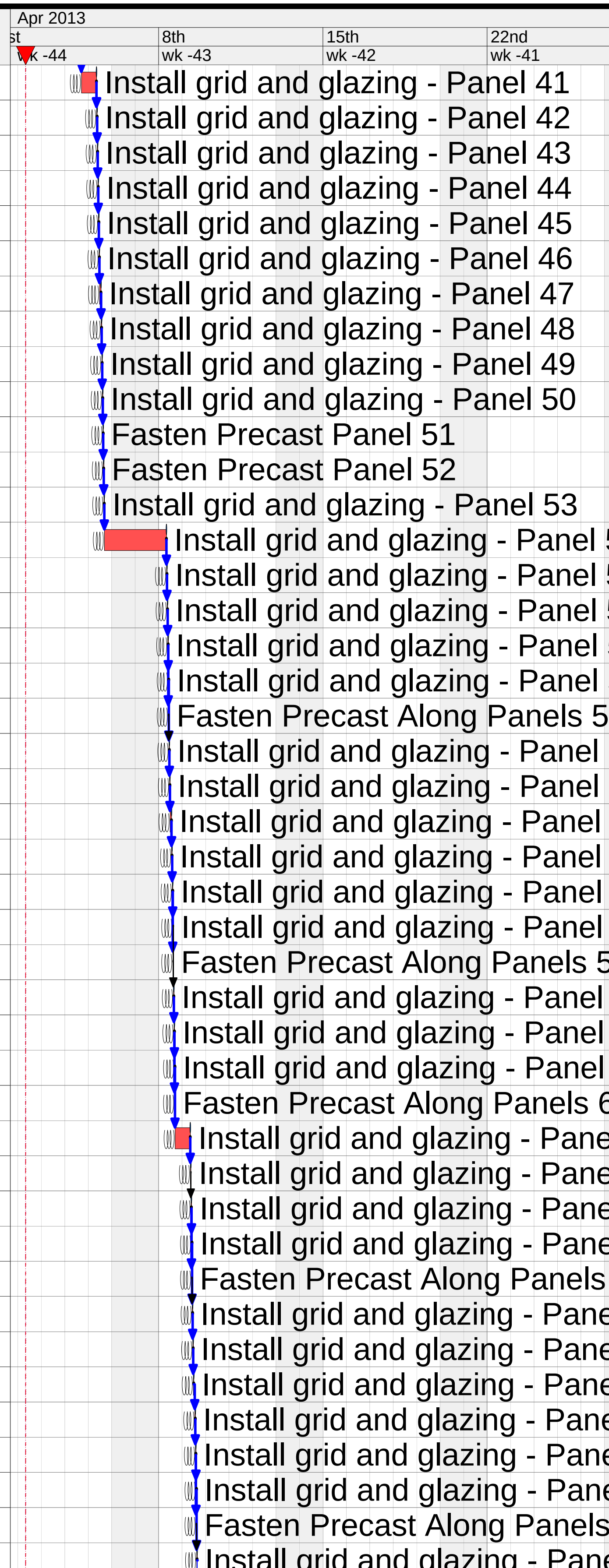
| Project title | | Dated | 02/04/13 | Drawn by Administrator | Programme No |
| Programme title | | Rev No | Rev comments | | |
| Client | | Notes | | | Printed: 13/02/14 |

SYNCHRO SOFTWARE

| | ID | Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 44 | ST00440 | Install grid and glazing - Panel 41 | 35m | 04/04/13 | 05/04/13 |
| 45 | ST00450 | Install grid and glazing - Panel 42 | 35m | 05/04/13 | 05/04/13 |
| 46 | ST00460 | Install grid and glazing - Panel 43 | 35m | 05/04/13 | 05/04/13 |
| 47 | ST00470 | Install grid and glazing - Panel 44 | 35m | 05/04/13 | 05/04/13 |
| 48 | ST00480 | Install grid and glazing - Panel 45 | 35m | 05/04/13 | 05/04/13 |
| 49 | ST00490 | Install grid and glazing - Panel 46 | 35m | 05/04/13 | 05/04/13 |
| 50 | ST00500 | Install grid and glazing - Panel 47 | 35m | 05/04/13 | 05/04/13 |
| 51 | ST00510 | Install grid and glazing - Panel 48 | 35m | 05/04/13 | 05/04/13 |
| 52 | ST00520 | Install grid and glazing - Panel 49 | 35m | 05/04/13 | 05/04/13 |
| 53 | ST00530 | Install grid and glazing - Panel 50 | 35m | 05/04/13 | 05/04/13 |
| 54 | ST00540 | Fasten Precast Panel 51 | 28m | 05/04/13 | 05/04/13 |
| 55 | ST00550 | Fasten Precast Panel 52 | 28m | 05/04/13 | 05/04/13 |
| 56 | ST00560 | Install grid and glazing - Panel 53 | 35m | 05/04/13 | 05/04/13 |
| 57 | ST00570 | Install grid and glazing - Panel 54 | 35m | 05/04/13 | 08/04/13 |
| 58 | ST00580 | Install grid and glazing - Panel 55 | 35m | 08/04/13 | 08/04/13 |
| 59 | ST00590 | Install grid and glazing - Panel 56 | 35m | 08/04/13 | 08/04/13 |
| 60 | ST00600 | Install grid and glazing - Panel 57 | 35m | 08/04/13 | 08/04/13 |
| 61 | ST00610 | Install grid and glazing - Panel 58 | 35m | 08/04/13 | 08/04/13 |
| 62 | ST00620 | Fasten Precast Along Panels 53 - 5 | 28m | 08/04/13 | 08/04/13 |
| 63 | ST00630 | Install grid and glazing - Panel 59 | 35m | 08/04/13 | 08/04/13 |
| 64 | ST00640 | Install grid and glazing - Panel 60 | 35m | 08/04/13 | 08/04/13 |
| 65 | ST00650 | Install grid and glazing - Panel 61 | 35m | 08/04/13 | 08/04/13 |
| 66 | ST00660 | Install grid and glazing - Panel 62 | 35m | 08/04/13 | 08/04/13 |
| 67 | ST00670 | Install grid and glazing - Panel 63 | 35m | 08/04/13 | 08/04/13 |
| 68 | ST00680 | Install grid and glazing - Panel 64 | 35m | 08/04/13 | 08/04/13 |
| 69 | ST00690 | Fasten Precast Along Panels 59 - 6 | 28m | 08/04/13 | 08/04/13 |
| 70 | ST00700 | Install grid and glazing - Panel 65 | 35m | 08/04/13 | 08/04/13 |
| 71 | ST00710 | Install grid and glazing - Panel 66 | 35m | 08/04/13 | 08/04/13 |
| 72 | ST00720 | Install grid and glazing - Panel 67 | 35m | 08/04/13 | 08/04/13 |
| 73 | ST00730 | Fasten Precast Along Panels 65 - 6 | 28m | 08/04/13 | 08/04/13 |
| 74 | ST00740 | Install grid and glazing - Panel 68 | 35m | 08/04/13 | 09/04/13 |
| 75 | ST00750 | Install grid and glazing - Panel 69 | 35m | 09/04/13 | 09/04/13 |
| 76 | ST00760 | Install grid and glazing - Panel 70 | 35m | 09/04/13 | 09/04/13 |
| 77 | ST00770 | Install grid and glazing - Panel 71 | 35m | 09/04/13 | 09/04/13 |
| 78 | ST00780 | Fasten Precast Along Panels 68 - 7 | 28m | 09/04/13 | 09/04/13 |
| 79 | ST00790 | Install grid and glazing - Panel 72 | 35m | 09/04/13 | 09/04/13 |
| 80 | ST00800 | Install grid and glazing - Panel 73 | 35m | 09/04/13 | 09/04/13 |
| 81 | ST00810 | Install grid and glazing - Panel 74 | 35m | 09/04/13 | 09/04/13 |
| 82 | ST00820 | Install grid and glazing - Panel 75 | 35m | 09/04/13 | 09/04/13 |
| 83 | ST00830 | Install grid and glazing - Panel 76 | 35m | 09/04/13 | 09/04/13 |
| 84 | ST00840 | Install grid and glazing - Panel 77 | 35m | 09/04/13 | 09/04/13 |
| 85 | ST00850 | Fasten Precast Along Panels 72 - 7 | 28m | 09/04/13 | 09/04/13 |
| 86 | ST00860 | Install grid and glazing - Panel 78 | 35m | 09/04/13 | 09/04/13 |

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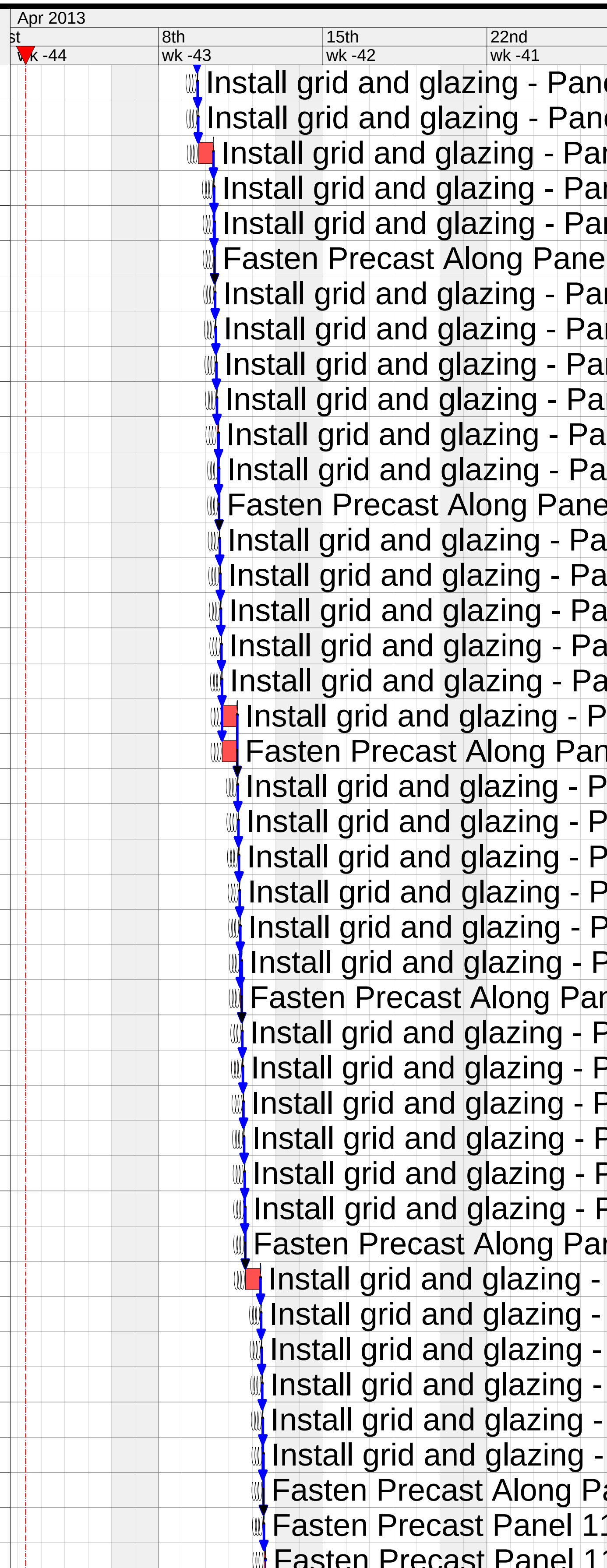
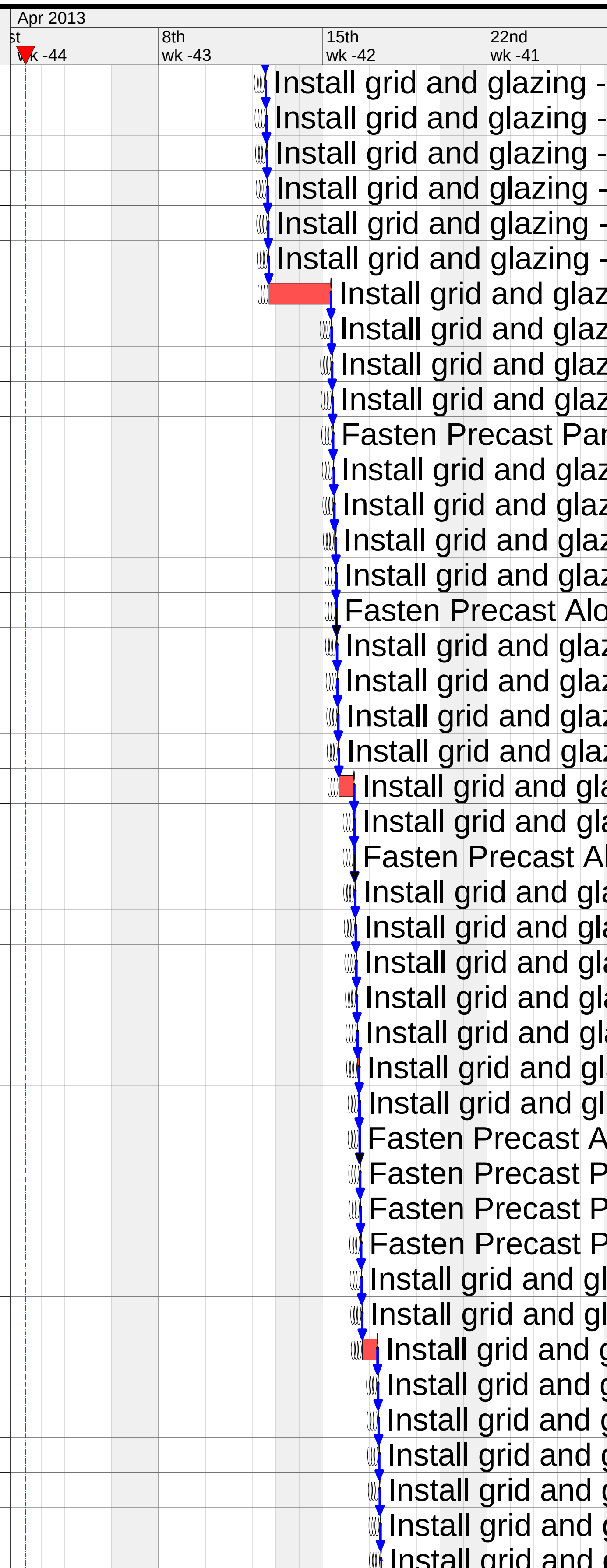
| Project title | | Dated | 02/04/13 | Drawn by Administrator | Programme No |
| Programme title | | Rev No | Rev comments | | |
| Client | | Notes | | | Printed: 13/02/14 |

| | ID | Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 87 | ST00870 | Install grid and glazing - Panel 79 | 35m | 09/04/13 | 09/04/13 |
| 88 | ST00880 | Install grid and glazing - Panel 80 | 35m | 09/04/13 | 09/04/13 |
| 89 | ST00890 | Install grid and glazing - Panel 81 | 35m | 09/04/13 | 10/04/13 |
| 90 | ST00900 | Install grid and glazing - Panel 82 | 35m | 10/04/13 | 10/04/13 |
| 91 | ST00910 | Install grid and glazing - Panel 83 | 35m | 10/04/13 | 10/04/13 |
| 92 | ST00920 | Fasten Precast Along Panels 78 - 8 | 28m | 10/04/13 | 10/04/13 |
| 93 | ST00930 | Install grid and glazing - Panel 84 | 35m | 10/04/13 | 10/04/13 |
| 94 | ST00940 | Install grid and glazing - Panel 85 | 35m | 10/04/13 | 10/04/13 |
| 95 | ST00950 | Install grid and glazing - Panel 86 | 35m | 10/04/13 | 10/04/13 |
| 96 | ST00960 | Install grid and glazing - Panel 87 | 35m | 10/04/13 | 10/04/13 |
| 97 | ST00970 | Install grid and glazing - Panel 88 | 35m | 10/04/13 | 10/04/13 |
| 98 | ST00980 | Install grid and glazing - Panel 89 | 35m | 10/04/13 | 10/04/13 |
| 99 | ST00990 | Fasten Precast Along Panels 84 - 8 | 28m | 10/04/13 | 10/04/13 |
| 100 | ST01000 | Install grid and glazing - Panel 90 | 35m | 10/04/13 | 10/04/13 |
| 101 | ST01010 | Install grid and glazing - Panel 91 | 35m | 10/04/13 | 10/04/13 |
| 102 | ST01020 | Install grid and glazing - Panel 92 | 35m | 10/04/13 | 10/04/13 |
| 103 | ST01030 | Install grid and glazing - Panel 93 | 35m | 10/04/13 | 10/04/13 |
| 104 | ST01040 | Install grid and glazing - Panel 94 | 35m | 10/04/13 | 10/04/13 |
| 105 | ST01050 | Install grid and glazing - Panel 95 | 35m | 10/04/13 | 11/04/13 |
| 106 | ST01060 | Fasten Precast Along Panels 90 - 9 | 28m | 10/04/13 | 11/04/13 |
| 107 | ST01070 | Install grid and glazing - Panel 96 | 35m | 11/04/13 | 11/04/13 |
| 108 | ST01080 | Install grid and glazing - Panel 97 | 35m | 11/04/13 | 11/04/13 |
| 109 | ST01090 | Install grid and glazing - Panel 98 | 35m | 11/04/13 | 11/04/13 |
| 110 | ST01100 | Install grid and glazing - Panel 99 | 35m | 11/04/13 | 11/04/13 |
| 111 | ST01110 | Install grid and glazing - Panel 100 | 35m | 11/04/13 | 11/04/13 |
| 112 | ST01120 | Install grid and glazing - Panel 101 | 35m | 11/04/13 | 11/04/13 |
| 113 | ST01130 | Fasten Precast Along Panels 96 - 1 | 28m | 11/04/13 | 11/04/13 |
| 114 | ST01140 | Install grid and glazing - Panel 102 | 35m | 11/04/13 | 11/04/13 |
| 115 | ST01150 | Install grid and glazing - Panel 103 | 35m | 11/04/13 | 11/04/13 |
| 116 | ST01160 | Install grid and glazing - Panel 104 | 35m | 11/04/13 | 11/04/13 |
| 117 | ST01170 | Install grid and glazing - Panel 105 | 35m | 11/04/13 | 11/04/13 |
| 118 | ST01180 | Install grid and glazing - Panel 106 | 35m | 11/04/13 | 11/04/13 |
| 119 | ST01190 | Install grid and glazing - Panel 107 | 35m | 11/04/13 | 11/04/13 |
| 120 | ST01200 | Fasten Precast Along Panels 102 - | 28m | 11/04/13 | 11/04/13 |
| 121 | ST01210 | Install grid and glazing - Panel 108 | 35m | 11/04/13 | 12/04/13 |
| 122 | ST01220 | Install grid and glazing - Panel 109 | 35m | 12/04/13 | 12/04/13 |
| 123 | ST01230 | Install grid and glazing - Panel 110 | 35m | 12/04/13 | 12/04/13 |
| 124 | ST01240 | Install grid and glazing - Panel 111 | 35m | 12/04/13 | 12/04/13 |
| 125 | ST01250 | Install grid and glazing - Panel 112 | 35m | 12/04/13 | 12/04/13 |
| 126 | ST01260 | Install grid and glazing - Panel 113 | 35m | 12/04/13 | 12/04/13 |
| 127 | ST01270 | Fasten Precast Along Panels 108 - | 28m | 12/04/13 | 12/04/13 |
| 128 | ST01280 | Fasten Precast Panel 114 | 28m | 12/04/13 | 12/04/13 |
| 129 | ST01290 | Fasten Precast Panel 115 | 28m | 12/04/13 | 12/04/13 |




| | | | | | |
|---|---|---|---|---|---|
| Project title | Dated 02/04/13 | Drawn by Administrator | Programme No | | |
| Programme title | Rev No | Rev comments | | | |
| Client | Notes | | | | Printed: 13/02/14 |

| | ID | Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 130 | ST01300 | Install grid and glazing - Panel 116 | 35m | 12/04/13 | 12/04/13 |
| 131 | ST01310 | Install grid and glazing - Panel 117 | 35m | 12/04/13 | 12/04/13 |
| 132 | ST01320 | Install grid and glazing - Panel 118 | 35m | 12/04/13 | 12/04/13 |
| 133 | ST01330 | Install grid and glazing - Panel 119 | 35m | 12/04/13 | 12/04/13 |
| 134 | ST01340 | Install grid and glazing - Panel 120 | 35m | 12/04/13 | 12/04/13 |
| 135 | ST01350 | Install grid and glazing - Panel 121 | 35m | 12/04/13 | 12/04/13 |
| 136 | ST01360 | Install grid and glazing - Panel 122 | 35m | 12/04/13 | 15/04/13 |
| 137 | ST01370 | Install grid and glazing - Panel 123 | 35m | 15/04/13 | 15/04/13 |
| 138 | ST01380 | Install grid and glazing - Panel 124 | 35m | 15/04/13 | 15/04/13 |
| 139 | ST01390 | Install grid and glazing - Panel 125 | 35m | 15/04/13 | 15/04/13 |
| 140 | ST01400 | Fasten Precast Panel 126 | 28m | 15/04/13 | 15/04/13 |
| 141 | ST01410 | Install grid and glazing - Panel 127 | 35m | 15/04/13 | 15/04/13 |
| 142 | ST01420 | Install grid and glazing - Panel 128 | 35m | 15/04/13 | 15/04/13 |
| 143 | ST01430 | Install grid and glazing - Panel 129 | 35m | 15/04/13 | 15/04/13 |
| 144 | ST01440 | Install grid and glazing - Panel 130 | 35m | 15/04/13 | 15/04/13 |
| 145 | ST01450 | Fasten Precast Along Panels 127 - | 28m | 15/04/13 | 15/04/13 |
| 146 | ST01460 | Install grid and glazing - Panel 131 | 35m | 15/04/13 | 15/04/13 |
| 147 | ST01470 | Install grid and glazing - Panel 132 | 35m | 15/04/13 | 15/04/13 |
| 148 | ST01480 | Install grid and glazing - Panel 133 | 35m | 15/04/13 | 15/04/13 |
| 149 | ST01490 | Install grid and glazing - Panel 134 | 35m | 15/04/13 | 15/04/13 |
| 150 | ST01500 | Install grid and glazing - Panel 135 | 35m | 15/04/13 | 16/04/13 |
| 151 | ST01510 | Install grid and glazing - Panel 136 | 35m | 16/04/13 | 16/04/13 |
| 152 | ST01520 | Fasten Precast Along Panels 131 - | 28m | 16/04/13 | 16/04/13 |
| 153 | ST01530 | Install grid and glazing - Panel 137 | 35m | 16/04/13 | 16/04/13 |
| 154 | ST01540 | Install grid and glazing - Panel 138 | 35m | 16/04/13 | 16/04/13 |
| 155 | ST01550 | Install grid and glazing - Panel 139 | 35m | 16/04/13 | 16/04/13 |
| 156 | ST01560 | Install grid and glazing - Panel 140 | 35m | 16/04/13 | 16/04/13 |
| 157 | ST01570 | Install grid and glazing - Panel 141 | 35m | 16/04/13 | 16/04/13 |
| 158 | ST01580 | Install grid and glazing - Panel 142 | 35m | 16/04/13 | 16/04/13 |
| 159 | ST01590 | Install grid and glazing - Panel 143 | 35m | 16/04/13 | 16/04/13 |
| 160 | ST01600 | Fasten Precast Along Panels 137 - | 28m | 16/04/13 | 16/04/13 |
| 161 | ST01610 | Fasten Precast Panel 145 | 28m | 16/04/13 | 16/04/13 |
| 162 | ST01620 | Fasten Precast Panel 146 | 28m | 16/04/13 | 16/04/13 |
| 163 | ST01630 | Fasten Precast Panel 147 | 28m | 16/04/13 | 16/04/13 |
| 164 | ST01640 | Install grid and glazing - Panel 144 | 35m | 16/04/13 | 16/04/13 |
| 165 | ST01650 | Install grid and glazing - Panel 145 | 35m | 16/04/13 | 16/04/13 |
| 166 | ST01660 | Install grid and glazing - Panel 146 | 35m | 16/04/13 | 17/04/13 |
| 167 | ST01670 | Install grid and glazing - Panel 147 | 35m | 17/04/13 | 17/04/13 |
| 168 | ST01680 | Install grid and glazing - Panel 148 | 35m | 17/04/13 | 17/04/13 |
| 169 | ST01690 | Install grid and glazing - Panel 149 | 35m | 17/04/13 | 17/04/13 |
| 170 | ST01700 | Install grid and glazing - Panel 150 | 35m | 17/04/13 | 17/04/13 |
| 171 | ST01710 | Install grid and glazing - Panel 151 | 35m | 17/04/13 | 17/04/13 |
| 172 | ST01720 | Install grid and glazing - Panel 152 | 35m | 17/04/13 | 17/04/13 |




| | | | |
|---|---|---|---|
| Project title | Dated 02/04/13 | Drawn by Administrator | Programme No |
| Programme title | Rev No | Rev comments | |
| Client | Notes | | Printed: 13/02/14 |

| | ID | Name | Duration | Start | Finish | Apr 2013 |
|---|---|---|---|---|---|---|
| 173 | ST01725 | Install grid and glazing - Panel 153 | 35m | 17/04/13 | 17/04/13 | Install grid and g |
| 174 | ST01727 | Install grid and glazing - Panel 154 | 35m | 17/04/13 | 17/04/13 | Install grid and g |
| 175 | ST01730 | Floor 3 South Façade Finished | 0 Days | 17/04/13 | | Floor 3 South Fa |
| 176 | ST01740 | Begin Floor 3 North Façade | 0 Days | 17/04/13 | | Begin Floor 3 No |

| | | | |
|---|---|---|---|
| Project title | Dated 02/04/13 | Drawn by Administrator | Programme No |
| Programme title | Rev No | Rev comments | SYNCHRO SOFTWARE |
| Client | Notes | | Printed: 13/02/14 |

# Appendix E

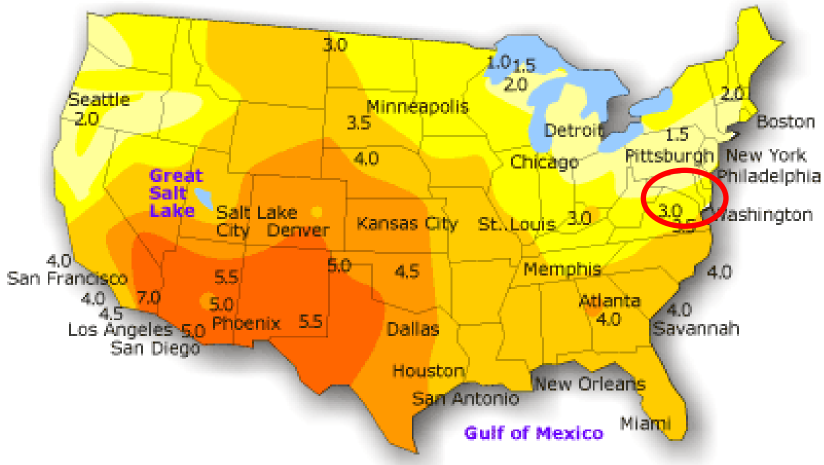
South Wing

| | | | | | |
|---|---|---|---|---|---|
| **Facade** | | 101 | 02-15-13 | 07-26-13 | 87 |
| ***Windows / Curtainwall*** | | 81 | 03-21-13 | 07-26-13 | 87 |
| 4210000 | Begin Windows & Storefront - South | 0 | 04-01-13 | | 106 |
| 4210100 | SOUTH TOWER WINDOWS & STOREFRONT SUMMARY | 35 | 04-01-13 | 05-23-13 | 124 |
| 4210300 | Install Windows 2nd Flr - South | 4 | 04-01-13 | 04-04-13 | 106 |
| 4210400 | Install Windows 3rd Flr - South | 4 | 04-05-13 | 04-11-13 | 106 |
| 4210500 | Install Windows 4th Flr - South | 4 | 04-12-13 | 04-17-13 | 106 |
| 4210600 | Install Windows 5th Flr - South | 4 | 04-18-13 | 04-23-13 | 106 |
| 4210700 | Install Windows 6th Flr - South | 4 | 04-25-13 | 04-30-13 | 106 |
| 4210800 | Install Curtainwall 6th Flr - South | 10 | 05-01-13 | 05-15-13 | 106 |
| 4210900 | Install Windows & Storefront 1st Flr - South | 5 | 05-16-13 | 05-23-13 | 124 |
| 4210990 | Complete Windows & Storefront - South | 0 | | 05-23-13 | 124 |
| 4220100 | Begin Curtainwall - South | 0 | 04-03-13 | | 87 |
| 4220200 | SOUTH TOWER CURTAINWALL SUMMARY | 26 | 04-03-13 | 05-13-13 | 133 |
| 4220300 | Install Curtainwall S Elev - South | 3 | 04-03-13 | 04-05-13 | 87 |
| 4220400 | Install Curtainwall E Elev - South | 10 | 04-08-13 | 04-22-13 | 87 |
| 4220500 | Install Curtainwall N&W Elev - South | 9 | 04-23-13 | 05-06-13 | 87 |
| 4220600 | Install Insulation, Firesafing S Elev - South | 2 | 04-08-13 | 04-09-13 | 145 |
| 4220700 | Install Insulation, Firesafing E Elev - South | 5 | 04-23-13 | 04-30-13 | 137 |
| 4220800 | Install Insulation, Firesafing N&W Elev - South | 4 | 05-07-13 | 05-13-13 | 133 |
| 4220990 | Complete Installation of Curtainwall System - South | 0 | | 05-13-13 | 133 |
| 4230100 | Erect CMU at N Entrance - South | 10 | 03-21-13 | 04-03-13 | 108 |
| 4230200 | Install Point Supported Curtainwall N Entrance - South | 20 | 05-07-13 | 06-07-13 | 87 |
| 4230300 | Install Entry Doors at N Entrance - South | 3 | 06-10-13 | 06-13-13 | 111 |
| 4230400 | Install Studs & Sheathing at N Entrance - South | 3 | 04-04-13 | 04-08-13 | 140 |
| 4230450 | Install Alum Extrusions at N Entrance - South | 5 | 06-10-13 | 06-17-13 | 102 |
| 4230500 | Install Metal Panels at N Entrance - South | 5 | 06-18-13 | 06-25-13 | 102 |
| 4230600 | Install Point Supported Curtainwall Main Entrance - South | 25 | 06-10-13 | 07-18-13 | 87 |
| 4230700 | Install Entry Doors at Main Entrance - South | 3 | 07-19-13 | 07-23-13 | 89 |
| 4230800 | Install Studs & Sheathing at Main Entrance - South | 3 | 04-09-13 | 04-12-13 | 147 |
| 4230900 | Install Metal Panels at Main Entrance - South | 5 | 07-19-13 | 07-26-13 | 87 |
| 4290100 | Caulking & Sealants - South | 20 | 06-26-13 | 07-26-13 | 87 |

North Wing

| | | | | | |
|---|---|---|---|---|---|
| **Facade** | | 66 | 03-14-13 | 06-26-13 | 106 |
| ***Windows / Curtainwall*** | | 45 | 04-16-13 | 06-26-13 | 106 |
| 5210000 | Begin Windows & Storefront - North | 0 | 04-16-13 | | 100 |
| 5210010 | NORTH TOWER WINDOWS & STOREFRONT SUMMARY | 30 | 04-16-13 | 05-31-13 | 119 |
| 5210100 | Install Windows 2nd Flr - North | 4 | 04-16-13 | 04-19-13 | 107 |
| 5210200 | Install Windows 3rd Flr - North | 4 | 04-22-13 | 04-26-13 | 107 |
| 5210300 | Install Windows 4th Flr - North | 4 | 04-29-13 | 05-02-13 | 107 |
| 5210400 | Install Windows 5th Flr - North | 4 | 05-03-13 | 05-09-13 | 107 |
| 5210500 | Install Curtainwall 5th Flr - North | 10 | 05-10-13 | 05-24-13 | 107 |
| 5210600 | Install Windows & Storefront 1st Flr - North | 4 | 05-28-13 | 05-31-13 | 119 |
| 5210700 | Complete Windows & Storefront - North | 0 | | 05-31-13 | 119 |
| 5220100 | Begin Installation of Curtainwall System - North | 0 | 04-23-13 | | 95 |
| 5220200 | NORTH TOWER CURTAINWALL SUMMARY | 34 | 04-23-13 | 06-17-13 | 110 |
| 5220300 | Install Curtainwall S Elev - North | 20 | 04-23-13 | 05-23-13 | 95 |
| 5220400 | Install Curtainwall E Elev - North | 5 | 05-24-13 | 05-31-13 | 95 |
| 5220500 | Install Curtainwall N Elev - North | 5 | 06-03-13 | 06-10-13 | 111 |
| 5220600 | Install Insulation, Firesafing S Elev - North | 10 | 05-24-13 | 06-10-13 | 110 |
| 5220700 | Install Insulation, Firesafing E Elev - North | 2 | 06-11-13 | 06-13-13 | 110 |
| 5220800 | Install Insulation, Firesafing N Elev - North | 2 | 06-14-13 | 06-17-13 | 110 |
| 5220900 | Complete Installation of Curtainwall System - North | 0 | | 06-17-13 | 110 |
| 5290100 | Caulking & Sealants - North | 20 | 05-24-13 | 06-26-13 | 106 |

# Appendix F




Map found at Solar Direct 2014 to get Kilowatt hours of sunlight per day in Northern Virginia

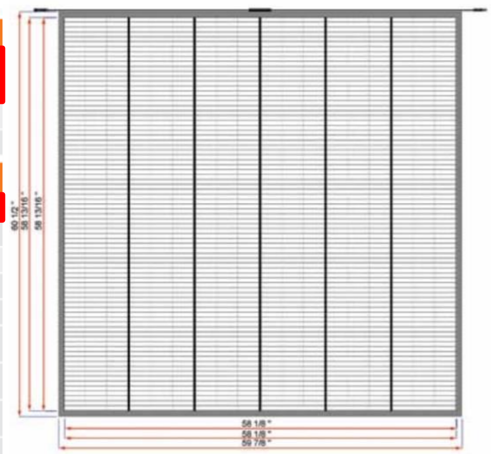
## Typical PVGU Window Specification

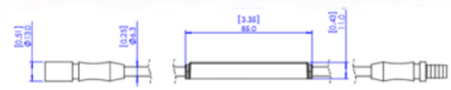
| UNIT MECHANICAL SPECIFICATIONS | |
|---|---|
| Length | 60" (1524mm) |
| Width | 60" (1524mm) |
| Thickness | 1 ¼" (32mm) |
| Weight | 209 lbs (95 kg) |

| UNIT ELECTRICAL SPECIFICATIONS | |
|---|---|
| $Power_{mpp}$ | 252.8 W |
| $V_{mpp}$ | 48.4 V |
| $V_{oc}$ | 58.2 V |
| $I_{mpp}$ | 5.2 A |
| $I_{sc}$ | 5.6 A |
| Tested Operating Temperature | -40°C – 85°C |
| Maximum System Voltage | 600 V DC |
| Maximum Series Fuse Rating | 15 amps |
| Power Tolerance | +/- 5% |

| UNIT GLAZING SPECIFICATIONS | |
|---|---|
| Outer Glass | 1/4" (6mm) ultra-clear |
| Inner Glass | 1/4"(6mm) low-e coated |
| U-value* | 0.30 |
| SHGC*** | 0.14 (for angles > 25 above normal) |
| VLT*** | 0.49 (for angles < 25 above normal) |
| UVT*** | 0.28 (for angles < 25 above normal) |
| Maximum System Voltage | 600 V DC |
| Maximum Series Fuse Rating | 15 amps |
| Power Tolerance | +/- 5% |

| ELECTRICAL COEFFICIENTS | |
|---|---|
| Nominal Operating Cell Temperature (NOCT) | 53°C |
| Temperature Coefficient of Pmpp | -0.55%/°C |
| Temperature Coefficient of Voc | -0.36%/°C |
| Temperature Coefficient of Isc | 0.03%/°C |

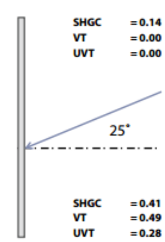




*Junction Box Dimensions: mm (inches)*

### Glazing Transmission Specifications

The PVGU's patented optical design accepts light from a range of angles and concentrates it onto solar cells. This unique ability allows the PVGU to obtain glazing transmission metrics unlike any product on the market today. For angles where direct sunlight would be incident on the window the PVGU blocks all direct sunlight thus creating a very low solar heat gain coefficient (SHGC). At the same time diffused light is transmitted at a rate corresponding to the visible transmittance (VT) of the glass specified. It is this optimization of SHGC and VT that allows the PVGU to achieve an effective light-to-solar-gain (LSG) unmatched by any glazing product on the market today.




*Glazing metrics are a function of angle and are generalized by the above drawing for illustration purposes.

Questions?
contact@pythagoras-solar.com
Main number: (650) 357-9093
Toll-free: (855) 357-9093

Visit us Online:
pythagoras-solar.com

Pythagoras Solar

Spec for PV window from Pythagoras Solar

# Appendix G

**Calculator for Overall DC to AC Derate Factor**

| Component Derate Factors | Component Derate Values | Range of Acceptable Values |
|---|---|---|
| PV module nameplate DC rating | 0.95 | 0.80 - 1.05 |
| Inverter and Transformer | 0.92 | 0.88 - 0.98 |
| Mismatch | 0.98 | 0.97 - 0.995 |
| Diodes and connections | 0.995 | 0.99 - 0.997 |
| DC wiring | 0.98 | 0.97 - 0.99 |
| AC wiring | 0.99 | 0.98 - 0.993 |
| Soiling | 0.95 | 0.30 - 0.995 |
| System availability | 0.98 | 0.00 - 0.995 |
| Shading | 1 | 0.00 - 1.00 |
| Sun-tracking | 1 | 0.95 - 1.00 |
| Age | 1 | 0.70 - 1.00 |
| Overall DC to AC derate factor | 0.769 | |

**Station Identification:**

WBAN Number: 93738
City: Sterling
State: Virginia

**PV System Specifications:**

DC Rating (kW): 96.60
DC to AC Derate Factor: 0.77 DERATE FACTOR HELP
Array Type: Fixed Tilt

Fixed Tilt or 1-Axis Tracking System:
Array Tilt (degrees): 90 (Default = Latitude)
Array Azimuth (degrees): 217 (Default = South)

**Energy Data:**

Cost of Electricity (cents/kWh): 8.20

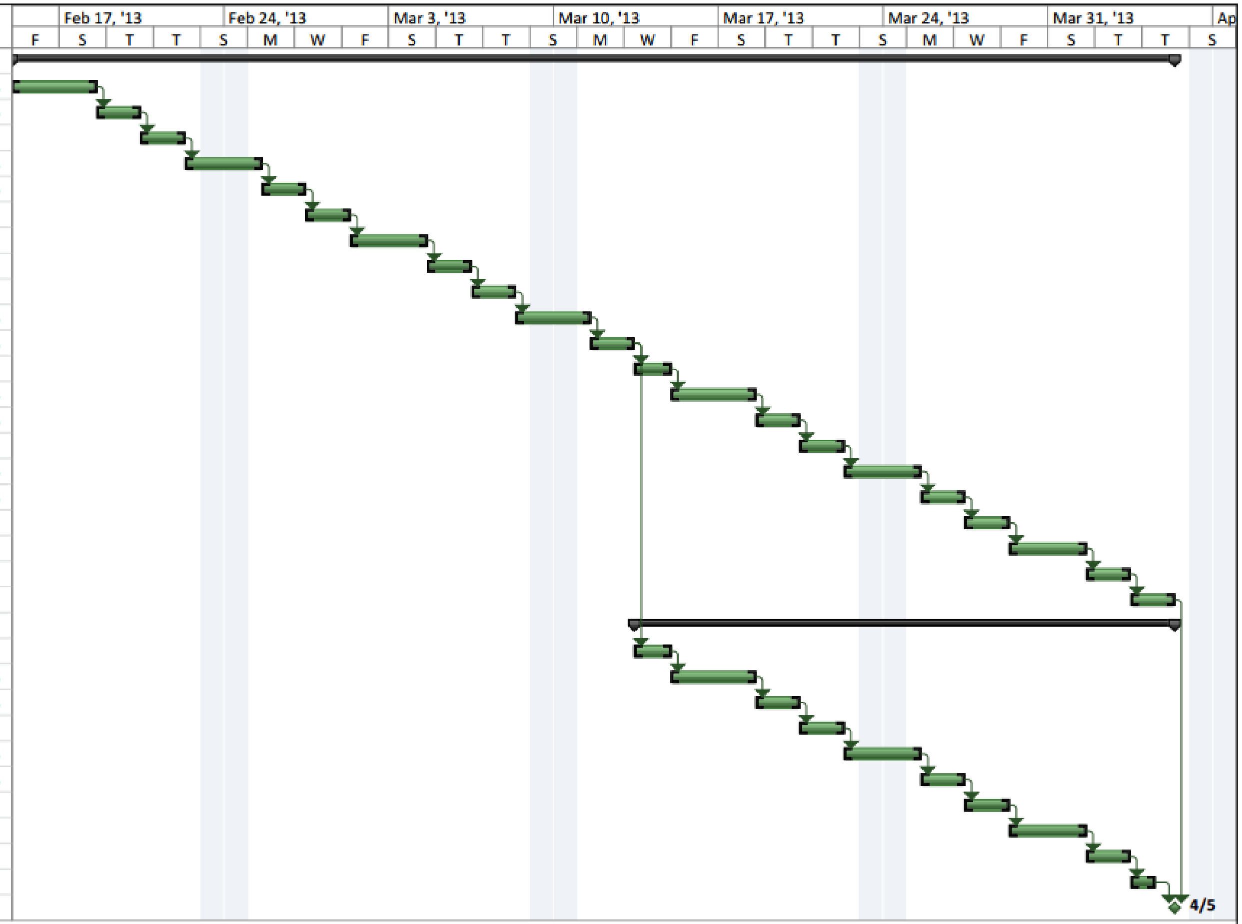
| Station Identification | |
|---|---|
| City: | |
| State: | Virginia |
| Latitude: | 38.95° N |
| Longitude: | 77.45° W |
| Elevation: | 82 m |
| PV System Specifications | |
| DC Rating: | 96.6 kW |
| DC to AC Derate Factor: | 0.770 |
| AC Rating: | 74.4 kW |
| Array Type: | Fixed Tilt |
| Array Tilt: | 90.0° |
| Array Azimuth: | 217.0° |
| Energy Specifications | |
| Cost of Electricity: | 8.2 ¢/kWh |

| Results | | | |
|---|---|---|---|
| Month | Solar Radiation ($kWh/m^2/day$) | AC Energy (kWh) | Energy Value ($) |
| 1 | 2.87 | 6630 | 543.66 |
| 2 | 3.10 | 6271 | 514.22 |
| 3 | 3.30 | 7170 | 587.94 |
| 4 | 3.26 | 6554 | 537.43 |
| 5 | 2.93 | 5665 | 464.53 |
| 6 | 2.96 | 5459 | 447.64 |
| 7 | 2.98 | 5618 | 460.68 |
| 8 | 3.11 | 6037 | 495.03 |
| 9 | 3.22 | 6292 | 515.94 |
| 10 | 3.35 | 6944 | 569.41 |
| 11 | 2.91 | 6133 | 502.91 |
| 12 | 2.61 | 5810 | 476.42 |
| Year | 3.05 | 74581 | 6115.64 |

**This information was generated with the help of National Renewable 2013 (See Appendix)

# Appendix H

| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **South Wing** | **35.19 days** | **Fri 2/15/13** | **Fri 4/5/13** |
| 2 | Install panels 1-27 (S Wing - SW corner) | 13.5 hrs | Fri 2/15/13 | Mon 2/18/13 |
| 3 | Install Strip Windows 28 - 54 (S Façade) | 13.5 hrs | Mon 2/18/13 | Wed 2/20/13 |
| 4 | Install Strip Windows 55 - 81 (S Façade) | 13.5 hrs | Wed 2/20/13 | Fri 2/22/13 |
| 5 | Install Strip Windows 82 - 108 (S Façade) | 13.5 hrs | Fri 2/22/13 | Mon 2/25/13 |
| 6 | Install Strip Windows 109 - 135 (S Façade) | 13.5 hrs | Mon 2/25/13 | Wed 2/27/13 |
| 7 | Install Strip Windows 136 - 162 (S Façade) | 13.5 hrs | Wed 2/27/13 | Fri 3/1/13 |
| 8 | Install Strip Windows 163 - 189 (S Façade) | 13.5 hrs | Fri 3/1/13 | Mon 3/4/13 |
| 9 | Install panels 190 -216 (SW corner) | 13.5 hrs | Mon 3/4/13 | Wed 3/6/13 |
| 10 | Install Strip Windows 217 - 243 (S Façade) | 13.5 hrs | Wed 3/6/13 | Fri 3/8/13 |
| 11 | Install Strip Windows 244 - 266 (S Façade) | 11.5 hrs | Fri 3/8/13 | Mon 3/11/13 |
| 12 | Install panels 267 -293 (NE Facade) | 13.5 hrs | Mon 3/11/13 | Wed 3/13/13 |
| 13 | Install panels 294 -320 (E Corner) | 13.5 hrs | Wed 3/13/13 | Thu 3/14/13 |
| 14 | Install panels 321 -347 (NE Façade) | 13.5 hrs | Fri 3/15/13 | Mon 3/18/13 |
| 15 | Install panels 348 -374 (N Façade) | 13.5 hrs | Mon 3/18/13 | Wed 3/20/13 |
| 16 | Install panels 375 -401 (N corner) | 13.5 hrs | Wed 3/20/13 | Fri 3/22/13 |
| 17 | Install panels 402 -428 (N Façade) | 13.5 hrs | Fri 3/22/13 | Mon 3/25/13 |
| 18 | Install panels 429 -455 (N Façade) | 13.5 hrs | Mon 3/25/13 | Wed 3/27/13 |
| 19 | Install panels 456 -482 (N Façade) | 13.5 hrs | Wed 3/27/13 | Fri 3/29/13 |
| 20 | Install panels 483 -509 (SE Façade) | 13.5 hrs | Fri 3/29/13 | Mon 4/1/13 |
| 21 | Install panels 510 -536 (S Façade) | 13.5 hrs | Mon 4/1/13 | Wed 4/3/13 |
| 22 | Install panels 537 -563 (NW Façade) | 13.5 hrs | Wed 4/3/13 | Fri 4/5/13 |
| 23 | **North Wing** | **16.88 days** | **Wed 3/13/13** | **Fri 4/5/13** |
| 24 | Install panels 564 -590 (E Corner) | 13.5 hrs | Wed 3/13/13 | Thu 3/14/13 |
| 25 | Install panels 591 -617 (E Corner) | 13.5 hrs | Fri 3/15/13 | Mon 3/18/13 |
| 26 | Install panels 618 -644 (S Corner) | 13.5 hrs | Mon 3/18/13 | Wed 3/20/13 |
| 27 | Install panels 645 -671 (E Corner) | 13.5 hrs | Wed 3/20/13 | Fri 3/22/13 |
| 28 | Install panels 672 -698 (E Corner) | 13.5 hrs | Fri 3/22/13 | Mon 3/25/13 |
| 29 | Install panels 699 -725 (SE Facade) | 13.5 hrs | Mon 3/25/13 | Wed 3/27/13 |
| 30 | Install panels 726 -752 (S Corner) | 13.5 hrs | Wed 3/27/13 | Fri 3/29/13 |
| 31 | Install panels 753 -779 (E Corner) | 13.5 hrs | Fri 3/29/13 | Mon 4/1/13 |
| 32 | Install panels 780 -806 (N Corner) | 13.5 hrs | Mon 4/1/13 | Wed 4/3/13 |
| 33 | Install panels 807 -833 (NW Facade) | 8.5 hrs | Wed 4/3/13 | Thu 4/4/13 |
| 34 | Prefabricated Façade Complete | 0 days | Fri 4/5/13 | Fri 4/5/13 |




Project: Prefab Schedule
Date: Thu 3/6/14

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

# Appendix I

# REFERENCE NOTES FOR BORING LOGS

## I. Drilling Sampling Symbols

| | | | |
|---|---|---|---|
| SS | Split Spoon Sampler | ST | Shelby Tube Sampler |
| RC | Rock Core, NX, BX, AX | PM | Pressuremeter |
| DC | Dutch Cone Penetrometer | RD | Rock Bit Drilling |
| BS | Bulk Sample of Cuttings | PA | Power Auger (no sample) |
| HSA | Hollow Stem Auger | WS | Wash sample |
| REC | Rock Sample Recovery % | RQD | Rock Quality Designation % |

## II. Correlation of Penetration Resistances to Soil Properties

Standard Penetration (blows/ft) refers to the blows per foot of a 140 lb. hammer falling 30 inches on a 2-inch OD split-spoon sampler, as specified in ASTM D 1586. The blow count is commonly referred to as the N-value.

### A. Non-Cohesive Soils (Silt, Sand, Gravel and Combinations)

| *Density* | | *Relative Properties* | |
|---|---|---|---|
| Under 4 blows/ft | Very Loose | Adjective Form | 12% to 49% |
| 5 to 10 blows/ft | Loose | With | 5% to 12% |
| 11 to 30 blows/ft | Medium Dense | | |
| 31 to 50 blows/ft | Dense | | |
| Over 51 blows/ft | Very Dense | | |

| *Particle Size Identification* | | |
|---|---|---|
| Boulders | | 8 inches or larger |
| Cobbles | | 3 to 8 inches |
| Gravel | Coarse | 1 to 3 inches |
| | Medium | ½ to 1 inch |
| | Fine | ¼ to ½ inch |
| Sand | Coarse | 2.00 mm to ¼ inch (dia. of lead pencil) |
| | Medium | 0.42 to 2.00 mm (dia. of broom straw) |
| | Fine | 0.074 to 0.42 mm (dia. of human hair) |
| Silt and Clay | | 0.0 to 0.074 mm (particles cannot be seen) |

### B. Cohesive Soils (Clay, Silt, and Combinations)

| *Blows/ft* | *Consistency* | *Unconfined Comp. Strength $Q_p$ (tsf)* | *Degree of Plasticity* | *Plasticity Index* |
|---|---|---|---|---|
| Under 2 | Very Soft | Under 0.25 | None to slight | 0 – 4 |
| 3 to 4 | Soft | 0.25-0.49 | Slight | 5 – 7 |
| 5 to 8 | Medium Stiff | 0.50-0.99 | Medium | 8 – 22 |
| 9 to 15 | Stiff | 1.00-1.99 | High to Very High | Over 22 |
| 16 to 30 | Very Stiff | 2.00-3.00 | | |
| 31 to 50 | Hard | 4.00–8.00 | | |
| Over 51 | Very Hard | Over 8.00 | | |

## III. Water Level Measurement Symbols

| | | | | | |
|---|---|---|---|---|---|
| WL | Water Level | BCR | Before Casing Removal | DCI | Dry Cave-In |
| WS | While Sampling | ACR | After Casing Removal | WCI | Wet Cave-In |
| WD | While Drilling | ▽ | Est. Groundwater Level | ▼ | Est. Seasonal High GWT |

The water levels are those levels actually measured in the borehole at the times indicated by the symbol. The measurements are relatively reliable when augering, without adding fluids, in a granular soil. In clay and plastic silts, the accurate determination of water levels may require several days for the water level to stabilize. In such cases, additional methods of measurement are generally applied.

| CLIENT | JOB # | BORING # | SHEET |
|---|---|---|---|
| Monument Realty, LLC | 11916-C | ECS-1 | 1 OF 4 |

ECS LLC MID-ATLANTIC

PROJECT NAME: Monument View Additional Borings

ARCHITECT-ENGINEER:

SITE LOCATION: 10th Street South & Jefferson Davis Hwy, Pentagon City, VA

-O- CALIBRATED PENETROMETER TONS/FT.² 1 2 3 4 5+

PLASTIC LIMIT % X — WATER CONTENT % ● — LIQUID LIMIT % △

ROCK QUALITY DESIGNATION & RECOVERY: RQD% — — — REC.% ——— 20% 40% 60% 80% 100%

⊗ STANDARD PENETRATION BLOWS/FT. 10 20 30 40 50+

DESCRIPTION OF MATERIAL — ENGLISH UNITS

BOTTOM OF CASING — LOSS OF CIRCULATION (100%)

SURFACE ELEVATION 17

| DEPTH (FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DIST. (IN) | RECOVERY (IN) | DESCRIPTION OF MATERIAL | ELEVATION (FT) | STANDARD PENETRATION BLOWS/FT. |
|---|---|---|---|---|---|---|---|
| 0 | | | | | Asphalt Depth 6" | | |
| | 1 | SS | 18 | 14 | CLAY, With Sand, Gravel, and Debris, Reddish Brown, Moist, Stiff, (FILL) | 15 | 14 (4-6-8) |
| | 2 | SS | 18 | 18 | CLAY, With Sand, Brick, and Gravel, Brown, Dry, Stiff to Very Stiff, (FILL) | | 10 (3-4-6) |
| 5 | 3 | SS | 18 | 16 | | | 22 (11-10-12) |
| | | | | | Sandy CLAY, With Gravel, Brown, Moist, Soft, (FILL) | 10 | |
| | 4 | SS | 18 | 6 | | | 3 (1-1-2) |
| 10 | | | | | | | |
| | | | | | Silty SAND, Trace Lignite, Brown and Gray, Moist, Loose, (FILL) | 5 | |
| | 5 | SS | 18 | 14 | | | 5 (1-2-3) |
| 15 | | | | | | | |
| | | | | | Silty CLAY, Trace Organics, Brown and Black, Moist, Medium Stiff, (FILL) | 0 | |
| | 6 | SS | 18 | 12 | | | 6 (2-2-4) |
| 20 | | | | | | | |
| | | | | | Clayey Fine SAND, Brown and Gray, Moist, Loose, (FILL) | -5 | |
| | 7 | SS | 18 | 18 | | | 5 (2-2-3) |
| 25 | | | | | | | |
| | | | | | Fine to Medium SAND, With Clay and Gravel, Moist to Wet, Medium Dense, (SC) | -10 | |
| | 8 | SS | 18 | 16 | | | 11 (4-5-6) |
| 30 | | | | | | | |

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THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY LINES BETWEEN SOIL TYPES IN-SITU THE TRANSITION MAY BE GRADUAL

| | | |
|---|---|---|
| WL 23.0 — BS OR WD | BORING STARTED 10/15/10 | DRILLER: Connelly |
| WL(BCR) 28.0 WL(ACR) 36.0 | BORING COMPLETED 10/15/10 | CAVE IN DEPTH @ 22.0' |
| WL | RIG 55 LC ATV FOREMAN Josh Lewis | DRILLING METHOD Hollow Stem Auger 3.25 |

| CLIENT | JOB # | BORING # | SHEET |
|---|---|---|---|
| Monument Realty, LLC | 11916-C | ECS-1 | 2 OF 4 |

ECS LLC MID-ATLANTIC

PROJECT NAME: Monument View Additional Borings

ARCHITECT-ENGINEER:

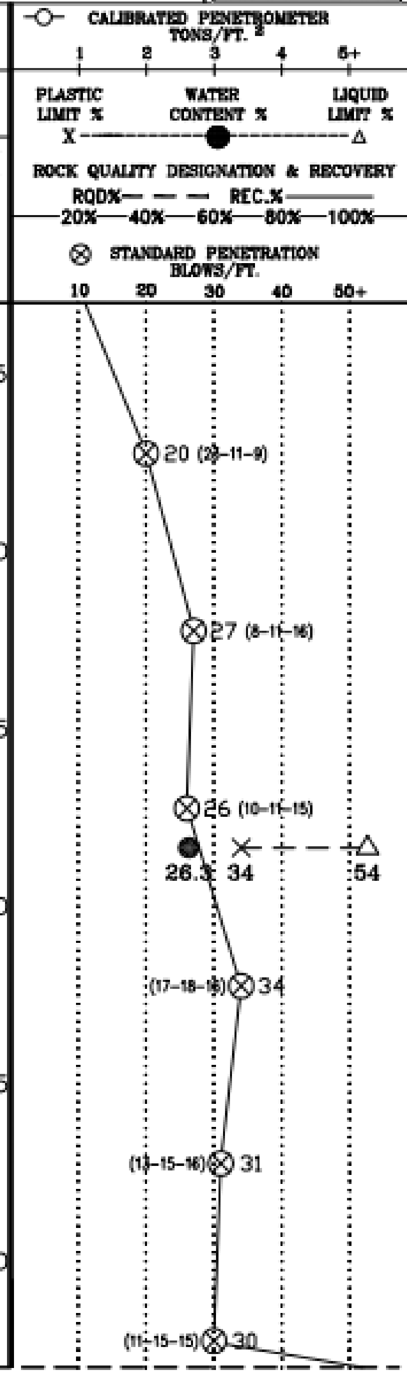
SITE LOCATION: 10th Street South & Jefferson Davis Hwy, Pentagon City, VA

DESCRIPTION OF MATERIAL — ENGLISH UNITS

BOTTOM OF CASING — LOSS OF CIRCULATION (100%)

SURFACE ELEVATION 17

| DEPTH (FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DIST. (IN) | RECOVERY (IN) | DESCRIPTION OF MATERIAL | ELEVATION (FT) |
|---|---|---|---|---|---|---|
| 30 | | | | | Fine to Medium SAND, With Clay and Gravel, Moist to Wet, Medium Dense, (SC) | −15 |
| 35 | 9 | SS | 18 | 5 | | |
| 40 | 10 | SS | 18 | 16 | Clayey SILT, Trace Sand, Reddish Brown and Gray, Moist, Very Stiff to Hard, (MH) | −20 |
| 45 | 11 | SS | 18 | 18 | | −25 |
| 50 | 12 | SS | 18 | 16 | | −30 |
| 55 | 13 | SS | 18 | 18 | CLAY, With Sand, Gray, Moist, Very Stiff to Hard, (CL) | −35 |
| 60 | 14 | SS | 18 | 18 | | −40 |

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| | | |
|---|---|---|
| WL 23.0 — BS OR WD | BORING STARTED 10/15/10 | DRILLER: Connelly |
| WL(BCR) 28.0 WL(ACR) 36.0 | BORING COMPLETED 10/15/10 | CAVE IN DEPTH ● 22.0' |
| WL | RIG 55 LC ATV FOREMAN Josh Lewis | DRILLING METHOD Hollow Stem Auger 3.25 |

| CLIENT | JOB # | BORING # | SHEET |
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| Monument Realty, LLC | 11916-C | ECS-1 | 3 OF 4 |

ECS LLC MID-ATLANTIC

PROJECT NAME: Monument View Additional Borings

ARCHITECT-ENGINEER:

SITE LOCATION: 10th Street South & Jefferson Davis Hwy, Pentagon City, VA

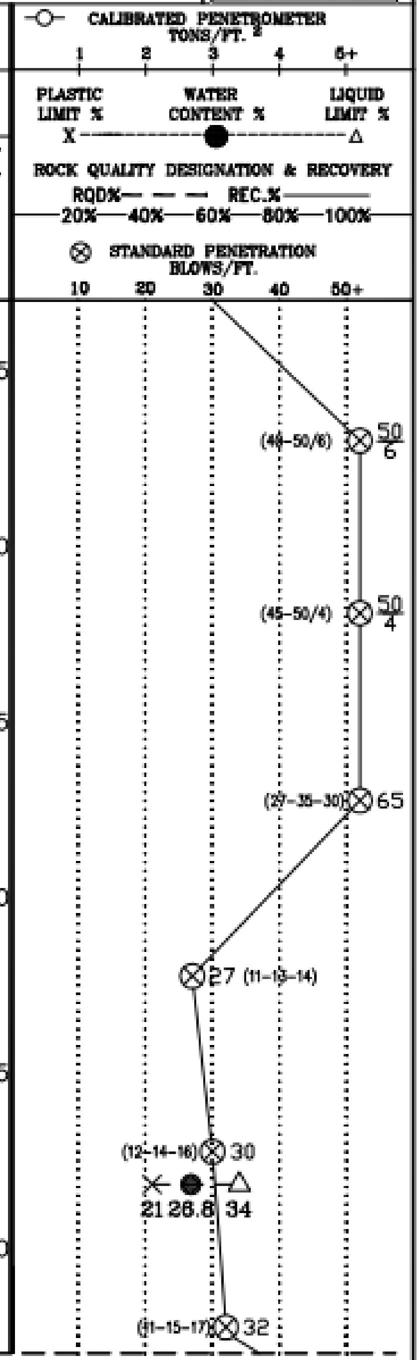
DESCRIPTION OF MATERIAL — ENGLISH UNITS

BOTTOM OF CASING — LOSS OF CIRCULATION (100%)

SURFACE ELEVATION: 17

| Depth (ft) | Description of Material | Elevation (ft) |
|---|---|---|
| 60 | CLAY, With Sand, Gray, Moist, Very Stiff to Hard, (CL) | -45 |
| 62 | Fine to Medium SAND, With Clay, Brown and Gray, Moist, Very Dense, (SP) | -50 |
| 67 | CLAY, Brown and Gray, Moist, Very Hard, (CH) | -55 |
| 72 | Sandy CLAY, Brown, Moist, Very Hard, (CL) | -60 |
| 77 | Clayey SAND, Gray, Moist, Medium Dense to Dense, (SC) | -65, -70 |

| Sample No. | Sample Type | Sample Dist. (in) | Recovery (in) |
|---|---|---|---|
| 15 | SS | 12 | 10 |
| 16 | SS | 10 | 4 |
| 17 | SS | 18 | 14 |
| 18 | SS | 18 | 16 |
| 19 | SS | 18 | 16 |
| 20 | SS | 18 | 18 |

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| | | |
|---|---|---|
| WL 23.0 — BORING OR WD | BORING STARTED 10/15/10 | DRILLER: Connelly |
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PLASTIC LIMIT % X — WATER CONTENT % ● — LIQUID LIMIT % △

ROCK QUALITY DESIGNATION & RECOVERY: RQD% — — — REC.% ——— 20% 40% 60% 80% 100%

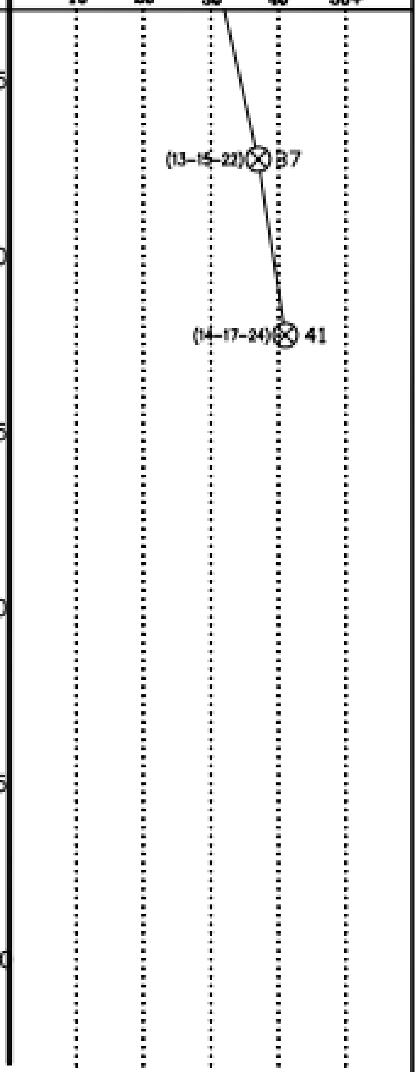
⊗ STANDARD PENETRATION BLOWS/FT. 10 20 30 40 50+

DESCRIPTION OF MATERIAL — ENGLISH UNITS

BOTTOM OF CASING — LOSS OF CIRCULATION (100%)

SURFACE ELEVATION: 17

| DEPTH (FT) | SAMPLE NO. | SAMPLE TYPE | SAMPLE DIST. (IN) | RECOVERY (IN) | DESCRIPTION OF MATERIAL | WATER LEVELS | ELEVATION (FT) |
|---|---|---|---|---|---|---|---|
| 90 | | | | | Clayey SAND, Gray, Moist, Medium Dense to Dense, (SC) | | |
| | | | | | Clayey SAND, With Gravel, Brown and Gray, Moist, Dense, (SC) | | -75 |
| 95 | 21 | SS | 18 | 18 | | | |
| | | | | | | | -80 |
| 100 | 22 | SS | 18 | 18 | | | |
| | | | | | END OF BORING @ 100.0' | | -85 |
| 105 | | | | | | | |
| | | | | | | | -90 |
| 110 | | | | | | | |
| | | | | | | | -95 |
| 115 | | | | | | | |
| | | | | | | | -100 |
| 120 | | | | | | | |

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