2010

Final Report

Marymount University 26th St Project
Arlington, VA

Spring 2010

Benjamin Mahoney
Construction Management
Consultant: Mr. James Faust

Marymount University

26th Street Project

Arlington, Virginia

Benjamin J. Mahoney | Construction Management

Project Information

Function | Residential, Business, Storage/Garage & Assembly
Size | 129,000-SF Academic/Residential + 138,000-SF Garage
Construction | April 2009 - September 2010
Building Cost | $42 Million
Delivery Method | Design/Bid/Build

Project Team

Owner | Marymount University
Owner's Representative/CM | Stranix Associates
General Contractor | James G. Davis Construction Corp.
Architect | Davis, Carter, Scott LTD.
Structural Engineer | Structura, Inc.
MEP Engineer | GHT Limited
Civil Engineer | VIKA, Inc.
Landscape Architect | Lewis Scully Gionet

Architectural Features

The 26th Street Project is situated on 1.45 acres and will provide Marymount University with additional dormitory units, a new academic facility, and underground parking. The project site is located at the corner of 26th Street, Yorktown Boulevard, and Old Dominion Drive in Arlington, VA. The residential building will contribute 62 new units, situated in four and five unit suite configurations. The academic building will provide state of the art scientific laboratory space, lecture halls, and office space for Marymount University personnel. Both the academic and residential buildings will be constructed on top of four levels of underground parking and separated by outdoor gathering space.

Structural System

Foundation
Cast-in-Place Concrete
34-54" Reinforced Mat Foundations along the perimeter
32"-54" Reinforced Spread Footings support the columns
Framing
Cast-in-Place Concrete,Reinforced columns
Shear Walls & Grade Beams provide lateral support
Floor System
Cast-in-Place Concrete
8", Reinforced Parking Deck slabs w/ 5.5" drop panels
7", Post-Tension Residential floor slabs w/ 6" drop panels
9", Post-Tension Academic floor slabs w/ 8" drop panels
Facade
Architectural Precast concrete
Roof
9", Post-Tension roof slab with a white TPO membrane

MEP Systems

Mechanical
(7) Rooftop AHU's ranging from 1,200-11,400 CFM
(1) 17,600 CFM AHU with Energy Recovery
(2) 500 Ton Cooling Towers
(2) 250 Ton Centrifugal Chillers
(3) Natural Gas Boilers produce a total of 1,900 MBH
Fan Coil Units service each Residential Unit
Electrical
480/277V, 3Φ, 4 wire primary electrical distribuion
350 kW, 480V, 3Φ, 4 wire CPS Emergency Generator
(23) Different types of Architectural Lighting Fixtures
Plumbing
Automatic Wet & Dry-Pipe Fire Suppression System
Reverse Osmossis System provides Distilled Water
Acid Waste Drainage System w/ Neutralization Tank
Compressed-Air System delivers clean, dry air
2 p.s.i.g. Natural Gas Supply System

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1.0 Acknowledgements

Throughout the course of my Senior Thesis Project, I would like to personally thank all of the individuals that provided me with assistance along the way. Without their guidance and cooperation, I would not have been able to accomplish what I have over the past two semesters.

Pennsylvania State University Faculty
Dr. David Riley Dr. Chris Magent Dr. Kevin Parfitt Mr. Robert Holland Mr. Jim Faust Mr. Craig Dubler
James G. Davis Construction Corp.
Mr. Erik Kaniecki Mr. Rami Natour Mr. Aaron Galvin
Marymount University
Dr. Ralph Kidder Mr. Upen Malani Dr. James Bundschuh
Stranix Associates
Ms. Bhavna Mistry Lee

2.0 Executive Summary

This report is intended to provide an in-depth analysis of the background information relating to the Marymount University 26th Street Project. Areas of investigation include client information, project delivery system, project milestones, key project team members, existing conditions, and major building systems. In addition to the background information, three detailed analysis topics have been investigated.

The analysis topics that were performed during the competition of this senior thesis project include the development of a Short Interval Production Schedule, MEP coordination techniques, and the implementation of a green roof. All of the research topics have been chosen to revolve around the critical industry issue relating to increasing efficiencies.

Analysis I:
The first analysis involves implementing Short Interval Production Scheduling into the interior finishes of the Residential Facility. The repetitive nature of the activities involved with this phase of the project provides a perfect opportunity to attempt to bring the efficiencies of the "manufacturing process" to the construction industry. The results of this analysis have determined that the duration for this particular activity could be reduced by ten working days. This shortened duration has the potential to generate a savings of $70,000 in general conditions costs.

Analysis II:
The second analysis involves the investigation into the MEP coordination process. All of the MEP coordination on the Marymount University Project was done "traditionally" with two-dimensional composite drawings. The rise of three-dimensional coordination has introduced another option but has yet to become widely accepted. The acceptance of the 3D MEP coordination process will be evaluated through a survey of the General Contractor and their subcontractors. The results of this analysis reinforce the fact that the General Contractor is remaining at the forefront of technological advances within the AEC Industry. They have maintained this status through the creation of a new position within their organization that helps to ensure that the 3D MEP Coordination process is managed successfully.

Analysis III:
The third analysis involves incorporating a green roof into the design of the facilities at Marymount University. This will require supplementary evaluations on both the structural and mechanical systems of the building. In addition to satisfying both of the structural and mechanical breadth requirements, Analysis III will serve as the M.A.E. requirement. Through the completion of this analysis, it has been determined that the university could potentially see an annual energy savings of $2,700, increase the durability of their roofing membrane, and improve their LEED status from Certified to Silver.

3.0 Project Overview

Project Summary

The 26th Street Project is situated on 1.45 acres and will provide Marymount University with additional dormitory units, a new academic facility, and underground parking. The project site is located at the corner of 26th Street, Yorktown Boulevard, and Old Dominion Drive in Arlington, VA.

The residential building will add 62 units, situated in four and five unit suite configurations. The academic building will provide state of the art scientific laboratory space, lecture halls, and office space for Marymount University personnel. The academic and residential buildings will be constructed on top of the four levels of underground parking and separated by outdoor gathering space.

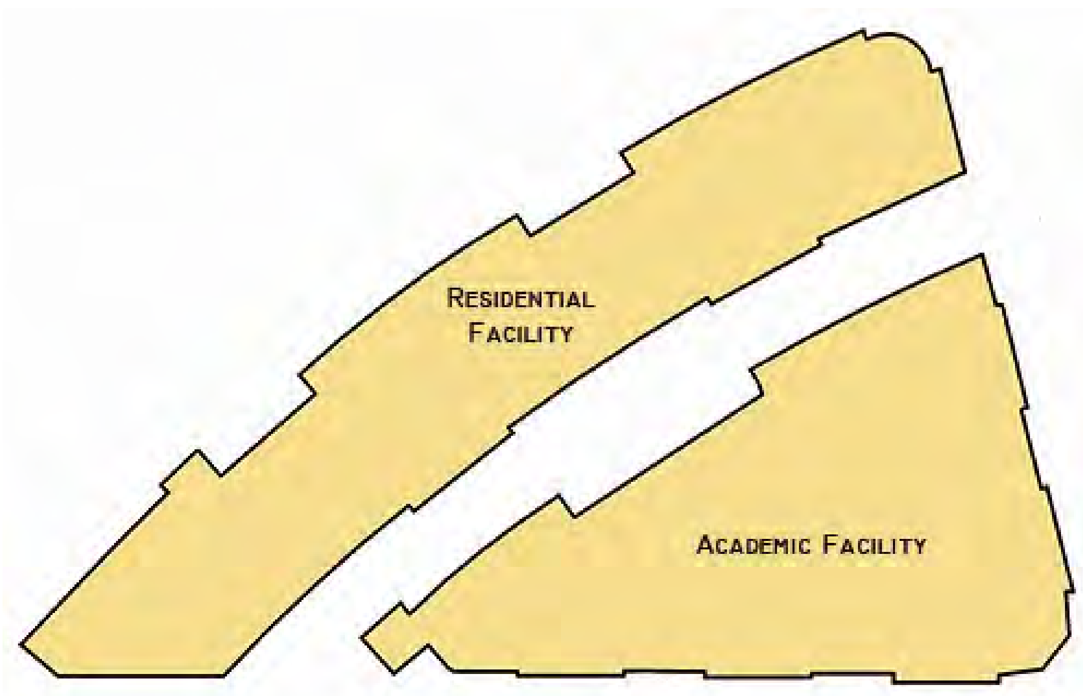


Figure 1: Building Footprint

To complete the construction of the $42,000,000 facility, Marymount University contracted James G. Davis Construction Corporation as the General Contractor in April of 2008. Construction on the 267,000 square foot facility began in February of 2009 and is scheduled to commence in September of 2010.

Client Information

The owner of this project is Marymount University, a catholic university located in Arlington, VA. The university offers associate's, bachelor's, master's, and doctoral degrees, undergraduate and graduate certification, and pre-professional programs in teaching, law, medicine, and physical therapy. With the addition of the 26th Street Project, Marymount University hopes to attract world class students and faculty.

The 26th Street Project is the most significant construction effort that the university has undertaken in nearly four decades. The project addresses three main concerns that are held by the leaders of the university; expanding academic space, student housing, and parking.

Throughout the construction of this project, the university is very concerned with being an outstanding citizen and neighbor to the surrounding residential communities. Marymount University feels strongly about keeping the local community informed and responding in a timely manner to any issues that may arise affecting the community. In order to keep the lines of communication open at all times, the university has established a project web site with information regarding the project. The web site can be found at www.marymount.edu/26thstreetproject/.

Marymount University feels strongly that the project should be turned over on-time and under budget. Time is an extremely critical issue as part of this project involves the construction of a new residential facility. If for whatever reason students cannot move in for the start of the fall 2010 semester, the students who are scheduled to move in will be without housing. If this were to occur, the students would be forced to reside in local hotels until the completion of the project.

Project Delivery System

To initiate the Marymount University 26th Street Project, the university entered into an AIA B151, standard form of Agreement between themselves and the architect, Davis, Carter, Scott, LTD. The architect was tasked with contracting the rest of the design consultants that will be a part of the project team. Aiding the owner throughout the duration of the design and construction, Stranix Associates, was brought on as an Owner's Representative at a fixed fee. Other key members of the project team include the constructors of the project. In this situation, James G. Davis Construction Corporation was awarded the preconstruction and construction services at a Guaranteed Maximum Price. The contractor holds an AIA 121 CMc, Standard Form between the Owner and the Construction Manager where the Construction Manager is the Constructor. As a General Contractor, James G. Davis is responsible for providing the General Liability Insurance, while the owner is responsible for providing the Builder's Risk Insurance.

Marymount University has not previously undertaken a project of this magnitude and with the assistance of an Owner's Representative, look to make the project a success. The inexperience of the owner and tight project schedule makes the selection of a General Contractor with a Guaranteed Maximum Price that most appropriate delivery method and contract type for this particular situation. In addition to the General Contractor, the university also has contracted with Construction Manager to act as an Owner's Representative. The university also chose to hire an Owner's Representative because of their ability to provide independent advice to the owner on both design and construction related issues.

Organizational Chart

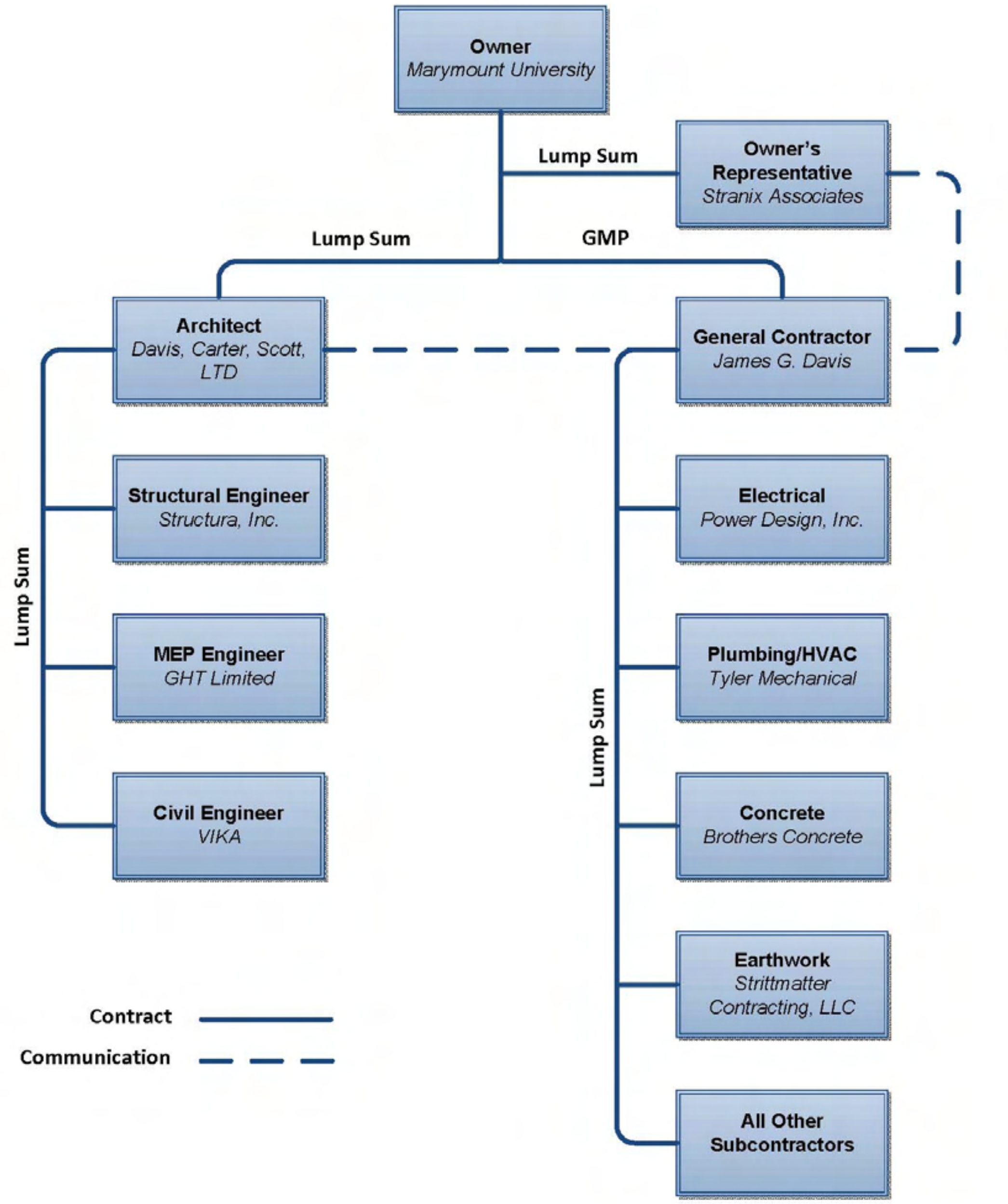


Figure 2: Marymount University 26th Street Project Team Organization Chart

Project Team

PROJECT TEAM	
Owner:	Marymount University
Owner's Representative/CM:	Stranix Associates
General Contractor:	James G. Davis Construction Corp.
Architect:	Davis, Carter, Scott LTD.
Structural Engineer:	Structura, Inc.
MEP Engineer:	GHT Limited
Civil Engineer:	VIKA
Landscape Architect:	Lewis Scully Gionet
LEED Consultant:	Sustainable Design Consulting
Cast-In Place Concrete Subcontractor:	Brothers Concrete Construction, Inc.
Pre-Cast Concrete Subcontractor:	Arban & Carosi
Mechanical/Plumbing Subcontractor:	Tyler Mechanical Contracting, Inc.
Electrical Subcontractor:	Power Design, Inc.

Figure 3: Marymount University Project Team

Project Schedule Summary

James G. Davis Construction Corporation is to be awarded the General Contracting responsibilities for the Marymount University 26th Street Project in April of 2008. This will provide the company with approximately 10 months to complete their preconstruction services. Services that include permit acquisition, procurement of materials, and completion of the Guaranteed Maximum Price contract.

Construction operations are scheduled to commence in February of 2009 when James G. Davis Construction is supplied with the Notice to Proceed from Marymount University. Mobilization of Davis field personnel as well as the Excavation/Demolition Contractor will follow directly after receiving the Notice to Proceed. Major construction activities that are to take place during this time include clearing of the existing parking, undergrounding of overhead utilities, installation of the excavation support system, and major excavation.

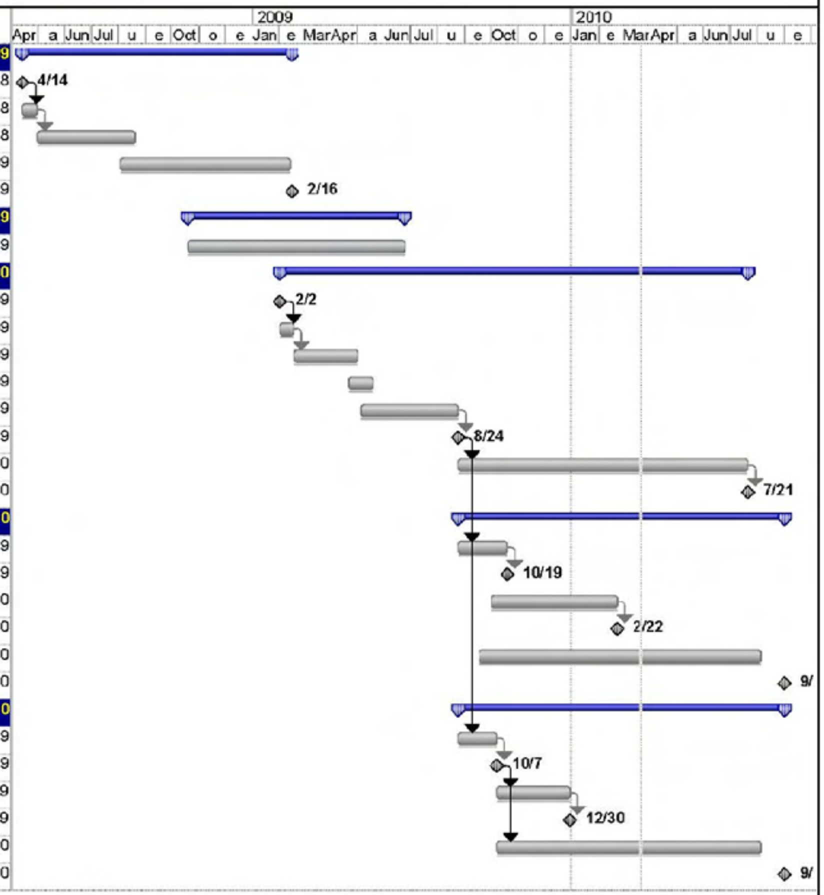
The major excavation/demolition activities are scheduled to kick-off in May of 2009, placing all of the foundation-to-grade activities directly in line with the critical path. This work will involve forming, reinforcing, and pouring the concrete mat foundations, spread footings, foundation walls, shear walls, columns, and floor slabs. The remaining concrete superstructure will be separated into two towers once it reaches the elevation at grade. One tower will be an academic facility, while the other tower will be a residence hall. The structures of both towers are sequenced to be constructed at the same time and are to top-out in October, 2009.

Both the academic facility and the residence hall will be enclosed with precast architectural concrete panels and aluminum framed windows. This enclosure system will provide the academic facility and the residence hall with a water tight status in December of 2009 and February of 2010, respectively.

The achievement of a water tight status will permit the start of the interior MEP rough-in and interior finishes in both the academic facility and the residential units. The completion of satisfactory inspections will allow the Marymount University 26th Street Project to achieve its final milestone, substantial completion, in early September of 2010. This will allow Marymount University students and personnel to inhabit their new facilities.

Marymount University
Summary Schedule

ID	Task Name	Duration	Start	Finish
1	**PRE-CONSTRUCTION**	**214 days**	**Mon 4/14/08**	**Mon 2/16/09**
2	Start of Project	0 days	Mon 4/14/08	Mon 4/14/08
3	Project Awarded to DAVIS	13 days	Mon 4/14/08	Wed 4/30/08
4	Prepare 90% Design Documents	78 days	Thu 5/1/08	Wed 8/20/08
5	Permit Application	136 days	Mon 8/4/08	Fri 2/13/09
6	Receive Building Permit	0 days	Mon 2/16/09	Mon 2/16/09
7	**PROCUREMENT**	**173 days**	**Mon 10/20/08**	**Wed 6/24/09**
8	General	173 days	Mon 10/20/08	Wed 6/24/09
9	**BELOW GRADE STRUCTURE**	**373 days**	**Mon 2/2/09**	**Wed 7/21/10**
10	NTP for Construction	0 days	Mon 2/2/09	Mon 2/2/09
11	Mobilization on Site	11 days	Mon 2/2/09	Tue 2/17/09
12	Excavation to Subgrade	53 days	Wed 2/18/09	Fri 5/1/09
13	F/R/P Foundations	20 days	Wed 4/22/09	Tue 5/19/09
14	F/R/P Slabs, Walls & Columns	77 days	Wed 5/6/09	Mon 8/24/09
15	Structure to Grade Complete	0 days	Mon 8/24/09	Mon 8/24/09
16	Interior MEP & Finishes	230 days	Tue 8/25/09	Wed 7/21/10
17	Final Completion - Garage	0 days	Wed 7/21/10	Wed 7/21/10
18	**RESIDENCE HALL**	**260 days**	**Tue 8/25/09**	**Thu 9/2/10**
19	F/R/P Slabs, Walls & Columns	39 days	Tue 8/25/09	Mon 10/19/09
20	Structure Top Out	0 days	Mon 10/19/09	Mon 10/19/09
21	Buiding Enclosure	97 days	Fri 10/2/09	Mon 2/22/10
22	Building Dry	0 days	Mon 2/22/10	Mon 2/22/10
23	Interior MEP & Finishes	224 days	Fri 9/18/09	Thu 8/5/10
24	Substantial Completion	0 days	Thu 9/2/10	Thu 9/2/10
25	**ACADEMIC FACILITY**	**260 days**	**Tue 8/25/09**	**Thu 9/2/10**
26	F/R/P Slabs, Walls & Columns	31 days	Tue 8/25/09	Wed 10/7/09
27	Structure Top Out	0 days	Wed 10/7/09	Wed 10/7/09
28	Buiding Enclosure	57 days	Thu 10/8/09	Wed 12/30/09
29	Building Dry	0 days	Wed 12/30/09	Wed 12/30/09
30	Interior MEP & Finishes	210 days	Thu 10/8/09	Thu 8/5/10
31	Substantial Completion	0 days	Thu 9/2/10	Thu 9/2/10



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Local Conditions

The 26th Street Project is located at Marymount University in Arlington, Virginia. The project site is triangular in shape and bordered by Old Dominion Drive, 26th Street, and Yorktown Boulevard.

Figure 4: Aerial view of the Project Site (Davis, Carter, Scott, LTD.)

The campus of Marymount University is adjacent to numerous areas that are zoned for residential use. This has the potential to create some problems when dealing with the issue of construction parking. On-site parking is not an option due to the congested nature of the site. On-street parking is available; however, it is very limited. Also, a majority of on-street parking spaces are for use by the residents and require a parking permit between the hours of 8:00 AM and 5:00 PM. As a solution to this problem, James G. Davis Construction will provide construction parking at a local shopping mall, Ballston. The mall is roughly two miles from the project site, so a shuttle will serve to transport workers to and from their personal vehicles. This will be the means of construction parking until the structure reaches a point where the below grade parking can be utilized.

Marymount University is considered to be located within the Washington, DC metro area and the project's construction methods fit into the local preferred methods of construction. A majority of buildings found within this area are constructed with reinforced concrete. This method is preferred in this area over steel structures as a direct result of the benefits they deliver. These benefits include larger floor-to-ceiling heights, elimination of fireproofing costs, and elimination of the construction involved in complex connections. The popularity of this construction method also supplies extensive amounts of experience to the field of contractors in the area.

The 1.45 acre site was examined by ECS Mid-Atlantic, LLC in August of 2005. The scope of their work included drilling four test bores to explore the subsurface soil and ground water conditions. The subsurface soil conditions were determined to be sufficiently dense. This allowed the building to be supported by shallow foundations. Foundation systems that include conventional spread footings and mat foundations. When establishing the elevation of ground water, it was determined that the water table exists between 21' and 25' below the existing grade.

Marymount University 26th Street Project

Arlington, Virginia

Site Utilities Plan

Drawn By:
Ben Mahoney

Date:
10/05/2009

C-001

4.0 Building Systems Summary

Building System Summary		
YES	**NO**	**Scope of Work**
X		Demolition Required
	X	Structural Steel Frame
X		Cast-in-Place Concrete
X		Precast Concrete
X		Mechanical System
X		Electrical System
X		Masonry
X		Curtain Wall
X		Support of Execavation

Figure 5: Building System Summary Table

Demolition

The site of the Marymount University 26th Street Project was previously utilized by the university as a surface parking lot. Before any excavation work could begin, all of the asphalt, debris, and vegetation needed to be cleared and grubbed from the 1.45 acre site.

The overall area of excavation is approximately 63,000 square feet and the depth of excavation ranges from 45' to 25' deep as a result of the slope of the existing site. Due to the depth of the excavation, roughly 80,000 CY of soils need to be hauled from the site by the excavation contractor. The excavated soils will be directly relocated to numerous other project sites in the Washington, D.C. metropolitan area.

Structural Steel Frame

There is no structural steel incorporated into the frame of the building.

Cast-in-Place Concrete

The entire superstructure, supporting foundation, and lateral systems consist of steel reinforced, cast-in-place concrete. The foundation is comprised of 34"-54" mat foundations, found along the perimeter of the building, while 32"-54" spread footings support the interior columns. These same columns will support the concrete slab above and any other loads found within their tributary area.

Different areas of the structure will be utilized for different types of occupancy; academic, residential, and storage/garage. Each of the corresponding slabs will have separate design specifications. The storage/garage slabs will have a monolithic thickness of 8" with 5½" drop panels at each of the columns. The residential and academic slabs will incorporate a post-tensioning system to help manage the tensile loads. The residential slabs will have a monolithic thickness of 7" with 6" drop panel at the columns. Lastly, the slabs found in the academic space will have a monolithic thickness of 9" with 8" drop panels at the columns.

The lateral system consists of reinforced, cast-in-place concrete shear walls and grade beams. Concrete shear walls can be found the perimeter of the building and extend up through the four levels of underground parking. Additional lateral support is provided by walls of the four stairwells that span from the lowest garage level up to the roof level. The last component of the later system includes grade beams. The beams provide addition support and tie individual spread footings to each other and to the perimeter mat foundation.

All of the work involved with placing the cast-in-place concrete will be performed by Brothers Concrete Construction, Inc. Brothers will utilize the two tower cranes on site to place the concrete via crane and bucket. Brother will utilize the PERI® SKYDECK Aluminum Slab Formwork System for horizontal slabs and PERI® TRIO Panel Formwork for vertical walls and columns.

Figure 7: PERI SKYDECK (www.peri.ca)

Figure 6: PERI TRIO (www.peri.ca)

Precast Concrete

The entire exterior façade of the Marymount University 26th Street Project is to be comprised of precast architectural panels. The panels will be connected to the concrete structure with steel embeds. These embeds will be placed into the precast panels and into the edges of the concrete slab. The connections are designed to withstand gravity, lateral, and earthquake loads. The panels will be delivered to the site from an offsite casting plant that the installer, Arban and Carosi, Inc., utilizes. Once the panels arrive on site, they will be laid and set into place by one of the two tower cranes.

Mechanical System

The Mechanical system is comprised of an air-water system containing both variable and constant volume rooftop air handling units. Along with the primary air that is supplied by the air handling units, the individual fan coil units are supplied with both chilled and hot water. The hot water is to be supplied from boilers found in the G3 Level Mechanical Room and the chilled water is to be supplied from pumps that are located within the G4 Level Mechanical Room. These fan coils units will provide individual control of heating and cooling to separate zones within the building. Also located on the roof, two 500 ton cooling towers help to dissipate the heat that is generated by the system.

Due to the different classes of occupancies of the building, the fire suppression system consists of both a wet and a dry pipe system. The wet pipe system will provide immediate fire suppression to each of the residential units while the dry pipe system services the rest of the building.

Electrical System

Marymount University is supplied with electrical service by Dominion Virginia Power, which services regions of both Virginia and North Carolina. The incoming service is to be stepped down by a transformer located outside of the building and brought into the building with 3$\emptyset$, 4 wire, 480/277V. The electrical system will also be accompanied with emergency power supplied by a 350kW, 3$\emptyset$, 4 wire, 480V, continuous power supply generator. The diesel powered generator will be supplied from a 50-gallon day tank and a 500-gallon reserve tank.

Masonry

The extent of masonry incorporated into the project at Marymount University is concrete masonry units (CMUs). The CMUs will serve as partition walls that provide a 2-hour fire rated wall. The CMUs will be non-load bearing and tie into the concrete structure with No. 5 steel reinforcing bars that are 48” high and spaced on 16” centers.

The mortar that will be used consists of Portland cement, hydrated lime, and aggregate. A mixing station will be located on site to mix the mortar with potable water as it is needed.

Curtain Wall

The curtain wall system found on this project is minimal as the façade is mainly constructed of architectural precast panels. The system consists of aluminum framed operable and non-operable Low-E Clear Vision Glass windows. The windows are located throughout the academic and residential facilities to allow daylight to penetrate into the space. Aluminum framed storefront doors are also found where the vestibules and entrances are located.

Support of Excavation

A sheering and shoring system will be utilized as the method of excavation support at Marymount University. The main components of this system include soldier piles, lagging boards, and tiebacks. The sheeting and shoring will not only serve to support the soils outside of the excavated area, but will also serve as one face of the formwork for the foundation walls.

The system will use a total of 132 soldier piles that are spaced approximately 8’ on center. The vibratory method will be the main means of installation. Once the piles contact bedrock and reach refusal, they will have to be impact-driven to the proper design elevation.

The amount of excavation will require roughly 26,000 square feet of lagging boards, installed in lifts of roughly 10’, and 188 tie-backs. Once a lift is completed, the tie-backs, found at the soldier beams, can be drilled, installed, and grouted. The grout will need to cure for five days from the time of installation. After the five days expires, the tie-backs will be tested for integrity by a third-party testing agency. If the tie-backs are found to meet or exceed the design criteria, excavation can continue below and the process repeats itself until the proper elevation at sub-grade is reached.

In an effort to keep the site as dry as possible, a dewatering system with 12 dewatering wells will be utilized. The water that is removed from the ground will be pumped into a sediment tank to allow the silt and any other debris to settle out before it is pumped off of the construction site.

5.0 Analysis I: Short Interval Production Schedule Development

Problem Statement

One of the additions to the campus of Marymount University is a Residential Facility. The new facility will provide suite-style housing for 239 students. There are 62 units situated in four and five person configurations. The interior finishes that are involved with the completion of the Residential Facility are extremely repetitive from unit to unit and from floor to floor.

This particular phase of the project is extremely important to both Marymount University and the entire project team. In order to generate the highest quality of work in the optimal amount of time, the interior finishes schedule will be required to be extremely consistent and predictable.

Proposed Solution

The repetitive nature of the work that is involved with the interior finishes in the residential facility provides an ideal location to implement Short Interval Production Scheduling (SIPS). This particular scheduling technique has traditionally been used in areas that are repetitive in nature.

Solution Method

1. Gain a full understanding of the original finishes schedule.
2. Identify the project milestones and interior finishes timeframe.
3. Establish each of the individual trades that are involved in the sequence.
4. Determine the specific trades that will be driving the critical path of the schedule.
5. Define specific activity durations and basic crew sizes for the specific trades that were identified to be driving the schedule.
6. Establish the project specific sequence of work for a typical unit.
7. Determine the standardized work durations for all of the activities.
8. Ensure the resources are level to attain consistent work durations.
9. Develop the Short Interval Production Schedule.

10. Compare the SIP schedule duration with the existing detailed CPM schedule.
11. Evaluate the cost implications of any changes in resources.

Resources

- ✓ Critical Path Project Schedule
- ✓ Marymount University Project Manager and Project Superintendant
- ✓ RS Means Cost Data
- ✓ Penn State Architectural Engineering Faculty Members
- ✓ Contact from PACE Roundtable with previous SIPS experience
- ✓ AE 473: Building Construction Management & Control

Expected Outcome

The development of Short Interval Production Schedule will result in an overall reduction in the project schedule. The work associated with the finishes schedule is extremely repetitive, which in turn will lead to a more efficient workforce. The implementation of this scheduling technique will also help to optimize activity durations, while maintaining the highest quality of work.

The expected benefits of SIPS include optimizing activity durations, while maintaining the highest quality of work. Additionally, the schedule is much more predictable, which makes it easier to track and communicate the progress of the schedule.

Introduction to Short Interval Production Scheduling

Short Interval Production Scheduling (SIPS) is a scheduling technique that is traditionally utilized to construct buildings that involve an immense amount of repetitive activities. The most common applications include high rise office buildings, apartment buildings, and hotels. As previously mentioned, the Residential Facility at Marymount University is much like an apartment building, consisting of four and five person individual units. This particular type of scheduling brings an assembly line approach to the construction industry. This allows trades to increase their efficiency as they move throughout each zone of the building. Each individual trade will work on a given activity, complete the activity, and move to the next unit to repeat that same activity. This helps to avoid "trade stacking" and creates a "parade of trades" that ensures that each space is not over loaded with laborers at any given time.

To begin the development of a SIP Schedule, the building must be broken down into sections or zones that involve manageable quantities of work. For the case of Marymount University, one zone is equivalent to one four-person residential unit. Each unit consists of two bedrooms, each with two occupants, two full bathrooms, a full kitchen, and a common living space. The total square footage for a unit of this size is approximately 860 square feet. Please refer to Figure 8. for a schematic model of an individual unit that can be found in the Residential Facility.

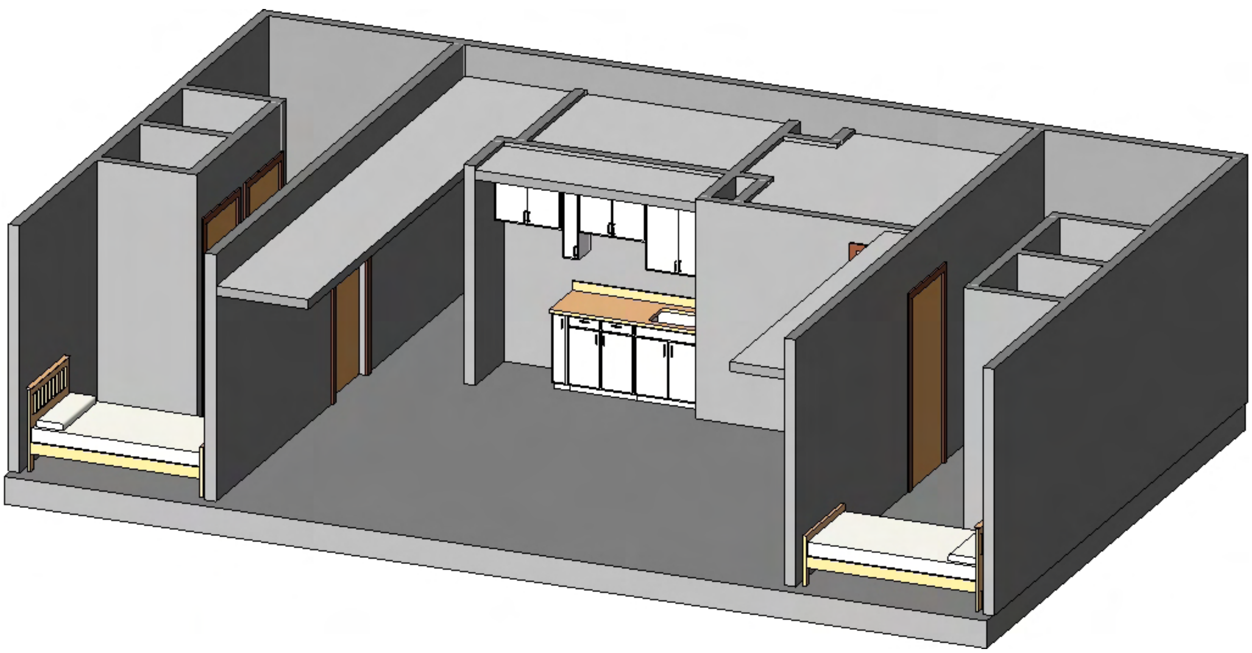


Figure 8: Autodesk Revit Model of a Typical Residential Unit

The next step in the development of a SIP Schedule involves determining which activities will be driving the critical path of the finish schedule and the overall timeframe in which these activities must be completed. After all of these tasks have been accomplished, quantity take-offs needed to be computed in order to determine the material totals that are present in each zone. The materials that were estimated include gypsum wall board, metal studs, vinyl composition tile, ceramic tile, interior paint, millwork, countertops, and casework. The

Autodesk Revit Model that is shown in Figure 7. was developed in order to compute the individual quantity take-offs. Following the computation of quantity take-offs, the project specific sequence of activities needed to be determined. This is critical, as all of the activities will have a start-to-finish relationship with each of their predecessors.

The final step in the process involved resource leveling. This entailed looking at each of the trades and either increasing or decreasing their crew size in an attempt to create an equivalent duration for each of the trades involved in the finish schedule. Resource leveling is as a common practice that helps to avoid "trade stacking". In the construction industry, "trade stacking" is an issue that is generally accepted, but has the potential to harm production rates. A SIP Schedule will attempt to negate this risk by only allowing a limited quantity of workers in a specific zone, at any given time.

After all of the steps are completed for one individual zone, the results can be extrapolated throughout the remaining zones within the building. The finished product provides an alternative to the traditional Critical Path Method of scheduling and is known as a Short Interval Production Schedule.

Project Constraints

The interior finishes for the Residential Facility at Marymount University must be complete by September 2010, as students are scheduled to move in for the Fall 20101 Semester. The start of the interior finishes is dependent upon the "Building Dry" milestone, which is scheduled to occur on February, 19, 2010. This allows approximately 26 weeks to complete all of the activities involved with finishing each of the six levels of the Residential Facility.

Once the "Building Dry" milestone is achieved, the building should be free from any unwanted moisture and all of the interior work can be put into place without the risk of being damaged. The only activities that can take place before this milestone is achieved include framing interior walls, MEP rough-ins, and in-wall quality inspections. A detailed Critical Path Method Finish Schedule can be found in Appendix A.

SIP Schedule Development

For the purposes of Marymount University, the SIP Schedule was generated for the finish activities for the G3 Level, which is one level above the lowest G4 Level, through the 3rd Level. Both the occupancy and the number of units vary from level to level. This ensured that the number of zones for each level would vary from floor to floor, as the zone determination is a function of occupancy. Figure 9. displays how the occupancy and number of zones changes from level to level within the Residential Facility.

Building Zones		
Level	**Zones**	**Occupancy**
G3	5	26
G2	7	36
G1	7	36
L1	9	42
L2	12	53
L3	12	53
Totals	**52**	**246**

Figure 9: Level Zones & Occupancy

As mentioned previously, the entire material estimate was determined with the use of an Autodesk Revit 3D Model. Only after the quantities were estimated could RSMeans be utilized to determine daily production rates and the corresponding crew sizes. In most cases, the crew sizes needed to be adjusted in order to achieve activity durations as close as possible to the others. For a SIP Schedule, this is necessary to ensure that each trade can continually move from zone to zone without interruption from the crew that was previously in that zone. Figure 10. displays all of the individual quantities that were estimated and the corresponding durations and crew sizes.

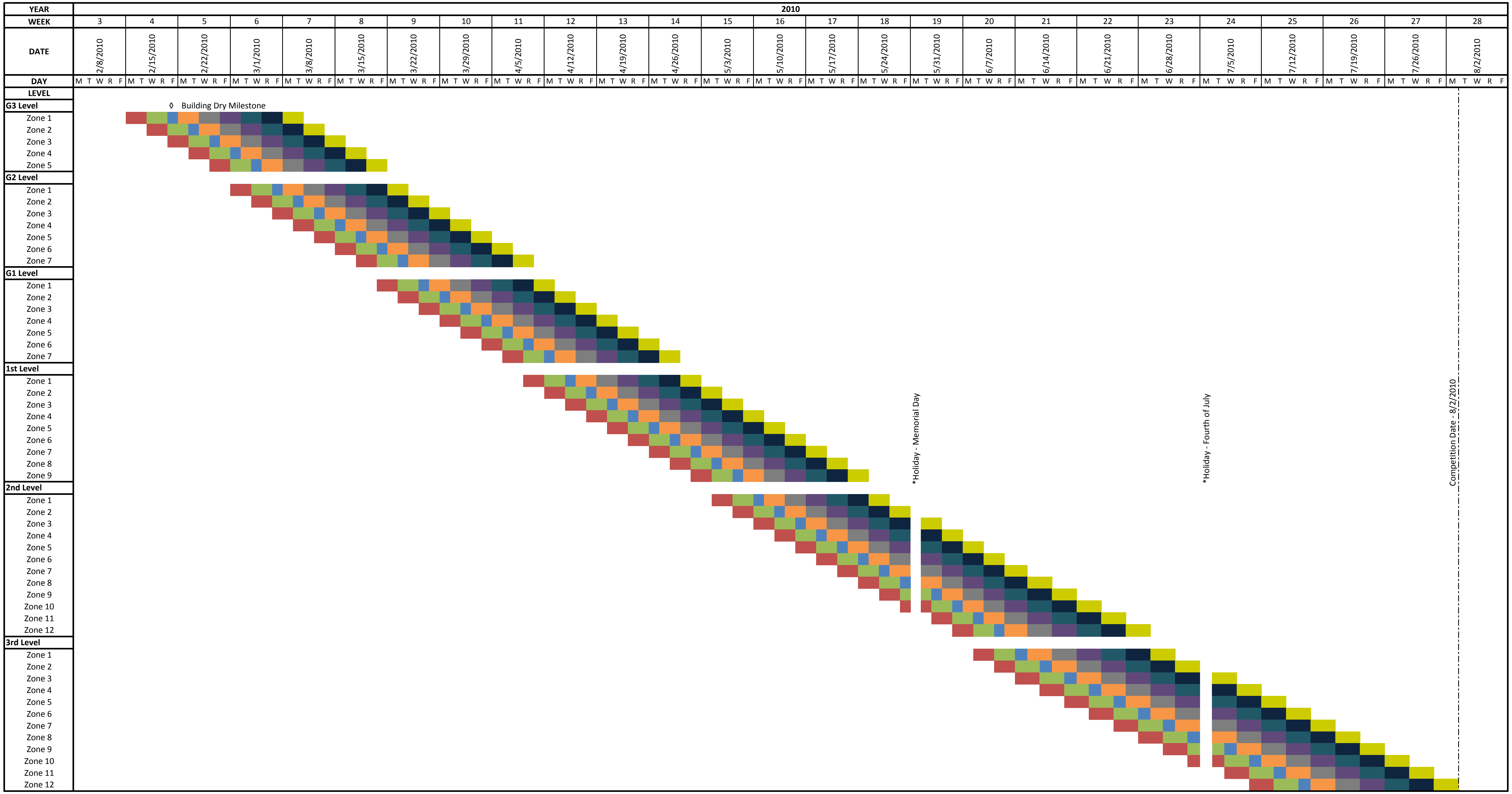
Quantity Take-Offs									
Line Number	**Material**	**Material Description**	**Quantity**	**Unit**	**Crew**	**Mult.**	**Daily Output**	**Total Duration**	**Matrix Duration**
092900	Gypsum Board (Walls)	4' x 8' x 1/2"	5581.0	SF	2	4	775.0	1.95	✓ 2
092900	Gypsum Board (Ceil.)	4' x 8' x 5/8"	456.0	SF	2	4	765.0		
054000	Lightweight Metal Studs	20 ga., 3 5/8", LW	1903.0	SF	1	10	175	1.09	✓ 2
096519	Vinyl Composition Tile	12" x 12" x 1/16"	715.4	SF	1 Tilf.	1	500	1.43	✓ 2
093000	Ceramic Tile	1' x 1' Tiles	118.6	SF	D7	1	82	1.45	✓ 2
099123	Paint	Primer/Finish Coat	3806.0	SF	1 Pord.	3	650	1.95	✓ 2
0622133	Millwork	Arch. Wood Moulding	250.0	LF	1 Carp.	1	250	1.79	✓ 2
1236230	Countertops	24" P-Lam.	13.2	LF	1 Carp.	2	30		
1232231	Casework	Manuf. Wood Casework	22.8	LF	2 Carp.	1	40		

Figure 10: Material Take-Offs

Now that all of the zones and the activities have been identified, the project sequence for the entire building could be determined. The sequence and a legend for the SIP Schedule for the G3 Level through the 3rd Level is shown in Figure 11.

Number	Color	Critical Activity
1		Frame Metal Studs
2		Rough-In MEP
3		Preform In Wall QC
4		Hang/Tape/Finish GWB
5		Prime Walls
6		Point-Up Drywall
7		Paint Final Coat
8		Install Ceramic Tile
9		Install Plumbing Fixtures
10		Install Millwork & Countertops
11		Install VCT & Carpet

Figure 11: Sequence and Color Key


YEAR
2010
WEEK
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
DATE
2/8/2010 2/15/2010 2/22/2010 3/1/2010 3/8/2010 3/15/2010 3/22/2010 3/29/2010 4/5/2010 4/12/2010 4/19/2010 4/26/2010 5/3/2010 5/10/2010 5/17/2010 5/24/2010 5/31/2010 6/7/2010 6/14/2010 6/21/2010 6/28/2010 7/5/2010 7/12/2010 7/19/2010 7/26/2010 8/2/2010
DAY
M T W R F
LEVEL
G3 Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
G2 Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
G1 Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
1st Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
2nd Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
3rd Level
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
◊ Building Dry Milestone
*Holiday - Memorial Day
*Holiday - Fourth of July
Competition Date - 8/2/2010

2nd Level Plan

Cost & Schedule Impacts

After completing the Short Interval Production Schedule, it was determined that this sequence of activities could be completed in 24 weeks. When comparing the SIP Schedule to the current Critical Path Schedule, it was calculated that the SIP Schedule would save 2 weeks. This would be equivalent to shortening the duration of this same sequence of activities by ten working days.

Conclusion & Recommendations

By implementing a Short Interval Production Schedule into the Residential Facilities Interior Finishes Schedule, the University would potentially be provided with a schedule that has a total duration which is two weeks shorter than their current schedule. The SIP Schedule will allow the work associated with the interior finishes begin in mid February, 2010 and commence in early August, 2010. The schedule acceleration is possible due to the repetitive nature of the work that is associated with the interior finish activities.

Through previous interactions with the Marymount University Project Team, it was established that two of their major concerns with the Interior Finishes Schedule involve maintaining the highest possible production rates through the entire duration of the interior finishes schedule, while never sacrificing quality. This scheduling technique proves to be a viable option to ensure that these two concerns are addressed.

The Short Interval Production Schedule not only serves as a technique to accelerate the schedule, but it also provides the Project Team with an additional two weeks of float. It may seem as though this amount of time may be insignificant, but it ensures that any unforeseen delays or stoppages of work will not affect the achievement of the Substantial Completion Milestone.

The Substantial Completion Milestone is extremely critical to both Marymount University and the Project Team, as students are scheduled to be moving into the Residence Hall in early September 2010. To ensure that the Project Team meets this milestone, the university has chosen to include a stringent liquidated damages clause into the contract with the General Contractor. The schedule acceleration that is provided by the SIP Schedule warrants that James G. Davis will avoid incurring the costs associated with the liquidated damages.

In conclusion, the Short Interval Production Schedule has the potential to generate results that will be beneficial to Marymount University and the Project Team, alike. The potential benefits are outlined in Figure 12. below.

Short Interval Production Schedule Results	
Result of SIP Schedule	**Benefit**
Decrease the overall Project Schedule by 10 working Days.	Eliminating 2 Weeks of General Condition costs ($35,000/Week). This will generate a total savings of $70,000.
The total duration for the Interior Finish Schedule is reduced by nearly 8%.	A shorter activity duration will ensure that any unforeseen delays or stoppages of work will not affect the overall project schedule.
Potential to generate early project completion.	Ensures that any of the costs that are associated with the Liquidated Damages are avoided.
Repetitive nature of the work associated with the interior finish activities optimizes durations.	Bringing an "assembly line approach" to the construction industry allows laborers to work at optimal levels of efficiency, while maintaining a high quality of work.
Schedule can be utilized as a tool that provides visual aid.	Creates a schedule that is much more predictable, easier to communicate and track the progress.

Figure 12: Results of a Short Interval Production Schedule

6.0 Analysis II: MEP Coordination

Problem Statement

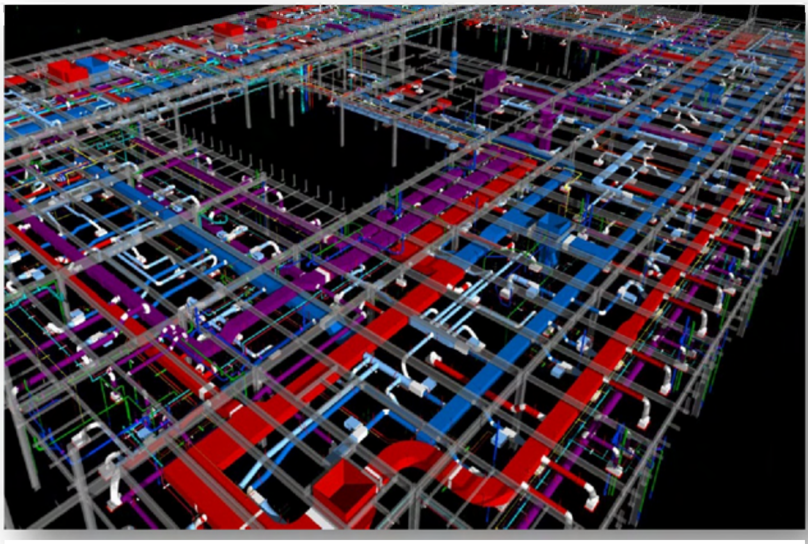


Figure 13:3D Model (www.mediacad.net)

As with most projects, the coordination of the mechanical, electrical, and plumbing systems are extremely problematic. This remains true for the coordination of the MEP systems at Marymount University. All of the equipment and components required extensive amount of coordination, both vertically and horizontally, to avoid clashes in the field. The MEP coordination was done traditionally by incorporating each of the individual trades into one drawing.

To help eliminate overlooking major conflicts within the MEP coordination process, the industry has begun to adopt the practice of three dimensional MEP coordination. This practice will help to increase the efficiency of MEP coordination meetings, increase the productivity in the field, and help to ensure the project remains on schedule. However, the project team and Marymount University chose to disregard this option.

Proposed Solution

Conduct interviews with the Marymount University Project Team to establish why this practice was not utilized on the project. The participants of the study will include the Project Manager, who was a major part of the MEP coordination process, Project Executive, and Vice President.

Additionally, other participants of the interview will include representatives from each of the major trades involved in the coordination process.

Solution Method

1. Acquire the Meeting Minutes from all of the MEP coordination meetings.
2. Obtain the MEP coordination drawings.
3. Model all of the components in a specific area of the building.
4. Identify the key subcontractors involved with MEP coordination.
5. Generate a questionnaire that will be distributed to some PSU AE faculty members to test the questions.
6. After the test is complete, determine which questions will be included in the final interview.
7. Interview the appropriate members of the project team.
8. Compile the results and establish any common themes.
9. Evaluate the cost and schedule impacts of 3D MEP coordination.

Resources

- ✓ MEP Coordination Meeting Minutes
- ✓ MEP Coordination Drawings
- ✓ AE 473: Building Construction Management & Control
- ✓ Autodesk Revit & Autodesk Navisworks

Expected Outcome

The results of the survey should present some of the challenges and motives as to why this practice was not utilized on the project. Even though the participants are a small representative sample of the industry, it is felt that the results will provide a realistic sample of the industry. The positive cost and schedule impacts that are expected to be generated will provide the project team with a more efficient MEP coordination practice to consider in the future.

MEP Coordination Techniques

Over the past few decades, the construction industry has been utilizing one method of coordinating the mechanical, electrical, and plumbing systems within a building. The "Traditional" Method, or 2D Coordination, involves compiling all of the individual trades' drawings into one composite drawing, then reviewing the two-dimensional drawings for clashes. This process has the potential to take an exorbitant amount of time and is far from perfect. The clashes that are missed in the coordination process have the potential to generate change orders and negatively impact the project schedule.

Technology within the Architecture, Engineering, and Construction Industry has created an alternative to this outdated form of clash detection. The alternative process, known as 3D MEP Coordination, involves utilizing three-dimensional modeling software accompanied with clash detection software. This process has proven to be much more efficient, especially as building architecture continues to get increasingly sophisticated. Figure 14. and Figure 15. below displays how challenging it can be to identify clashes when utilizing two-dimensional coordination.

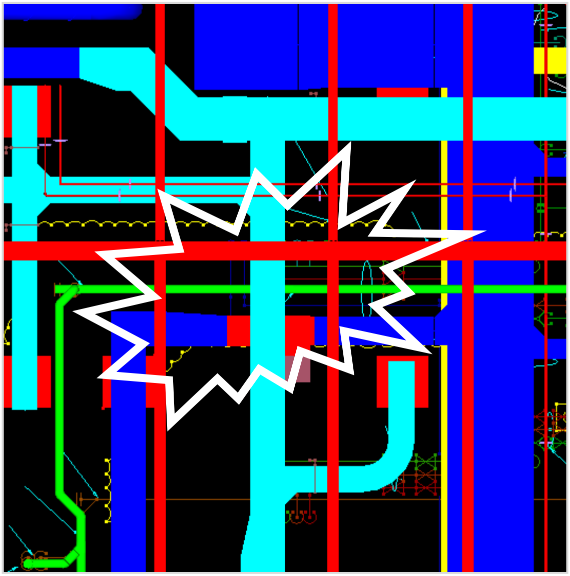


Figure 14: 2D MEP Coordination - Hershey Medical Center (*PSU CIC*)

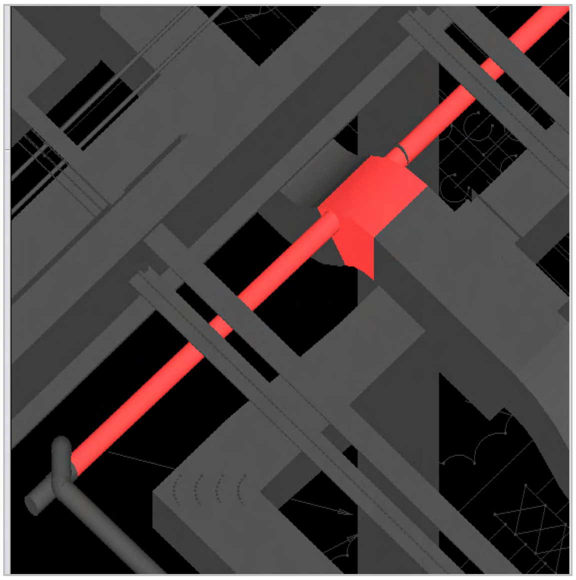


Figure 15: 3D MEP Coordination - Hershey Medical Center (*PSU CIC*)

The impacts of utilizing this type of MEP Coordination have both immediate and long term benefits. All of the impacts that are associated with 3D MEP Coordination are outline below.

Initial Benefits:

- ✓ Efficient Coordination of a sophisticated MEP System.
- ✓ Provides a 3D Model that can be easily visualized.
    - Ensures that every member of the Project Team is one the same page.
    - Tradesmen can see an area prior to installation.
- ✓ Increased interaction between individual trades.
    - All of the individual detailers interactively work in one large room.

Long-Term Benefits:

- ✓ 3D Model can be utilized for digital fabrication of equipment.
- ✓ Evaluating problematic areas in 3D promotes increased productivity in the field.
- ✓ Decreasing the amount of clashes simultaneously decreases the total number of RFI's and Change Orders.
- ✓ The Owner is provided with a higher quality product.
- ✓ In the end, the Owner is provided with a physical model that will serve as a 3D As-Built of the system.

Even with all of these enticing benefits, 3D MEP Coordination has yet to become a standard practice within the Construction Industry. As part of my research, I was looking to determine the reasons as to why this practice has yet to become "Industry Standard", and more specifically, why the General Contractor is not utilizing it more frequently.

General Contractor Survey

To help understand why this has yet to become an "Industry Standard, a survey title "MEP Coordination" was disturbed to various professionals within James G. Davis Construction. The purpose of this survey was to collect information pertaining to the utilization of 3D MEP Coordination within the organization. The survey can be found in its entirety within Appendix B.

MEP Coordination Survey Results

In total, ten total responses where gathered thorough the course of the survey. The diversity of the respondents ranged from entry-level Project Engineers to Senior Vice Presidents. This was done purposefully in an attempt to establish if there are any differing opinions within the organization's corporate ladder. To ensure that the participants of the survey were as honest as possible, the survey was designed to be anonymous. However, each participant was asked to provide their current position and total years of experience with the organization. This information can be found in Figure 16.

Survey Participants		
Num.	Current Position	Years of Experience
1	Senior Project Manager	12
2	Project Engineer	3
3	Project Manager	13
4	Virtual Construction Manager	2
5	Project Engineer	4
6	Project Executive	11
7	Senior Vice President	32
8	Project Engineer	11
9	Project Executive	12
10	Senior Vice President	19

Figure 16: MEP Coordination Survey Participants

The first half of the survey was developed to encourage the participants to provide their personal opinions regarding traditional, two-dimensional, MEP coordination, while the second half of the survey involved questions regarding 3D MEP Coordination. Through this section of the survey, the participants were asked to provide information regarding their basic knowledge of the 3D MEP Coordination process and various advantages/disadvantages of the 3D MEP Coordination Process.

When dealing with past Project Teams, the participants were first asked to provide the resources that feel are most involved with the 2D MEP Coordination process. An overwhelming majority responded that Project Managers are the most common participants involved with this particular process. Additionally, it was determined that a Foreman representing each of the major contractors, along with a CAD Technician are commonly involved in the MEP Coordination Process. After analyzing the results, it was determined that this process is very exhaustive of resources and any delays in this process will waste both time and money of the multiple parties involved. A detailed response breakdown to this question can be found below in Figure 17.

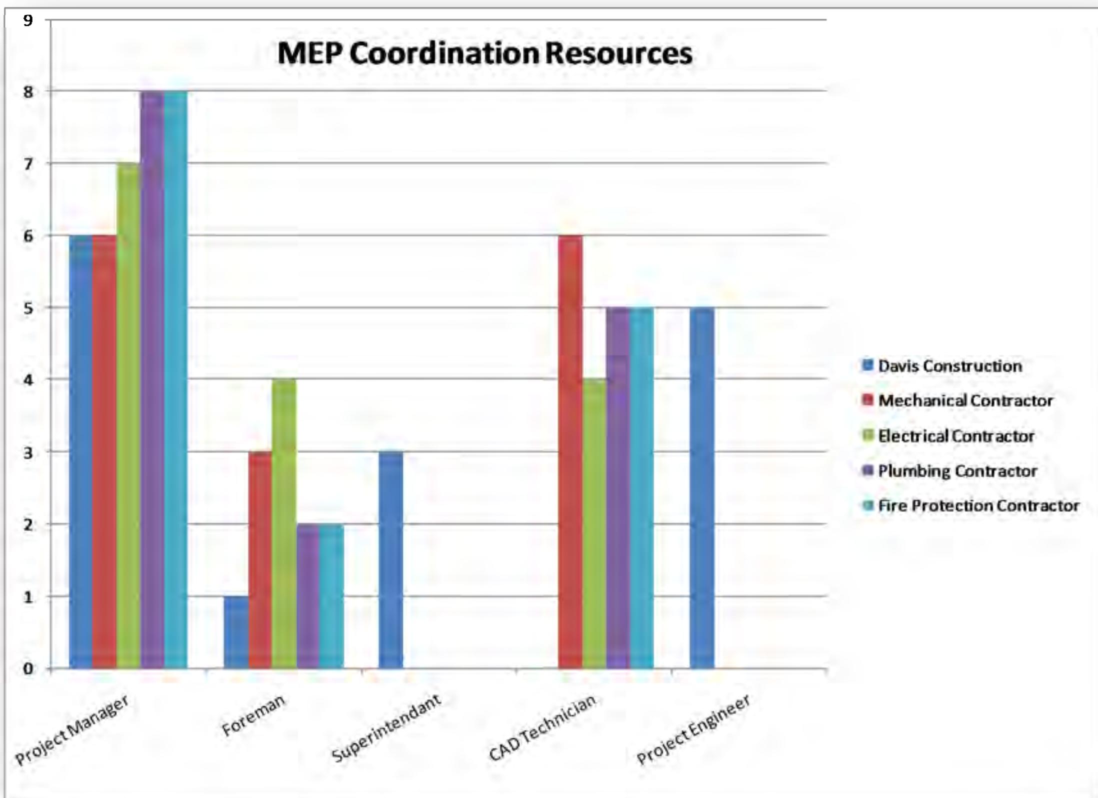


Figure 17: MEP Coordination - Resources

Following the question regarding the resources involved with the MEP Coordination Process, the participants were asked to provide their professional opinion on the turn-around time they typically see with 2D composite drawings. Based off of the statistics gathered in Figure 18., it was determined that a majority of the participants feel that the average turn-around time is roughly two to four weeks. However, it should be noted that this duration is highly dependent on the project size and complexity. Additional knowledge that was gained from this survey question includes ensuring that the project schedule is capable of accommodating the time for this process to occur. It is critical that the composite MEP Coordination Drawings become "approved" in a reasonable amount of time. Additionally, any delays incurred by this process need to be accounted for within the overall project schedule.

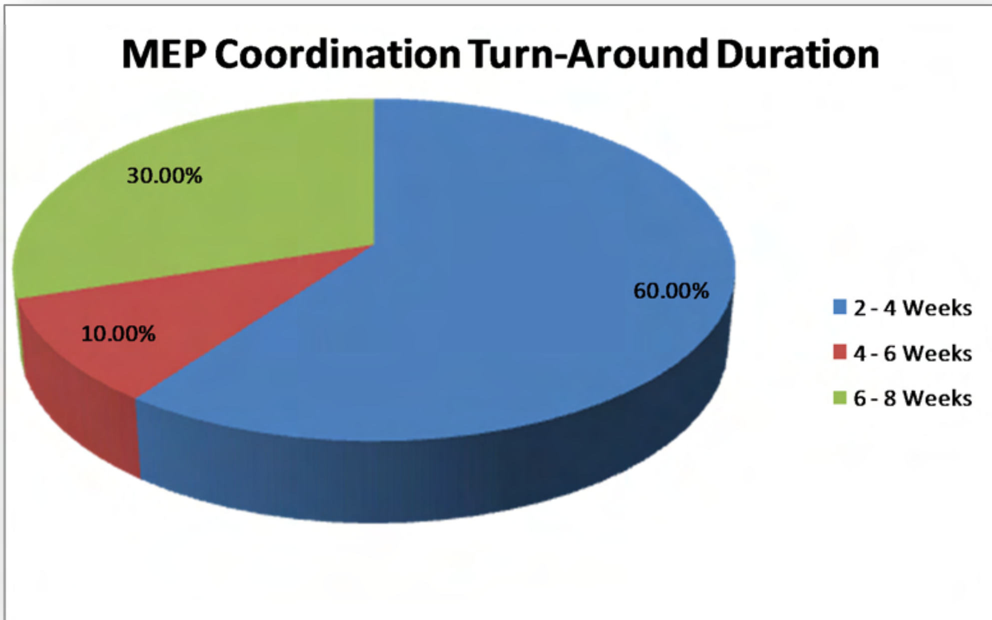


Figure 18: MEP Coordination Turn-Around Duration

The final question in the first half of the survey aimed at determining if a project's budget has money allocated for the purposes of MEP Coordination. The outcome of this question wasn't very informative as it resulted in a fifty-fifty split. Those who answered "yes" to the question were then asked to provide an approximate budget value as a percentage of the overall project cost. The responses to this question were also fairly inconsistent; however, the value was generally less than 1.0%. The results of this question reinforce the fact that each Project Team within the organization has an individual way of establishing and maintaining their budget.

As mentioned above, the second half of the survey was intended to gauge the participant's knowledge regarding 3D MEP Coordination practices. The first question of this section asked if the individuals were aware if any trades currently were using three-dimensional modeling software to generate their specific components or equipment. The statistics in Figure 19.

confirm that members within the organization are aware that multiple trades are beginning to model in 3D.

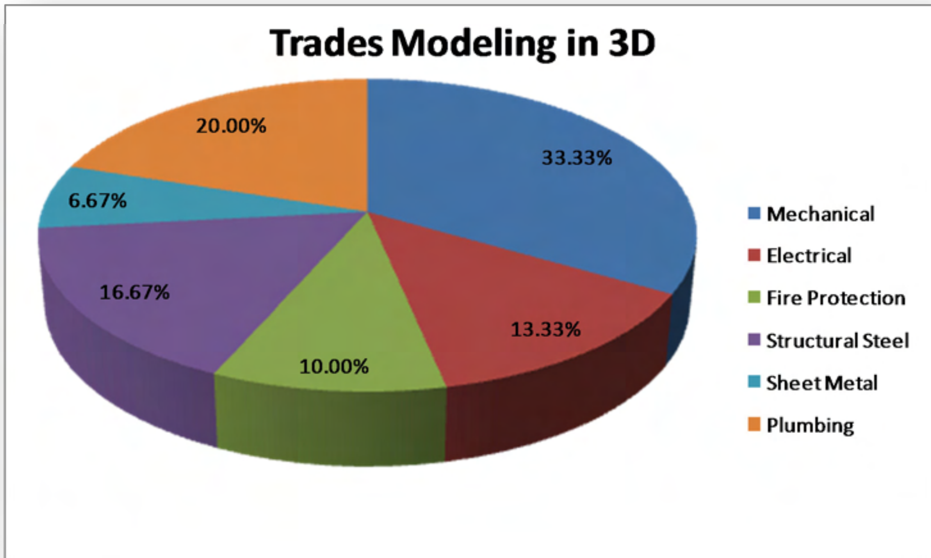


Figure 19: Trades Modeling in 3D

The basis for the next question of the survey was to establish reasons as to why 3D MEP coordination was not pursued on previous projects, from a Project Management standpoint. To answer this question, the participants were provided with four possible selections that included potential cost increase, additional time requirements, experience of project team members, and limited amount of resources. The resources include items such as computer software, computers, workspaces, etc. In addition to the four selections, the participants were also given the option to provide an alternative selection that was not listed.

The results of this survey question provide evidence that the members within the organization feel that a limited amount of resources has been a major contributor to not pursing 3D MEP Coordination on past projects. For a complete breakdown of this question, please refer to Figure 20.

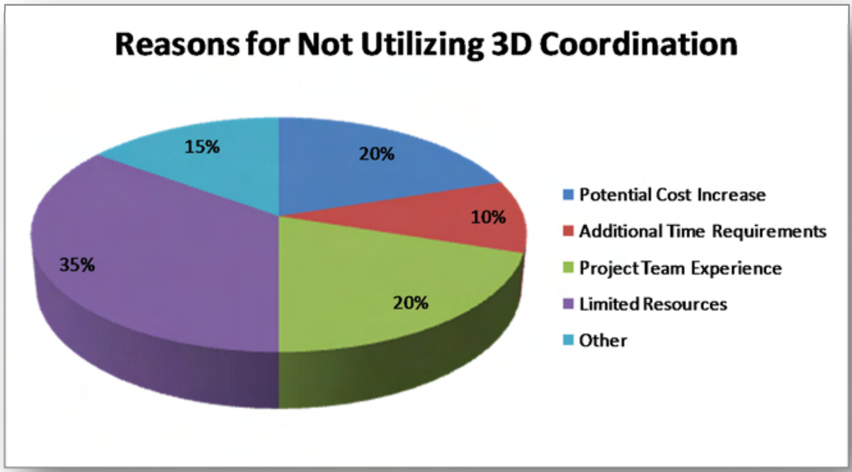


Figure 20: Reasons for not pursuing 3D MEP Coordination

In an attempt to establish trends involving individual trade participation, the participants were asked to identify which trades they feel would be most likely accept or reject the change to 3D MEP Coordination. Through the results of this question, it was determined that the Mechanical Contractor would be most likely to accept this change, while the Fire Protection Contractor would be most likely to resist this change. The results of this survey question can be found in Figure 21. and Figure 22.

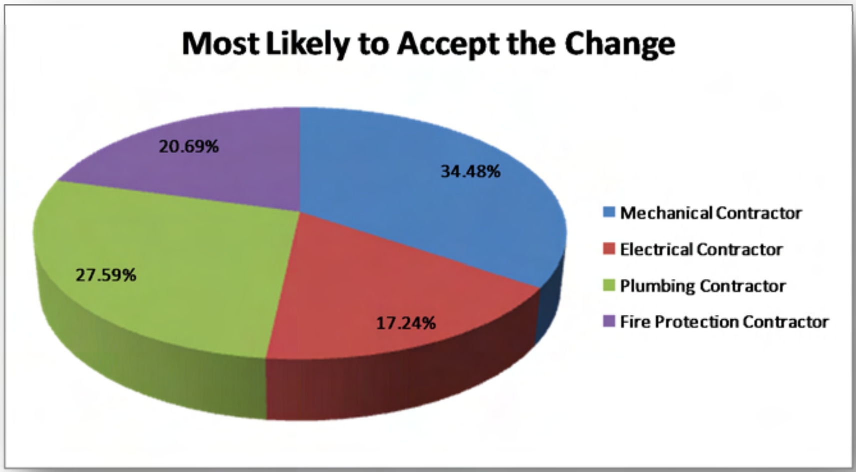


Figure 21: Trades Most Likely to Accept the Change to 3D Coordination

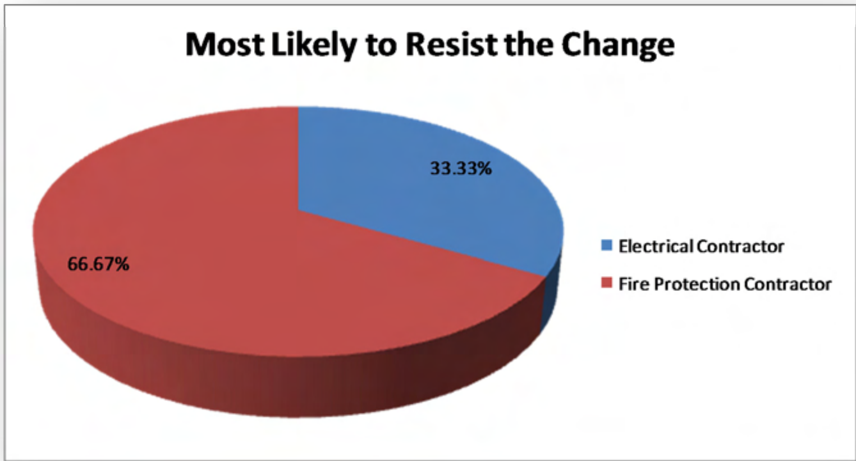


Figure 22: Trades Most Likely to Resist the Change to 3D Coordination

One of the final questions of the survey asked the participants to cite specific examples of advantages and disadvantages of utilizing 3D MEP Coordination over traditional, 2D Coordination. This was an open ended question with no pre-determined answers. However, there were common trends that continued to appear among all of the answers provided. Some of the common themes have been outlined below.

Advantages:

- ✓ Reduces the possibility of major cost and schedule delays in the field because all of the major clashes have been resolved.
- ✓ Allows for more materials to be pre-fabricated, which provides a more efficient installation process.
- ✓ The owner is provided with an accurate "As-Built" Model.
- ✓ Model can be used as a visualization tool that provides contractors with a clearer understanding of space allocation.

Disadvantages:

- ✓ More time is consumed up front to create an accurate model, which ultimately increases costs.

- ✓ At this time, not all trades have the capability of modeling in 3D.
- ✓ 3D Coordination process is very technical and requires training of inexperience team members.

The final question of the survey asked the participants if they felt that they were experienced enough to successfully lead the 3D MEP Coordination process on a future project. The results of this question yielded impressive results, as 80% of the participants feel that they can successfully lead the 3D MEP Coordination Process. An interesting fact about this statistic is that only one out of the ten participants has previously been on a project that utilized 3D Coordination. This reinforces the fact that the organization has been taking active measures to keep up with this form of technology.

Impacts on the Organization

After speaking with a representative from James G. Davis, it has been determined that the organization is currently beginning to utilize 3D MEP Coordination on projects of significant size. At this time, James G. Davis is coordinating three projects with the use of three-dimensional modeling software.

Not only have they begun to utilize these new technologies, but they have also launched an educational program that is structured to provide their employees with the appropriate knowledge base to successfully manage this process. Currently, there are eleven employees within the organization that have completed this educational program. Once completed, these former Project Engineers, Assistant Superintendants, and Layout Engineers titles have changed to Integrated Construction Engineers (ICEs).

An Integrated Construction Engineer is becoming an integral part of a Project Team, as their main role has become guiding Project Teams throughout the 3D MEP Coordination Process. The position of an ICE has not been transformed into an overhead position, as they remain intact within Vice Presidential Groups and continue to be associated with specific projects.

For the Integrated Construction Engineer position to be successful, individuals at James G. Davis feels as though it is imperative that ICEs stem from various backgrounds. This is a result of the previous experience that was gained by the ICE's in previous roles within the organization. Previous Project Engineers have knowledge in areas such as managing RFI's and other aspects of project management, while Assistant Superintendants and Layout Engineers are competent in managing contractors and verifying field installations.

Through the development of this employee training program, it is obvious that James G. Davis is committed to being at the forefront of technological advances within the AEC Industry.

Impacts on the Project Team

Within the organization's development of the position of an Integrated Construction Engineer, it can be suggested that the Marymount University Project Team would have seen significant benefits from this newly created role. An ICE would have allowed the Project Team to utilize 3D MEP Coordination, which would have made this process much more efficient. Additional reasons supporting this assumption are summarized below.

- ✓ Intricate MEP System required to support Laboratory Equipment
- ✓ Experienced Project Engineer managing the coordination process
- ✓ Sheet Metal Contractor & Mechanical Contractor have all components modeled in 3D.
- ✓ Tight Project Schedule

The entire Marymount University Project Team including the Project Management Personnel, the Field Supervision Staff, and the Contractors would have benefited from 3D MEP Coordination. The potential impacts on the Project Team have been outlined below.

- ✓ The Project Management Personnel would have seen a reduction in the number of RFI's and Change Orders.
- ✓ The Field Supervision Staff would have been provided with a visual tool that could assist them in conveying information to the contractors they are managing.
- ✓ The Contractors would have be provided with a higher level of confidence that their individual systems can be installed as coordinated, thus allowing a more streamlined and efficient installation process.

Conclusions & Recommendations

Through the results of the survey, it has been established that a large majority of James G. Davis employees have the appropriate knowledge base to successfully manage the 3D MEP Coordination Process. Employees are fully aware that the MEP Coordination process is very exhaustive of both time and resources. Additionally, they are aware of the initial and downstream benefits that are associated with 3D MEP Coordination.

If a given Project Team feels strongly that their project would benefit from this technology, it is strongly recommended that they should seek assistance from an Integrated Construction Engineer or the Virtual Construction Manager. This would help to ensure that the 3D MEP Coordination process goes as fluid as possible. Other recommendations to Project Teams that wish to utilize 3D MEP Coordination on their projects have been outlined below.

- ✓ To avoid delays within the project schedule, start the 3D process as soon as possible
- ✓ 3D Modeling should be incorporated into each trade's scope of work
- ✓ A Building Information Modeling Trailer should be located on site
- ✓ General Contractor / Construction Manager should fully manage the Coordination Process
- ✓ A clearly defined order to coordination should be established by the GC/CM
- ✓ If at all possible, the Designer / Engineer should be involved in the Coordination Process
- ✓ A Foreman from each trade involved in Coordination should be involved in resolving clashes

After analyzing the results of the survey and speaking to individuals within the organization, it is strongly believed that if the Marymount University 26th Street Project were to have been awarded to James G. Davis in April, 2010, as opposed to April 2008, 3D MEP Coordination most definitely would have been utilized. This is due to the fact that James G. Davis has made a serious commitment to keeping up with technology by developing their new role of an Integrated Construction Engineer.

7.0 Analysis III: Green Roof Design

Structural Breadth/Mechanical Breadth

Problem Statement

The implementation of a green roof will help further enforce the university's commitment to sustainability. Altering the design of the current white, thermoplastic polyolefin (TPO), fully adhered, roofing membrane will generate additional LEED points in both the sustainable sites and energy categories of LEED New Construction Version 2.2.

Proposed Solution

Design a green roof that will help to increase the thermal efficiency of the building envelope, improve storm water management, and increase the durability of the roof. Additionally, these objectives will help Marymount University achieve LEED points.

Solution Method

1. Research various types to green roofs to determine which is the most appropriate.
2. Investigate all of the potential advantages and disadvantages of each type.
3. Select the most appropriate green roof for Marymount University.
4. Redesign the current concrete roof structure to meet the newly introduced loads of the green roof.
5. Evaluate the thermal efficiencies and resize the mechanical equipment accordingly.
6. Determine which LEED New Construction Version 2.2 points have been achieved.
7. Assess the cost and schedule implications of a green roof addition.

Resources

- ✓ Structural drawings for the roof
- ✓ White TPO roof product data
- ✓ Whole Building Design Guide (www.wbdg.org)
- ✓ AE 597D: Sustainable Building Methods
- ✓ AE 404: Building Structural Systems in Steel & Concrete

- ✓ AE 310: Fundamental of HVAC

Expected Outcome

The addition of a green roof is expected to increase the thermal performance of the building's envelope, thus reducing the loads on the HVAC system. However, this system will carry significant schedule impacts and most likely be more expensive than the specified white TPO roof. These negative cost and schedule impacts are anticipated to be offset by the extended lifecycle and increased thermal efficiencies of a green roof.

Introduction to Green Roofs

To begin the selection process of a green roof system for Marymount University's 26th Street Project, the benefits of both intensive and extensive green roofs were thoroughly investigated. This was done to ensure that the university is receiving the highest quality alternative to their current white TPO roofing system.

Some of the benefits that the university would be looking to gain from this design change include notable energy savings, prolonged lifespan, as well as additional square footage of usable area. These three items are highly critical to the university as they are undertaking the construction of their new academic and residential facilities. Due to the occupancy of these two buildings, the university will expect them to be operational for nearly twenty four hours a day, seven days a week, for years to come.

Figure 23. displays the characteristics of the two different types of green roof systems that were analyzed.

Types of Green Roofs		
Characteristic	Extensive	Intensive
Depth of Growth Medium	> 6"	< 6"
Accessibility	Mostly Inaccessible	Mainly Accessible
Fully Saturated Weight	12 - 35 lb/sf	50 - 200 lb/sf
Plant Diversity	Low	Greatest
Installed Cost	$18 - 20/sf	< $20/sf
Maintenance	Minimal	Highest

Figure 23: Types of Green Roofs (Sika Sarnafil)

As it is shown in Figure 24., extensive green roofs contain a much thinner soil medium, thus introduce minimal superimposed dead loads on the roof structure, require minimal maintenance, and cost less. However, this type of roofing system eliminates the potential for creating an inhabitable space and has lower levels of plant diversity. When evaluating an intensive green roof system, it can be seen in Figure 25. that they involve a much thicker soil medium which often ranges from six inches up to several feet thick. Due to the additional thickness of this system, it will introduce significant superimposed dead loads. However, it is capable of sustaining a wide variety of plant live, including shrubs and small trees.

Figure 24: Extensive Green Roof (Sika Sarnafil)

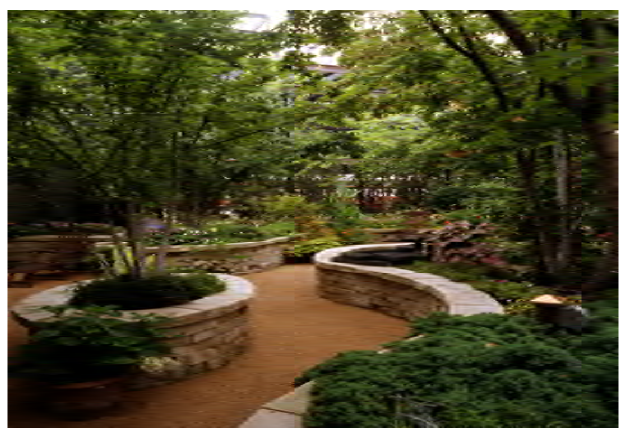


Figure 25: Intensive Green Roof (Sika Sarnafil)

After evaluating all of the basic characteristics, the advantages of each system needed to be analyzed to ensure that the correct system was selected for the purposes of Marymount University. Figure 26. outlines the advantages of both extensive and intensive green roofs.

Green Roof Advantages	
Extensive	**Intensive**
Lightweight	Greater diversity of plant
Suitable for large areas	Best insulation and storm water management
Low maintenance costs and no irrigation required after fully established	Greater range of design
Suitable for retrofit projects	Usually accessible
Lower Capital Costs	Greater variety of human uses
Easier to replace	Greater biodiversity potential

Figure 26: Advantages by Green Roof Type (Sika Sarnafil)

After analyzing all of the potential advantages and disadvantages of each type of green roof system, it was determined that an extensive green roof would be most appropriate for Marymount University.

- ✓ The lightweight system will have minimal impact on the existing Post-Tensioned roof deck.
- ✓ The system will require no irrigation, as all of the vegetation will be indigenous to the area.
- ✓ Any additional maintenance costs incurred by the green roof will be minimal and comparable to the existing roofing system.
- ✓ The soil cover ensures that the underlying waterproofing membrane is not degraded by exposure to ultra-violet light.
- ✓ The growth media provides an additional insulating value, which has the potential to lower the buildings energy costs.
- ✓ A thinner growth media depth is still capable of reducing stormwater run-off by 50%.

Green Roof System

The green roof manufacturer that was selected to be most appropriate for this specific application was Sika Sarnafil, Inc. Sarnafil was chosen over their competitors due to their proven success on rooftops throughout Europe over the past three decades. As result of their success, Sika Sarnafil's products have migrated to the United States and their waterproofing system was selected to protect Chicago's City Hall.

Figure 27. below visually displays all of the components of the Sarnafil green roof system. The system includes a waterproofing membrane, a drainage layer, a root barrier, an insulation layer, a filter fabric, growth media, and vegetation. The individual components of this particular system are defined below and the product data for each of the components can be found in Appendix C.

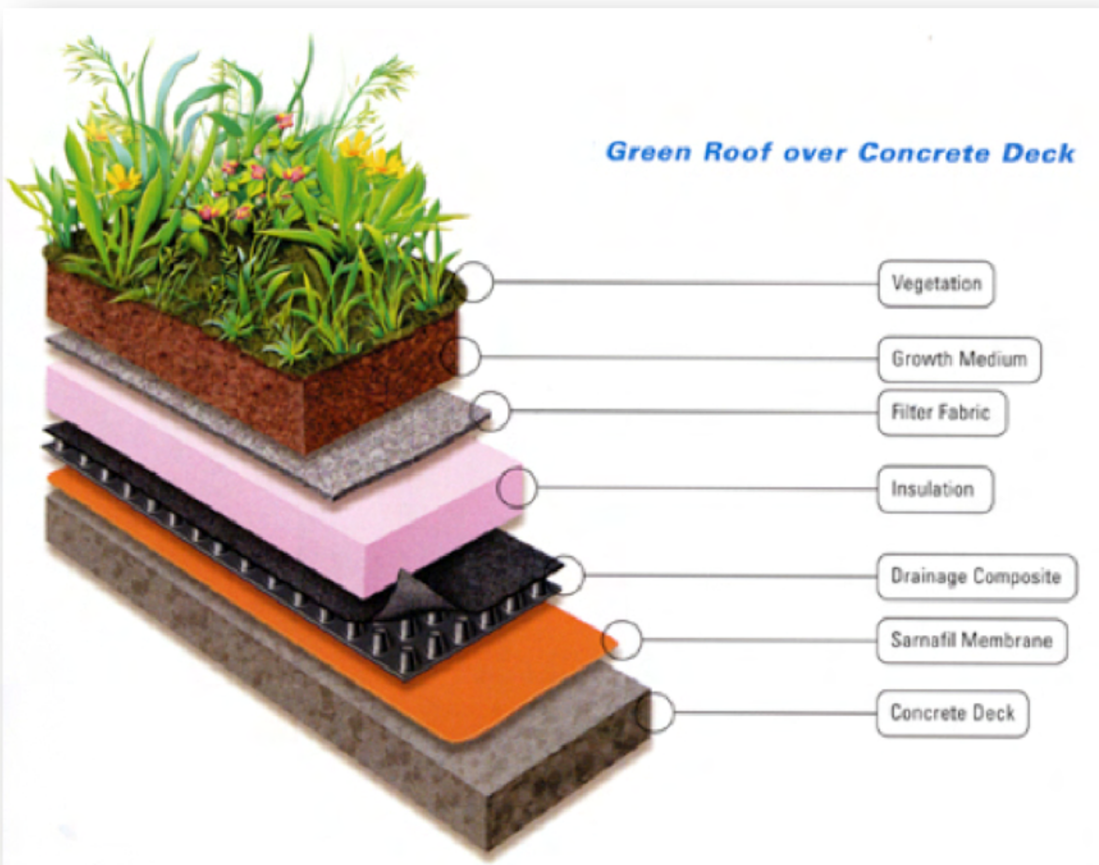


Figure 27: Extensive Green Roof Components (Sika Sarnafil)

Sarnafil Waterproofing Membrane (Sarnafil G476):

- ✓ The G476 waterproofing membrane is specially compounded for sub-grade environments of constant dampness, high alkalinity, exposure to plant roots, fungi, and bacterial organisms, as well as varying levels of hydrostatic pressure including pounded water conditions. The membrane is highly dimensionally stable and fastened together at the seams with the use of heat welds.

Sarnafelt NWP Separation Layer:

- ✓ Sarnafelt NWP separation layer is compatible with all Sarnafil membranes, and is typically used in Sika Sarnafil Waterproofing Systems. The Sarnafelt NWP separation layer acts as a barrier between the Sika Sarnafil waterproofing membrane and extruded polystyrene insulations which are un-faced. In addition, installation of the NWP separation layer significantly increases the puncture resistance of the waterproofing assembly when installed between the waterproofing membrane and the protection layers.

Sarnatherm XPS Insulation

- ✓ Sarnatherm XPS is a rigid extruded polystyrene insulation board. The insulation board is installed over the Sika Sarnafil waterproofing membrane. Also, the boards are available in tapered configurations to enhance drainage.

Sarnafil Drainage Panel (Panel 980):

- ✓ The Panel 980 is a prefabricated panel designed for enhancing the performance of the Sika Sarnafil waterproofing system. The panels channel water away from the waterproofing relieving hydrostatic pressure build up. The multidimensional core provides a uniform flow path for water to escape. The interlocking and overlapping dimple and flange assembly capability ensure low continuity across panels. However, this component is not compatible with electronic leak detection systems.

Growth Media:

- ✓ The growth media will be approximately four inches in depth. The soil will need to be lightweight and are comprised of both inorganic and organic materials. The inorganic material will make up roughly 75% of the soil and consist mainly of expanded slate and crushed clay, while the organic material will make up the remaining 25% of the soil and consist mostly of humus and topsoil.
- ✓ This type of soil will be able to support the growth of small flower and native grasses, both of which will require no additional irrigation to sustain life.

Green Roof Structural Analysis

If Marymount University were to replace their current white TPO roofing system will a Sika Sarnafil Extensive green roof system, the roof structure will require to be reanalyzed. This is necessary to ensure that the structure is capable of withstanding the additional loads that are introduced by a green roof.

In order to begin this structural analysis, the loads associated with each of the components that make up the green roof system were required to be calculated. This was done for both the Academic and Residential Facilities due to their differing structural characteristics. The load calculations are shown for the Residential and Academic Facilities in Figures 28. and Figure 29., respectively.

TOTAL DEAD LOAD - Residential Facility Green Roof					
Mark	**Area (sf.)**	**Area Comparison**	**Density**	**Total (lbs.)**	**Total (psi)**
Growth Media	11563.00	0.33	85.00	327618.33	28.333
Separation Layer	11563.00	1.00	0.03	38.54	0.003
Drainage Pannel	11563.00	0.17	60.00	115630.00	10.000
XPS Insulation	11563.00	0.33	1.80	6937.80	0.600
Waterproofing Membrane	11563.00	1.00	0.14	1618.82	0.140
				TOTAL	40

Figure 28: Load Tabulation - Residential Facility

TOTAL DEAD LOAD - Academic Facility Green Roof					
Mark	**Area (sf.)**	**Area Comparison**	**Density**	**Total (lbs.)**	**Total (psi)**
Growth Media	16896.00	0.33	85.00	478720.00	28.333
Separation Layer	16896.00	1.00	0.03	56.32	0.003
Drainage Pannel	16896.00	0.17	60.00	168960.00	10.000
XPS Insulation	16896.00	0.33	1.80	10036.22	0.594
Waterproofing Membrane	16896.00	1.00	0.14	2365.44	0.140
				TOTAL	40

Figure 29: Load Tabulation - Academic Facility

Currently, the roof structure for the entire facility consists of post-tensioned, cast-in-place, structural slabs that are supported by reinforced concrete columns. The design criterion for each of the facilities is outlined below:

<u>Academic Facility</u>

- ✓ Slab Thickness = 9”
- ✓ Live Loads = 30 PSF
- ✓ Snow Load = 20 PSF
- ✓ f’c = 5000 psi

<u>Residential Facility</u>

- ✓ Slab Thickness = 7”
- ✓ Live Loads = 30 PSF
- ✓ Snow Load = 20 PSF
- ✓ f’c = 5000 psi

After all of the initial design specifications have been identified, the effects of the newly introduced loads of a green roof needed to be analyzed.

In order to begin the process of evaluating a two-way post-tensioned structure, a guide titled, “Time Saving Design Aid”, provided by the Portland Cement Association was utilized. All of the calculations follow methods presented in ACI 318-05 and comply with IBC 2003. This is imperative as the entire Marymount University 26th Street Project was designed according to this edition of the International Building Code.

Now that the newly introduced loads from the green roof have been established, the remaining design criterion is listed below.

Loads:

- Framing Dead Load = self-weight
- Superimposed Dead Load = 40 psf (Green Roof)
- Live Load = 30 psf (Section 1607.0, 2003 IBC)
- Snow Load = 20 psf
- 2 hour fire-rating

Materials:

- Concrete: Normal weight 150 pcf

f'_c = 5,000 psi

f'_{ci}= 3,000 psi

- Rebar: f_y = 60,000 psi
- PT: Un-bonded Tendons
  ½" ϕ, 7-wire strands, A = 0.153 in^2
  f_{pu} = 270 ksi
  Estimated pre-stress losses = 15 ksi (ACI 18.6)
  f_{se} = 0.7*(270 ksi) – 15 ksi = 174 ksi (ACI 18.5.1)
  P_{eff} = A*f_{se} = (0.153 in^2)*(174 ksi) = 26.6 kips/tendon

Structural Redesign

All of the appropriate calculations associated with this analysis can be found in Appendix D. The results of these calculations determined that the 9" post-tensioned roof slab for the Academic Facility was capable of withstanding the new introduced loads. However, the results also proved that the roof slab for the Residential Facility was inadequate and required a full redesign. This redesign involved increasing the thickness of the post-tension roof slab, altering the steel reinforcing sizes and layout, and increasing the number of tendons within a typical bay. Figure 30. displays a typical bay and the corresponding reinforcing bar sizing and layout.

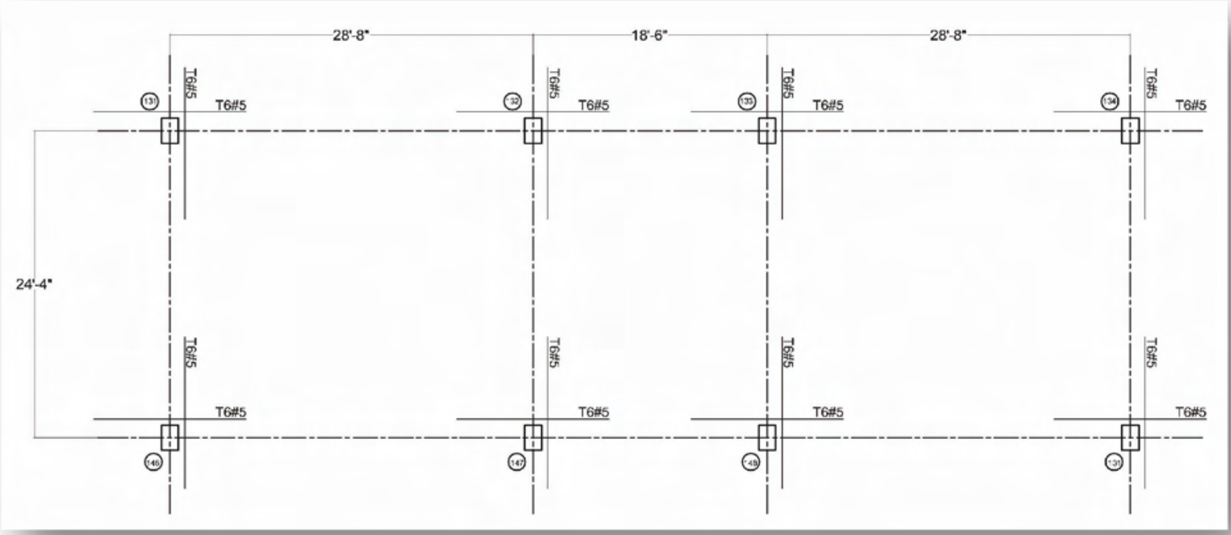


Figure 30: Typical Bay Size and Reinforcing Layout

In addition to altering the rebar sizing and layout, the thickness of the roof slab was also increased from 7” to 8”. Increasing thickness will ultimately require additional concrete in both the roof slab and all of the columns that span from the third level to the underside of the roof slab. The columns on this level needed to be extended by an extra inch in order to ensure that the floor to ceiling height remained consistent. The original design specifications have the elevation of the Roof Level set at 456.67’, while the elevation of the 3rd Level is set at 446.67’. This provides a floor-to-floor height of exactly 10’-0”.

To ensure that the plenum space remains fully intact, the roof will be required to be raised by one inch. This will raise the elevation to 446.75’, which falls below limits set by the International Building Code, as well as the local code authorities. According to section 504.2 of the International Building Code, the building is permitted to have a total height of 160’-0”, plus an additional 20’-0” due to the fact that the building is fully sprinklered. However, Arlington County, the local code authority, has implemented a set of use conditions on the university, of which limits the total building height to 45’-0”. Currently, the extents of the roof rise to an elevation that is 44’-6” above the finished grade. That being said, extending the columns and raising the roof of the Residential Facility by one inch will ensure that the new building height still remains within the permissible limits set by the local code authorities.

Green Roof Mechanical Analysis

One of the major benefits of a green roof system is that it is capable of significantly improving the building’s energy efficiency. Their ability to reduce the overall heat transfer through the building’s envelope makes this possible. If the heat transfer can be reduced, the heating and cooling loads induced on the building can be reduced accordingly. In order to create a basis for comparison, the heat transfer through the existing roof was first calculated using the following equation:

$$Q = U \times A \times \Delta T$$

The first step of this analysis involves calculating the thermal transmittance (U Value) for the existing white TPO roof. The associated calculations can be seen in Figure 31.

White TPO Roof Thermal Properties				
Layer	Material	Thickness (L) in.	Total R-Value °F*ft2*h/Btu	U - Value Btu/°F*ft2*h
1	Outside Air Film	-	0.17	5.882
2	TPO Membrane	0.06"	0.05	20.000
3	Extruded Polystyrene Insulation	4"	20.00	0.050
4	Concrete Slab	7"	0.70	1.429
5	Inside Air Film	-	0.61	1.639
		Total	**21.530**	**0.046**

Figure 31: TPO Thermal Properties

The thermal properties for the green roof system are much more difficult to calculate due to their dynamic properties. The thermal performance will be consistently fluctuating with changes in both moisture content and temperature. As a solution to this problem, a study that was performed was performed at the National Research Center in Toronto, Canada was utilized as a reference. The study was set up to compare the thermal properties of a conventional roofing system to that of a green roof system. The findings of this two year study determined that a green roof is capable of reducing heat gain and heat loss by a total of 95% and 26%, respectively.

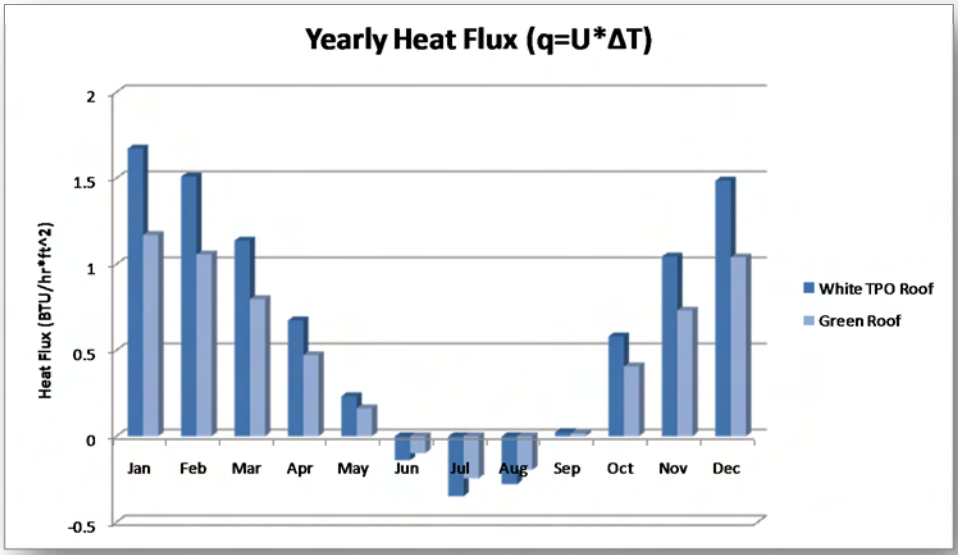


Figure 32: Yearly Heat Flux

When calculating the data that can be found in Figure 32., conservative values for both heat gain and heat loss were utilized. A 70% reduction in heat gain and a 20% reduction in heat loss were utilized to perform the appropriate calculations.

Through the research at the National Research Center in Toronto, Canada, it was concluded that green roofs provide the best thermal performance in the warmer, summer months. This is at a time when the building is constantly being cooled to keep the building's occupants at a comfortable temperature.

After evaluating the values in Figure 32., it was determined that the greatest energy savings will occur in July. The impacts of a green roof allow the average heat flux to drop by approximately 2 BTU/sq. ft. of roof area for the month of July.

Existing TPO Roof System:

- $Q_{TPO} = U \times A \times \Delta T$
- $Q_{TPO} = 0.046 \frac{BTU}{ft^2 \times hr \times °F} \times (11{,}550\ ft^2 + 16{,}900\ ft^2) \times (77.5\ °F - 70\ °F)$
- $Q_{TPO} = 9{,}815\ \frac{BTU}{hr}$

Extensive Green Roof System:

- $Q_{GR} = 9{,}815\ \frac{BTU}{hr} \times (1 - 0.70)$
- $Q_{GR} = 2{,}945\ \frac{BTU}{hr}$

Total Savings:

- $Savings = \left(9{,}815\ \frac{BTU}{hr} - 2{,}945 \frac{BTU}{hr}\right) / 12{,}000 \frac{BTU}{ton}$
- $Savings = 0.5725\ \frac{tons}{hr}$

Yearly Energy Savings:

- $Q = Area\ (ft^2) \times Cummulative\ Annual\ Savings\ \times \frac{hr}{day} \times \frac{days}{year}$
- $Q = 28{,}450\ ft^2\ \times 1.9 \frac{BTU}{hr \times ft^2} \times 24\ \frac{hr}{day} \times 365 \frac{days}{year}$
- $Q = 473{,}521{,}800\ \frac{BTU}{year}$

Yearly Cost Savings:

- $Annual\ Savings = \frac{\frac{BTU}{Year} \times \frac{\$}{kWhr}}{Seasonal\ Energy\ Efficiency\ Ratio}$
- $Annual\ Savings = \frac{473{,}521{,}800\,\frac{BTU}{year} \times \frac{\$0.08}{kWhr}}{14^{*}\frac{BTU}{W \times hr} \times 1{,}000\frac{W}{kW}}$

*(*Seasonal Energy Efficiency Ratio of 14 is required for an Energy Star rating.)*

- $\boldsymbol{Annual\ Savings = \$2,705}$

LEED Analysis

Marymount University has opted to incorporate sustainable features into the 26th St Project. The project is striving to achieve a LEED® Certified rating and was designed according to LEED NCv2.2. Some of the major the major sustainable features of this project are listed below.

- ✓ On-site bicycle racks for residents and university employees
- ✓ Preferred parking for carpools, vanpools, and Zip Cars
- ✓ All plumbing fixtures will be “Low-Flow” and consume 21% less water
- ✓ Building envelope, lighting, power, and HVAC systems have been designed according to ASHREA 90.1-2004
- ✓ CFC-based refrigerants will not be utilized in the HVAC systems
- ✓ All building occupants will have access to on-site storage receptacles for recyclable materials
- ✓ At least 10% of products used during construction will contain recycled material
- ✓ At least 10% of the materials used during construction will be regionally located (extracted, processed & manufactured)
- ✓ All paints, adhesives, sealants, and carpets have been specified to be low-emitting

If Marymount University were to incorporate an extensive green roof into the design of their new facilities, they would eligible to potentially achieve a Silver Rating. Additional credits can be earned in each of the following categories;

LEED & Green Roofs				
Credit	**Category**	**Comment**	**Direct**	**Indirect**
Sustainable Sites				
Credit 5.1	**Reduce Site Disturbance:** Protect or Restore Open Spaces	Green roof with native or adapted vegetation will cover a minimum of 50% of the open space of the site.	X	
Credit 6.1	**Stormwater Management:** Rate and Quantity	Green roofs can reduce or eliminate the rate and quantity of storm water discharged from the site through direct absorption and storage of excess water.	X	
Credit 7.2	**Heat Island Effect:** Roof	50% of the total roof area will be covered by green roof	X	
Water Efficiency				
Credit 1.2	**Water Efficient Landscaping:** No Potable Use or No Irrigation	All potable water will be eliminated for irrigation of the green roof and all associated landscape features.	X	
Credit 2.0	**Innovation Wastewater Technologies**	The green roof will serve as an on-site wastewater treatment media.	X	
Credit 3.1	**Water Use Reduction:** 20% Reduction	One credit can be earned if potable water is reduced by 20%.		X
Energy and Atmosphere				
Credit 1.0	**Optimize Energy Performance:** 28% New, 21% Existing	A green roof can contribute to enhanced energy performance of the building. Credits earned are based on % of reduction of energy costs. The total reduction of must equal 28% in order to achieve the 4 credits		X
Materials and Resources				
Credit 4.1	**Recycled Content**	Most of the materials that make-up the green roof contain recycled content. Materials with recycled content must constitute 5% to 10% of the total materials used.		X
Credit 5.1	**Regional Materials**	10% of all building materials, based on total cost, must be produced with a 500 mile radius of the project location.		X
Innovation & Design Process				
Credit 1.1	**Innovation in Design:** Green Roof Design	Green roofs allow the designer to be innovative in the total building design.	X	

Figure 33: Potential Credits Generated by a Green Roof

In total, a green roof is capable of generating a potential of twenty-five LEED points. In combination will all of the other sustainable features that have been incorporated into the design of the facilities at Marymount University, the total project score would be 33. This would put the 26th Street Project at the lower limits of a LEED Silver rating, with 13 total points still possible. A completed LEED Scorecard can be found within Appendix F.

Cost & Schedule Impacts

In order to accurately determine the cost impacts of an intensive green roof system, cost data was obtained from the manufacturer, Sika Sarnafil. It was determined that the total cost of an extensive green roof system for a project of this size will have an installed cost of roughly $20.00/SF. The estimated cost that is shown in Figure 34. does not include additional costs associated with maintenance or up keeping of the green roof. However, this should be minimal and generally limited to routine seasonal maintenance.

Sika Sarnafil Extensive Green Roof System	
Component	**Cost/SF**
Green Roof System (Membrane, Drainage Fabric, Filter Fabric, Growth Media)	$12.00
Installation Costs	$8.00
TOTAL	**$20.00**

Figure 34: Extensive Green Roof $/SF

The green roof redesign would cover approximately 16,900 square feet of the Academic Facility and roughly 11,550 square feet of the Residential Facility. Areas that are not affected by this redesign include stair towers, elevator shafts, and any other space that is being occupied by mechanical equipment.

A complete cost comparison of the two separate roofing systems can be found in Figure 35.

Roofing System Cost Comparison			
Roofing System Cost Comparison	**Sq. Feet**	**$/SF**	**Total Cost**
Existing White TPO Roofing System	28,450	$11.00	$312,950.00
Extensive Green Roof system	28,450	$20.00	$569,000.00

Figure 35: Cost Comparison - Roofing Systems

In addition to the cost increase of the green roof materials, the costs of the structure also saw an increase. This increase in cost was a result of the additional labor and materials that were required to accommodate the new introduced loads of the green roof. The increase in material totals is outline below.

- ✓ An additional 36 cubic yards of concrete was required, this is roughly equivalent to a 0.25% increase.
- ✓ An additional 15 tons of steel reinforcing bar was required, this is approximately a 2.0% increase.
- ✓ The formwork totals netted an increase of 190 square feet of materials.

After all of the individual quantities were established from the structural drawings, RSMeans CostWorks software was utilized as a source for cost data. All of the data that was taken from RSMeans was appropriately adjusted for both location and time.

The estimated cost for the entire structural system came to $8,529,185. This includes the additional structural requirements that were required by introducing a green roof. This is equivalent to 20% of the total project cost. A detailed breakdown of material quantities and cost data can be found in Figure 37. Please refer to Appendix E for a detailed quantity take-offs.

Also, the newly estimated value of $8,529,185 is only $140,000 greater than the originally estimated price for the structure. This results in a new building cost per square foot of $31.94, which is equivalent in a $0.52 increase. A complete cost comparison can be seen in Figure 36.

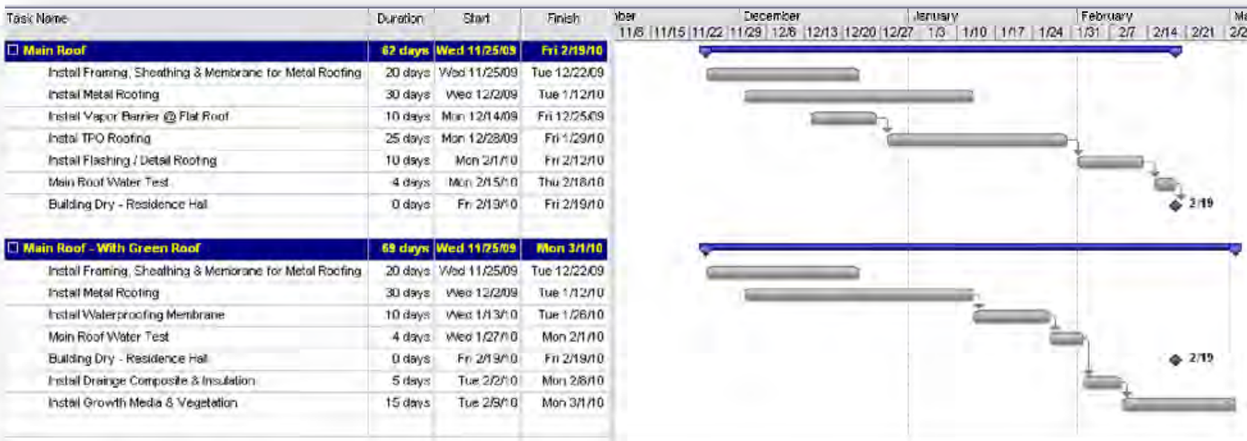
Green Roof Cost Comparison			
Description	**Total Cost**	**Cost/SF**	**% of Project Cost**
RSMeans + Quantity Take-offs	$ 8,389,288.31	$ 31.42	20%
Structure with Green Roof	$ 8,529,185.33	$ 31.94	20%

Figure 36: Green Roof Structural Impacts

Total Cost for the Structural System (Green Roof)								
Description	Quantity	Unit	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O &P	Final O & P
REBAR								
Columns	67	Tons	$ 1,550.00	$ 950.00	$ -	$ 2,500.00	$3,250.00	$ 217,750.00
Beams/Girders	32	Tons	$ 1,550.00	$ 890.00	$ -	$ 2,440.00	$3,150.00	$ 99,369.13
Elevated Slabs	450	Tons	$ 1,650.00	$ 490.00	$ -	$ 2,140.00	$2,605.00	$ 1,172,250.00
Spread Footings	186	Tons	$ 1,400.00	$ 395.00	$ -	$ 1,795.00	$2,175.00	$ 404,550.00
Foundation/Shear Walls	183	Tons	$ 1,475.00	$ 1,340.00	$ -	$ 2,815.00	$3,265.00	$ 439,200.00
Expoxy Coated Rebar	129	Tons	$ 2,340.00	$475.00	$ -	$ 2,815.00	$3,265.00	$ 421,185.00
							REBAR TOTAL	**$ 2,754,304.13**
CONCRETE								
Beams/Girders (5000 psi)	347	CY	$ 110.00	$ 55.00	$ 26.50	$ 191.50	$ 249.00	$ 86,403.00
Columns (5000 psi)	574	CY	$ 110.00	$ 61.50	$ 30.00	$ 201.50	$ 262.00	$ 150,388.00
Elevated Slabs (5000 psi)	7193	CY	$ 106.00	$ 22.50	$ 10.90	$ 139.40	$ 182.00	$ 1,309,126.00
Spread Footings (5000 psi)	737	CY	$ 110.00	$ 55.00	$ 26.50	$ 191.50	$ 249.00	$ 183,513.00
Mat Foundations (5000 psi)	2410	CY	$ 110.00	$ 8.20	$ 3.99	$ 122.19	$ 159.00	$ 383,190.00
Foundation/Shear Walls (4000 psi)	2196	CY	$ 106.00	$ 27.50	$ 13.30	$ 146.80	$ 191.00	$ 419,436.00
Slab on Grade (4000 psi)	776	CY	$ 106.00	$ 55.00	$ 26.50	$ 187.50	$ 244.00	$ 189,344.00
							CONCRETE TOTAL	**$ 2,721,400.00**
FORMWORK								
Columns	39267	SFCA	$ 0.15	$ 0.79	$ 5.65	$ 6.44	$ 9.62	$ 377,748.54
Elevated Slabs	265675	SFCA	$ 0.09	$ 1.55	$ 3.43	$ 4.98	$ 7.01	$ 1,862,384.34
Foundation/Shear Walls	81144	SFCA	$ 0.12	$ 0.78	$ 4.73	$ 5.51	$ 8.21	$ 666,189.27
Beams/Girders	14461	SFCA	$ 0.12	$ 0.90	$ 4.73	$ 5.63	$ 8.34	$ 120,608.34
Mat Foundations	2944	SFCA	$ 0.14	$ 0.70	$ 5.35	$ 6.05	$ 9.02	$ 26,550.71
							FORMWORK TOTAL	**$ 3,053,481.20**
							GRAND TOTAL	**$ 8,529,185.33**

Figure 37: Total Cost for the Structural System

It can be seen in the proposed schedule below, that altering the roofing system will add seven days to the existing roof schedule. The total duration for this set of activities has been lengthened; however the overall construction schedule is not affected. In both scenarios, the Building Dry Milestone remains consistent. This is extremely important, as all of the interior finishes are depending on the achievement of this milestone.



Task Name	Duration	Start	Finish
Main Roof	62 days	Wed 11/25/09	Fri 2/19/10
Install Framing, Sheathing & Membrane for Metal Roofing	20 days	Wed 11/25/09	Tue 12/22/09
Install Metal Roofing	30 days	Wed 12/2/09	Tue 1/12/10
Install Vapor Barrier @ Flat Roof	10 days	Mon 12/14/09	Fri 12/25/09
Install TPO Roofing	25 days	Mon 12/28/09	Fri 1/29/10
Install Flashing / Detail Roofing	10 days	Mon 2/1/10	Fri 2/12/10
Main Roof Water Test	4 days	Mon 2/15/10	Thu 2/18/10
Building Dry - Residence Hall	0 days	Fri 2/19/10	Fri 2/19/10
Main Roof - With Green Roof	69 days	Wed 11/25/09	Mon 3/1/10
Install Framing, Sheathing & Membrane for Metal Roofing	20 days	Wed 11/25/09	Tue 12/22/09
Install Metal Roofing	30 days	Wed 12/2/09	Tue 1/12/10
Install Waterproofing Membrane	10 days	Wed 1/13/10	Tue 1/26/10
Main Roof Water Test	4 days	Wed 1/27/10	Mon 2/1/10
Building Dry - Residence Hall	0 days	Fri 2/19/10	Fri 2/19/10
Install Drainge Composite & Insulation	5 days	Tue 2/2/10	Mon 2/8/10
Install Growth Media & Vegetation	15 days	Tue 2/9/10	Mon 3/1/10

Figure 38: Green Roof Schedule Impacts

Life Cycle Cost Analysis

As mentioned previously, the roofs of both facilities at Marymount University are specified to have white TPO roofing membranes. Through the literature provided by the manufacturer of this particular roofing membrane, it has been determined that the warranty period is 15 years. The warranty is limited because the roofing membrane will be fully-adhered, thus unprotected from elements such as ultraviolet radiation and high wind speeds for extended periods of time.

Assuming that the university was to have incorporated a green roof into the design of their new facilities, they would have seen an increase in the durability of their roof's waterproofing membrane. This is due to the fact that the growth media is capable of protecting the membrane from ultraviolet radiation, extreme winds, and temperature fluctuations, keeping it from prematurely degrading.

The life cycle cost analysis in Figure 39. was performed to compare these two systems. The analysis includes initial costs, replacement costs, routine maintenance costs, and energy savings. The calculation of the energy savings was determined through a building enclosure study that can be found within the Mechanical Analysis.

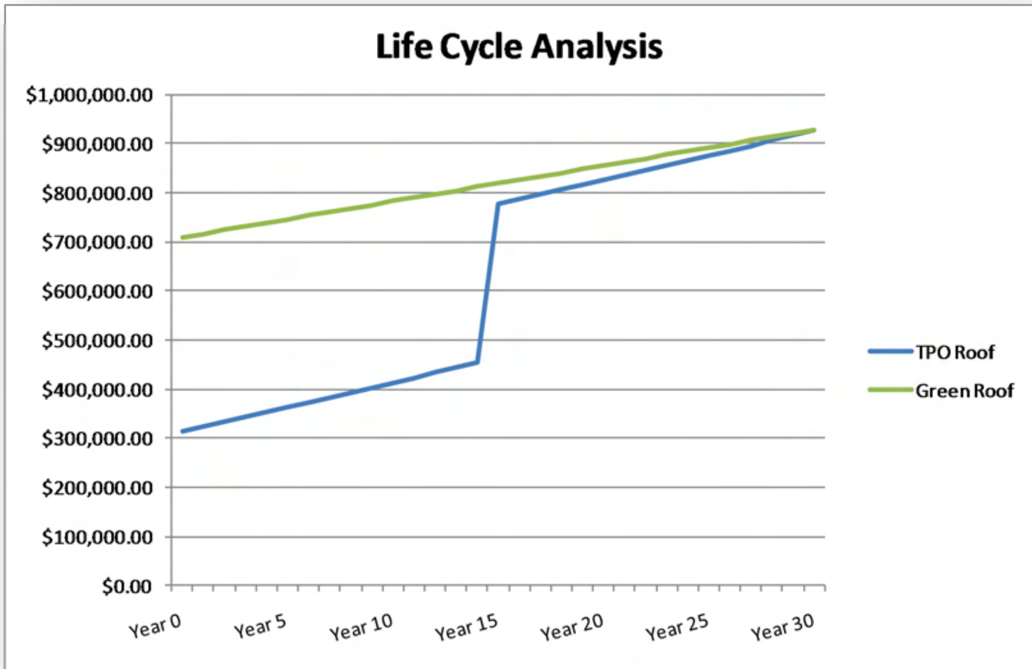


Figure 39: Life Cycle Cost Analysis

From Figure 39., it can be seen that the green roof has a much higher initial cost associated with it. This is because the system is $9.00/SF greater than the currently specified system and requires additional structural requirements that total $140,000. However, around year 15, when the warranty period for the TPO roofing membrane expires, the roof will most likely need to be completely replaced. The spike at year 15 can be explained by the additional costs that are associated with replacing the entire roofing system. This is not the case with a green roof, as it is much more durable, lasting upwards of 50 years.

For the university to completely capitalize on their initial investment, they will have to wait approximately 30 years. This is not out of the question, as they look to utilize this building for decades to come.

Conclusions & Recommendations

Through the completion of this analysis topic, it has been determined that implementing a green roof into the design of Marymount University 26th Street Project is viable alternative to a white, TPO Roofing system. An extensive green roof system does carry higher initial costs, but its durability proves to be a critical factor.

If Marymount University were to incorporate this change into the design of their roofing system, they would potentially see a $2,700 reduction in energy costs, yearly. Additionally, through a life cycle cost analysis comparing the two systems proved that the university would begin to see a return on their investment around year 30.

Financial incentives are not the only benefits that would be seen if the university opted for an extensive green roof. A green roof would provide a visual showcase that proves to faculty, students, university personnel, and community members that they are committed to improving the sustainability of their new facilities. Currently, the Marymount University 26th Street Project is slated to achieve a rating of LEED Certified. However, through the addition of an extensive green roof, they could easily achieve a rating of LEED Silver.

8.0 Master of Architectural Engineering Requirement

Knowledge gained in 500-Level Architectural Engineering classes has been displayed through the incorporation and design of a green roof in Analysis III. The addition of a green roof has proven to increase the building's sustainability and significantly improve the thermal performance of the building's envelope. The topic of sustainability was the main theme of AE 597D: Sustainable Building Construction, while AE 542: Building Enclosure Science and Design provided adequate knowledge involving building envelope systems, both of which are highly involved in the design of a green roof.

AE 597D: Sustainable Building Construction provided an understanding of sustainability concepts and green design principles as applied in the building construction industry. Through the completion of this course, the appropriate vocabulary and skills regarding sustainable methods of construction were developed. This course also provide an in-depth background of the LEED rating system, which allowed the building's current LEED Rating to be reanalyzed due to the sustainable impacts that are associated with a Green Roof.

AE 542: Building Enclosure Science and Design provided the knowledge regarding issues involving the building enclosures, science, and design.

- ✓ The building enclosure: nature, importance, loadings
- ✓ Science: control of heat, moisture, air, hydrothermal analysis
- ✓ Design: walls, windows, roofs joints

This course is in the process of completion; however the topics of heat transfer and roofing systems have been covered thoroughly enough to select, design, and analyze the thermal characteristics of a green roof system.

9.0 Final Conclusions

Through the completion of the Marymount University 26th Street Project, the university feels strongly that the project should be completed on time and under budget. Additionally, the university has made it clear that they wish to utilize these facilities for decades to come. These factors alone provided opportunities to perform critical industry research, investigate value engineering ideas, provide constructability reviews, and look for ways to reduce the schedule.

Through the completion of the analysis on Short Interval Production Scheduling, it has been determined that the Academic Facility at Marymount University would be a prime candidate for this scheduling technique, as it involves a series of repetitive activities. Throughout the completion of these activities, the contractors would be capable of maximizing their rates of production, while avoiding any sacrifices in quality. Additional factors that would have benefited the entire Project Team involve a schedule reduction of approximately ten working that generate a savings of $70,000 in general conditions costs. This would not only provide a savings to the owner, but it would also ensure that the project is turned over on time.

The conclusion of the analysis involving MEP Coordination Methods reinforces the fact that 3D MEP Coordination is becoming increasingly popular within the construction industry. The General Contractor, James G. Davis, has acknowledged this trend with the development of a new position within their organization. Once properly educated, Integrated Construction Engineers (ICEs), are supplied with the proper knowledge to successfully manage the 3D MEP Coordination process. Overall, it can be concluded that the Project Team, as well as the university, would have benefited significantly from this newly created role and the utilization of 3D MEP Coordination.

Through the completion of the research that was performed in the green roof analysis, it has been determined that an extensive green roof will provide the university with a roofing system that is more energy efficient and much more durable. The green roof would carry higher initial costs, but through a life cycle cost analysis, the cost was proven to be offset by its durability. Additionally, the university would reinforce their public commitment to sustainability, as their LEED rating would increase from Certified to Silver.

Over the completion of these three analysis topics, it has been determined that the results have the potential to increase efficiencies in multiple aspects of the project. In all, the university will be provided with more efficient and predictable project schedule, a more efficient method of MEP Coordination, and a more efficient roofing system. When combined, all three analysis topics have the ability to present the university with a high quality product that they can occupy for years to come.

10.0 Resources

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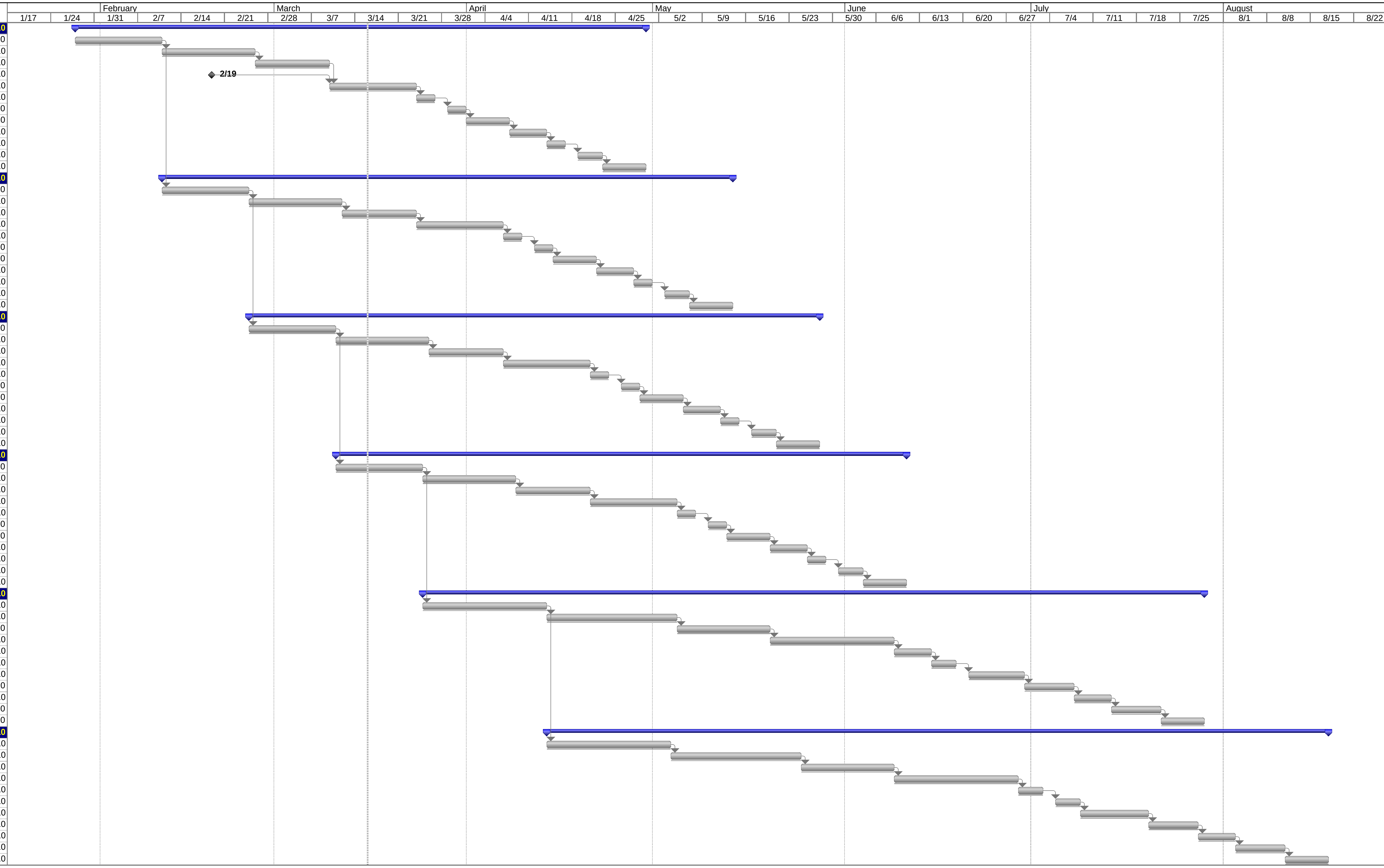
Appendix A: Critical Path Method Finish Schedule

Marymount University

Detailed Finish Schedule

ID	Task Name	Duration	Start	Finish
1	**G3 LEVEL**	**66 days**	**Thu 1/28/10**	**Thu 4/29/10**
2	Frame Walls	10 days	Thu 1/28/10	Wed 2/10/10
3	Rough-In MEP	11 days	Thu 2/11/10	Thu 2/25/10
4	In Wall QC	8 days	Fri 2/26/10	Tue 3/9/10
5	Building Dry Milestone	0 days	Fri 2/19/10	Fri 2/19/10
6	Hang/Tape/Finish GWB	10 days	Wed 3/10/10	Tue 3/23/10
7	Prime Walls	3 days	Wed 3/24/10	Fri 3/26/10
8	Point-Up Drywall	3 days	Mon 3/29/10	Wed 3/31/10
9	Paint Final Coat	5 days	Thu 4/1/10	Wed 4/7/10
10	Install Ceramic Tile	4 days	Thu 4/8/10	Tue 4/13/10
11	Install Plumbing Fixtures	3 days	Wed 4/14/10	Fri 4/16/10
12	Install Millwork & Countertops	4 days	Mon 4/19/10	Thu 4/22/10
13	Install VCT & Carpet	5 days	Fri 4/23/10	Thu 4/29/10
14	**G2 Level**	**66 days**	**Thu 2/11/10**	**Thu 5/13/10**
15	Frame Walls	10 days	Thu 2/11/10	Wed 2/24/10
16	Rough-In MEP	11 days	Thu 2/25/10	Thu 3/11/10
17	In Wall QC	8 days	Fri 3/12/10	Tue 3/23/10
18	Hang/Tape/Finish GWB	10 days	Wed 3/24/10	Tue 4/6/10
19	Prime Walls	3 days	Wed 4/7/10	Fri 4/9/10
20	Point-Up Drywall	3 days	Mon 4/12/10	Wed 4/14/10
21	Paint Final Coat	5 days	Thu 4/15/10	Wed 4/21/10
22	Install Ceramic Tile	4 days	Thu 4/22/10	Tue 4/27/10
23	Install Plumbing Fixtures	3 days	Wed 4/28/10	Fri 4/30/10
24	Install Millwork & Countertops	4 days	Mon 5/3/10	Thu 5/6/10
25	Install VCT & Carpet	5 days	Fri 5/7/10	Thu 5/13/10
26	**G1 Level**	**66 days**	**Thu 2/25/10**	**Thu 5/27/10**
27	Frame Walls	10 days	Thu 2/25/10	Wed 3/10/10
28	Rough-In MEP	11 days	Thu 3/11/10	Thu 3/25/10
29	In Wall QC	8 days	Fri 3/26/10	Tue 4/6/10
30	Hang/Tape/Finish GWB	10 days	Wed 4/7/10	Tue 4/20/10
31	Prime Walls	3 days	Wed 4/21/10	Fri 4/23/10
32	Point-Up Drywall	3 days	Mon 4/26/10	Wed 4/28/10
33	Paint Final Coat	5 days	Thu 4/29/10	Wed 5/5/10
34	Install Ceramic Tile	4 days	Thu 5/6/10	Tue 5/11/10
35	Install Plumbing Fixtures	3 days	Wed 5/12/10	Fri 5/14/10
36	Install Millwork & Countertops	4 days	Mon 5/17/10	Thu 5/20/10
37	Install VCT & Carpet	5 days	Fri 5/21/10	Thu 5/27/10
38	**Level 1**	**66 days**	**Thu 3/11/10**	**Thu 6/10/10**
39	Frame Walls	10 days	Thu 3/11/10	Wed 3/24/10
40	Rough-In MEP	11 days	Thu 3/25/10	Thu 4/8/10
41	In Wall QC	8 days	Fri 4/9/10	Tue 4/20/10
42	Hang/Tape/Finish GWB	10 days	Wed 4/21/10	Tue 5/4/10
43	Prime Walls	3 days	Wed 5/5/10	Fri 5/7/10
44	Point-Up Drywall	3 days	Mon 5/10/10	Wed 5/12/10
45	Paint Final Coat	5 days	Thu 5/13/10	Wed 5/19/10
46	Install Ceramic Tile	4 days	Thu 5/20/10	Tue 5/25/10
47	Install Plumbing Fixtures	3 days	Wed 5/26/10	Fri 5/28/10
48	Install Millwork & Countertops	4 days	Mon 5/31/10	Thu 6/3/10
49	Install VCT & Carpet	5 days	Fri 6/4/10	Thu 6/10/10
50	**Level 2**	**90 days**	**Thu 3/25/10**	**Wed 7/28/10**
51	Frame Walls	14 days	Thu 3/25/10	Tue 4/13/10
52	Rough-In MEP	15 days	Wed 4/14/10	Tue 5/4/10
53	In Wall QC	11 days	Wed 5/5/10	Wed 5/19/10
54	Hang/Tape/Finish GWB	14 days	Thu 5/20/10	Tue 6/8/10
55	Prime Walls	4 days	Wed 6/9/10	Mon 6/14/10
56	Point-Up Drywall	4 days	Tue 6/15/10	Fri 6/18/10
57	Paint Final Coat	7 days	Mon 6/21/10	Tue 6/29/10
58	Install Ceramic Tile	6 days	Wed 6/30/10	Wed 7/7/10
59	Install Plumbing Fixtures	4 days	Thu 7/8/10	Tue 7/13/10
60	Install Millwork & Countertops	6 days	Wed 7/14/10	Wed 7/21/10
61	Install VCT & Carpet	5 days	Thu 7/22/10	Wed 7/28/10
62	**Level 3**	**90 days**	**Wed 4/14/10**	**Tue 8/17/10**
63	Frame Walls	14 days	Wed 4/14/10	Mon 5/3/10
64	Rough-In MEP	15 days	Tue 5/4/10	Mon 5/24/10
65	In Wall QC	11 days	Tue 5/25/10	Tue 6/8/10
66	Hang/Tape/Finish GWB	14 days	Wed 6/9/10	Mon 6/28/10
67	Prime Walls	4 days	Tue 6/29/10	Fri 7/2/10
68	Point-Up Drywall	4 days	Mon 7/5/10	Thu 7/8/10
69	Paint Final Coat	7 days	Fri 7/9/10	Mon 7/19/10
70	Install Ceramic Tile	6 days	Tue 7/20/10	Tue 7/27/10
71	Install Plumbing Fixtures	4 days	Wed 7/28/10	Mon 8/2/10
72	Install Millwork & Countertops	6 days	Tue 8/3/10	Tue 8/10/10
73	Install VCT & Carpet	5 days	Wed 8/11/10	Tue 8/17/10



Project: Davis Finish Schedule
Date: Tue 3/16/10

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Appendix B: MEP Coordination Survey

MEP Coordination Survey

Exit this survey

1. Survey Questions

The purpose of this survey is to collect information pertaining to the utilization of 3D MEP Coordination within the organization. This survey should take roughly ten minutes to complete, and is completely anonymous. I appreciate your time and participation. If you would like a copy of the results, please send an e-mail to Ben Mahoney at bjm5024@gmail.com.

1. Please list your current position and years of experience with the organization.

Current Position:

Years of Experience:

2. On the Project Teams that you have been associated with in the past, what resources are involved with the MEP Coordination Process and present at Coordination Meetings?

	Davis Construction	Mechanical Contractor	Electrical Contractor	Plumbing Contractor	Fire Protection Contractor
Project Manager	☐	☐	☐	☐	☐
Foreman	☐	☐	☐	☐	☐
Superintendant	☐	☐	☐	☐	☐
CAD Technician	☐	☐	☐	☐	☐
Asst. Project Manager	☐	☐	☐	☐	☐

3. When dealing with the traditional methods of MEP Coordination (2D), what is the typical turnaround time from the coordination meeting to receiving "approved" composite drawings?

4. Is there money allocated in your budget for MEP Coordination? If "yes", what is value represented as a percentage of the overall project cost?

☐ Yes

☐ No

% of Project Cost

5. Are you aware if any of the individual trades are beginning to use 3D Modeling Software to generate the drawings of their components/equipment, if "yes", please specify the appropriate trades.

☐ Yes

☐ No

Trades (please specify)

6. Have you ever been involved with a project in which the owner contractually required 3D MEP Coordination, if "yes", what type of project was it?

- ☐ Yes
- ☐ No

Project Type (please specify)

7. In your opinion, which trade would be most likely to accept/reject the change to 3D MEP Coordination?

	Accept	Reject
Mechanical Contractor	○	○
Electrical Contractor	○	○
Plumbing Contractor	○	○
Fire Protection Contractor	○	○

8. When comparing 2D and 3D MEP Coordination, please list some of the potential advantages and disadvantages of utilizing 3D MEP Coordination.

9. Please provide some of the reason(s) for not pursing 3D MEP Coordination on projects that you have been involved with in the past.

- ☐ Potential Cost Increase
- ☐ Experience of Project Team Members
- ☐ Additional Time Required for Coordination
- ☐ Limited Resources (Software, Computers, Workspace)

Other (please specify)

10. Do you feel like you are experienced enough to successfully lead the 3D MEP Coordination Process on your next project?

- ☐ Yes
- ☐ No

Appendix C: Sika Sarnafil Product Data

Product Data Sheet
Edition: 5/2009
Version no.: 0006

Drainage Panel 980

Overview:	Drainage Panel 980 is a high quality prefabricated composite panel designed to provide continuous free flow of water in applications with soil overburden such as green roofs, landscaped plazas and planters. The drainage panel has a three dimensional high impact polymeric core and woven geotextile fabric that provides better filtration of small soil particles. Water passes freely into the drain core, where it is gravity fed to the drain or to discharge.
Composition:	Panel 980 is composed of a high impact resistant polymeric core and woven geotextile fabric. The panel is available in rolls 4 ft wide and 50 ft long (1.2 m x 15.2 m).
Features:	Panel 980 is a prefabricated panel designed for enhancing the performance of the Sika Sarnafil waterproofing system. The panel channels water away from the waterproofing relieving hydrostatic pressure build up. The multidimensional core provides a uniform flow path for water to escape. The interlocking and overlapping dimple and flange assembly capability ensures flow continuity across panels. It is not compatible with electronic leak detection systems.
Packaging:	Panel 980 is packaged individually in polyethylene bags weighing 45 lbs (20.4 kg) each.
Installation:	Panel 980 is installed by an authorized Sika Sarnafil Waterproofing Applicator. The drainage panel is loosely laid over the completed waterproofing system. Panels are interlocked or snapped together to form one continuous layer of material. Consult with Sika Sarnafil Extensive and Intensive Green Roof Waterproofing Specifications for further information.
Availability:	Panel 980 is available directly from Sika Sarnafil Authorized Applicators when used within a Sika Sarnafil Waterproofing System. Contact Sika Sarnafil or visit our website www.sikacorp.com for further information.
Warranty:	As a Sika Sarnafil-supplied accessory, Drainage Panel 980 is included in Sika Sarnafil's Standard or System Warranty.

Sarnafil®

Maintenance: Drainage Panel 980 requires no maintenance.

Technical: Sika Sarnafil provides technical support. Technical staff is available to advise applicators as to the proper installation method.

Technical Data (as manufactured):

Core	ASTM Test Method	Value
Compressive Strength	D 1621	21,000 psf (1,005 kN/m^2)
Thickness	D 5199	0.40 in (10.2 mm)
Flow	D 4716	21 gpm/ft^2 W (260 lpm/m^2 W)
Fabric		
Flow	D 4491	95 gpm/ft^2 (3,866 lpm/m^2)
Puncture	D 4833	130 lbs (0.58 kN)
Apparent Opening Size (EOS)	D 4751	80 US Sieve (0.18 mm)
Grab Tensile	D 4632	205 lbs (0.92 kN)

Information contained herein is offered solely for the customer's consideration, investigation and verification. Determination of suitability for use is the sole responsibility of the user.

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Product Data Sheet
Edition: 8/2009
Version no.: 0006

Sarnafelt NWP
Separation Layer

Overview:	Sarnafelt NWP separation layer is a high quality geotextile fabric of non-woven polypropylene. Sarnafelt NWP separation layer is installed between the waterproofing membrane and the extruded polystyrene (XPS) insulation. It can also be used between the waterproofing membrane and protection layers. It is intended to act as separation between products and also to increase the puncture resistance of the waterproofing assembly.
Composition:	The Sarnafelt NWP separation layer is a 9 oz/yd^2 (305 g/m^2) geotextile fabric composed of 100% recycled polypropylene fibers tightly knit together. The tight needle punch produces a fabric which is highly resistant to puncture. The polypropylene is naturally resistant to most chemicals, and is particularly resistant to high alkaline exposure. It is available in a roll 90 in (2.3 m) wide and 135 ft (41.1 m) long.
Features:	Sarnafelt NWP separation layer is compatible with all Sarnafil membranes, and is typically used in Sika Sarnafil Waterproofing Systems. Consult with these specifications. The Sarnafelt NWP separation layer acts as a barrier between the Sika Sarnafil waterproofing membrane and extruded polystyrene insulations which are unfaced. In addition, installation of the NWP separation layer significantly increases the puncture resistance of the waterproofing assembly when installed between the waterproofing membrane and the protection layers.
Packaging:	The NWP separation layer rolls are wrapped in a protective film and weigh 75 lbs (34 kg).
Installation:	Sarnafelt NWP separation layer is installed by an authorized Sika Sarnafil Waterproofing Applicator. The NWP separation layer is typically loose-laid and lapped 4 in (102 mm) over the previous roll.
Availability:	Sarnafelt NWP separation layer is available directly from Sika Sarnafil Authorized Applicators when used within a Sika Sarnafil Waterproofing System. Contact Sika Sarnafil or visit our website www.sikacorp.com for further information.
Warranty:	As a Sika Sarnafil-supplied accessory, Sarnafelt NWP is included in Sika Sarnafil's Standard or System Warranty..

Maintenance: Sarnafelt NWP requires no maintenance.

Technical: Sika Sarnafil provides technical support. Technical staff is available to advise applicators as to the proper installation method.

Technical Data (as manufactured):

Parameters	ASTM Test Method	Typical Physical Properties
Weight	D 3776	9 oz/yd^2 (305 g/m^2)
Fiber Type		100% recycled polypropylene nonwoven, needle punched
Thickness	D 1777	0.160 in (4.1 mm)
Burst Strength	D 3786	315 lbs (1400 N)
Tensile Strength	D 5034	70 M.D./140 C.M.D.

Recycled Content Up to 90% Post-Consumer/Up to 20% Post-Industrial

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Product Data Sheet
Edition: 5/2009
Version no.: 0006

Sarnafil® G476
Waterproofing Membrane

Overview:	Sarnafil G476 waterproofing membrane is a heat-weldable thermoplastic waterproofing and flashing membrane formulated with an integral fiberglass mat carrier sheet for dimensional stability. G476 is used in horizontal applications receiving overburden such as plaza decks, green roofs, planters, balconies, terraces and split slab applications. G476 membrane and flashings must be covered and can not be left permanently exposed. G476 waterproofing membrane is produced in a variety of lengths and a width of 6.56 ft (2 m).
Composition:	G476 is a high quality product containing PVC resin, pigments, stabilizers, biocide and fiberglass carrier sheet. The standard color is orange and the underside is dark gray.
Features:	G476 waterproofing membrane is specially compounded for sub-grade environments of constant dampness, high alkalinity, exposure to plant roots, fungi, and bacterial organisms, as well as varying levels of hydrostatic pressure including ponded water conditions. G476 is highly dimensionally stable. The seams are heat welded providing the most secure seaming method available and will not deteriorate even in the presence of moisture, roots or under stress. G476 is available in 60 mil (1.5 mm), 80 mil (2.0 mm) and 96 mil (2.4 mm) thicknesses.
Packaging:	G476 rolls are 6.56 ft (2 m) wide wrapped in a protective film and strapped to a wood pallet. Individual rolls weigh between 134-168 lbs (61-71 kg) depending on thickness and roll length.
Installation:	G476 is installed by an authorized Sika Sarnafil Waterproofing Applicator. The membrane is used as the primary waterproofing sheet and concealed flashing membrane with Sika Sarnafil Waterproofing Systems and Green Roofs. Consult with these specifications and your local Sika Sarnafil representative.
Availability:	Sarnafil G476 is available from an authorized Sika Sarnafil Waterproofing Applicator. Contact Sika Sarnafil or visit our website www.sikacorp.com for further information.

Warranty: Upon successful completion of the waterproofing system application, a Sika Sarnafil warranty may be available. Consult with your Sika Sarnafil Regional Office for further information.

Maintenance: Sarnafil G476 requires no maintenance. Although the membrane is typically not easily accessible, regular standard maintenance of plaza decks and green roofs should include regular inspection of drains and termination sealants at least twice per year and after each storm.

Technical: Sika Sarnafil provides technical support. Technical staff is available to advise applicators as to the proper installation method.

Technical Data (as manufactured):

Parameters	ASTM Test Method	Typical Physical Properties
Reinforcing Material	--	Fiberglass
Overall Thickness(1), min.	D638	(see note 1)
Tensile Strength, min., psi (MPa)	D638	1600 (11.1)
Elongation at Break, min.	D638	240% M.D. 240% C.M.D.
Seam Strength(2), min., (% of tensile strength)	D638	90
Retention of Properties After Heat Aging	D3045	--
Tensile Strength, min., (% of original)	D638	95
Elongation, min., (% of original)	D638	95
Tearing Resistance, min., lbf (N)	D1004	21.3 (94.7)
Low Temperature Bend, -40°F (-40°C)	D2136	Pass
Linear Dimensional Change	D1204	0.002%
Weight Change After Immersion in Water	D570	2.0%
Static Puncture Resistance, 56 lbf (250 N)	D5602	Pass
Dynamic Puncture Resistance, 117.7 ft-pdl (5 J)	D5635	Pass

(1)Typical Physical Properties data is applicable for 0.048 in. (1.2 mm) membrane thickness and greater. (2)Failure occurs through membrane rupture not seam failure.

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Product Data Sheet
Edition: 5/2009
Version no.: 0004

Sarnatherm XPS Insulation

Overview:	Sarnatherm XPS is a rigid extruded polystyrene insulation board. Sarnatherm XPS is installed either under or over the Sika Sarnafil waterproofing membrane depending on the waterproofing system design. Always place a separation layer such as Sarnafelt NWP between the Sarnatherm XPS and the warterproofing membrane.
Composition:	The core of Sarnatherm XPS is extruded polystyrene closed-cell foam. The core has continuous skin surfaces on the face and back surfaces. Sarnatherm XPS is available in various sizes depending upon the thermal resistance requirements and application.
Features:	Sarnatherm XPS is also available in tapered configurations to enhance drainage.
Packaging:	Sarnatherm XPS is provided in labeled bundles that are wrapped in a protective polyethylene film. The amount of Sarnatherm per bundle varies with board thickness.
Installation:	Sarnatherm XPS is typically loose-laid on the substrate or over the waterproofing membrane. Overburden is utilized to hold the insulation in place. During installation in hot, sunny weather, protect the insulation with a white covering to prevent excessive heat build-up and potential warping of the insulation boards.
Availability:	Sarnatherm XPS is available directly from Sika Sarnafil Authorized Applicators when used within a Sika Sarnafil Roofing or Waterproofing System. Contact Sika Sarnafil or visit our website www.sikacorp.com for further
Warranty:	As a Sika Sarnafil-supplied accessory, Sarnatherm XPS is included in Sika Sarnafil's Standard or System Warranty.
Maintenance:	Sarnatherm XPS requires no maintenance. Areas of frequent traffic may require protection from damage.

Technical: Sika Sarnafil provides technical support. Technical staff is available to advise applicators as to the proper installation method.

Technical Data (as manufactured):

Thermal Values

Nominal Thickness	R-Value	C-Value
1.0 inch (25 mm)	5.0	0.200
1.5 inch (38 mm)	7.5	0.133
2.0 inch (51 mm)	10.0	0.100
2.5 inch (64 mm)	12.5	0.080
3.0 inch (76 mm)	15.0	0.067
4.0 inch (102 mm)	20.0	0.050

(not all available thicknesses are listed)

Property(1)	ASTM Test Method	400	600	1000
Thermal Resistance, per in (25 mm), @ 75°F (24°C) mean temp., ft²·h·°F/Btu (m²·°C/W), R-value (RSI), min.	C 518, C177	5.0 (.88)	5.0 (.88)	5.0 (.88)
Compressive Strength, psi (kPa), min. (2)	D 1621	40 (275)	60 (415)	100 (690)
Flexural Strength, psi (kPa), min.	C 203	60 (480)	75 (585)	100 (585)
Water Absorption, % by volume, max.	C 272	0.1	0.1	0.1
Water Vapor Permeance, perms (ng/Pa·s·m²) (3)	E 96	0.8 (35)	0.8 (35)	0.8 (35)
Maximum Use Temperature, °F (°C)	--	165 (74)	165 (74)	165 (74)
Coefficient of Linear Thermal Expansion, in/in·°F (mm/m·°C)	D 696	3.5×10^{-5} (6.3×10^{-2})	3.5×10^{-5} (6.3×10^{-2})	3.5×10^{-5} (6.3×10^{-2})
Flame Spread(4)	E 84	5	5	5
Smoke Developed	E 84	165	165	165
Complies with ASTM C 578, Type	--	VI	VII	V
Complies with CAN/ULC S701, Type	--	4	4	4

(1) Properties shown are representative values for 1in (25 mm) thick material based upon most recent product quality audit data. (2) Value at yield or 5% whichever occurs first. (3) Water vapor permeance varies with product type and thickness. Values are based on the desiccant method and they apply to insulation 1 in (25 mm) or greater in thickness (4) This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

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Appendix D: Structural Hand Calculations

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TWO-WAY POST TENSION DESIGN

LOADS:

- Framing Dead Load = self-weight
- Superimposed Dead Load : 40 psf (Green Roof)
- Live Load = 30 psf (Section 1607.0 2003 IBC code)
- Snow Load = 20 psf

MATERIALS:

Concrete : Normal weight 150 pcf
f'_c = 5000 psi
f'_{ci} = 3000 psi

Rebar : f_y = 60,000 psi
PT : Unbonded tendons
1/2" Φ, 7-wire strands, $A = 0.153 in^2$
f_{pu} = 270 ksi
Estimated prestress losses = 15 ksi (ACI 18.6)
$f_{se} = 0.7(270) - 15 = 174$ (ACI 18.5.1)
$P_{eff} = A \cdot f_{se} = (0.153)(174) = 26.62$ kips/tendon

PRELIMINARY SLAB THICKNESS :

Starts with L/h = 45
Longest Span = 28' - 8"

$h = (28.667')(12)/45$
$= 7.64''$
= 8" preliminary slab thickness

LOADING :
· IBC 1607.9.1 allows for LL reduction

Exterior Bay : A_T = (28' - 8")(24' - 4")
K_{LL} = 1.0

$LL = 0.83 LL_o = 0.83(30) = 25.0$ psf

D_L = Selfweight = (8")(150 pcf) = 100 psf
SIDL = 40 psf
LL_o = 30 psf (25.0 psf)
Snow = 20 psf

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DESIGN OF EAST - WEST INTERIOR FRAME :

- Total Bay width between centerlines = 24'-4"
- No pattern Loading, since LL/DL < 0.75 => 0.3 < 0.75 ∴ ok ✓

CALCULATE SECTION PROPERTIES :

$A = bh = (24.333)(12)(8") = 2336 \text{ in}^2$

$S = bh^2/6 = (292)(8)^2/6 = 3115 \text{ in}^3$

SET DESIGN PARAMETERS :

Allowable stresses : Class U (ACI 18.3.3)

- At time of jacking (ACI 18.4.1)

$f'_{ci} = 3000$ psi
Compression $= 0.60 f'_{ci} = 0.6(3000) = 1800$ psi
Tension $= 3\sqrt{f'_{ci}} = 3\sqrt{3000} = 164$ psi

- At service loads (ACI 18.4.2a & 18.3.3)

$f'_c = 5000$ psi
Compression $= 0.45 f'_c = 0.45(5000) = 2,250$ psi
Tension $= 6\sqrt{f'_c} = 6\sqrt{5000} = 424$ psi

Average precompression limits :

P/A = 125 psi min. (ACI 18.12.4)
= 300 psi max.

Target Load Balances :
- Assuming 75% of DL (self-weight) for slabs

$0.75\, w_{DL} = 0.75(100) = 75$ psf

Cover Requirements : (2-hour fire rating) => IBC 2003

Restrained slabs = 3/4" bottom

Unrestrained slabs = 1½" bottom
= 3/4" top

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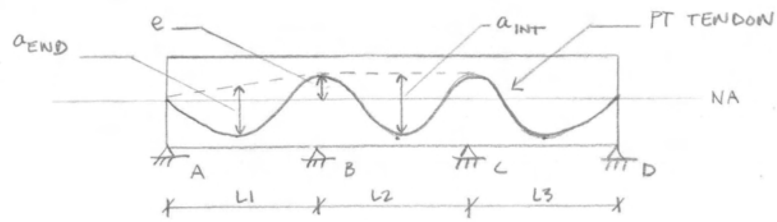
TENDON PROFILE:



CONTINUOUS POST-TENSIONED BEAM

TENDON ORDINATE	TENDON (CG) LOCATION*
Exterior Support - Anchor	4.0"
Interior Support - Top	7.0"
Interior Span - Bottom	1.0"
End span - Bottom	1.75"

(CG) = center of gravity
*Measured from bottom of slab

a_{INT} = 7.0" − 1.0" = 6.0"

a_{END} = (4.0" + 7.0")/2 − 1.75" = 3.75"

e = distance from the center of the tendon to the NA (varies)

PRESTRESS FORCE REQUIRED TO BALANCE 75% OF SELFWEIGHT DL:

$W_b = 0.75\,W_{DL} = 0.75(100)(24.33) = 1825$ plf $= 1.825$ K/ft

Force needed in tendons to counteract the load in the end bay:

$P = W_b L^2 / 8 a_{END}$

$= (1.825 \text{ K/ft})(28.667 \text{ ft})^2 / [8(3.75 \text{ in}/12)]$

$= 600$ K

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CHECK PRECOMPRESSION ALLOWANCE:

- Determine number of tendons to achieve 600 k

tendons = (600 k) / (26.62 k / tendon)

= 22.54

∴ use 22 tendons

- Actual force for bonded tendons

P_{actual} = (22 tendons)(26.62) = 586 k

- The balanced load for end span is slightly adjusted

P_{actual} / A = (586 k)(1000)/(2336 in²)

= 251 psi > 125 psi min. ∴ OK ✓

≤ 300 psi max. ∴ OK ✓

CHECK INTERIOR SPAN FORCE:

$P = (1.825\ k/ft)(18.5\ ft)^2 / [8(6.0in/12)]$

= k ≤ 586 (LESS force for center bay)

- Assuming force required for end spans are carried into the interior spans

$W_b = (586k)(8)(6.0\ in/12)/(18.5)^2$

= k/ft

W_b / W_{DL} = 92% ≤ 100% ∴ Acceptable for this design

East - West Interior Frame:

Effective prestress force, P_{eff} = 586 kips

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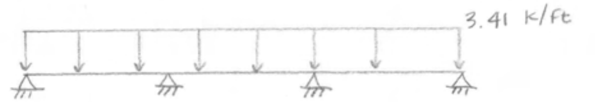
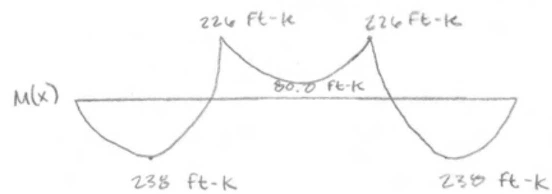
CHECK SLAB STRESSES

Dead Load Moments :

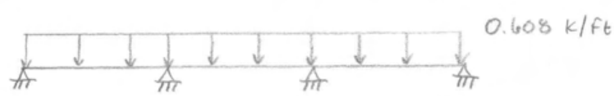
$W_{DL} = (140 \text{ psf})(24.333 \text{ ft}) / 1000 = 3.41 \text{ klf}$

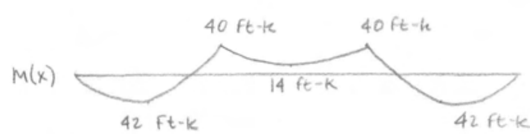




Live Load Moments :

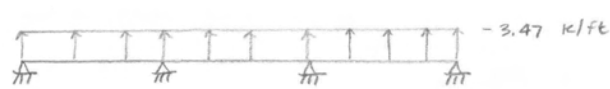
$W_{LL} = (25.0 \text{ psf})(24.333 \text{ ft}) / 1000 = 0.608 \text{ k/ft}$

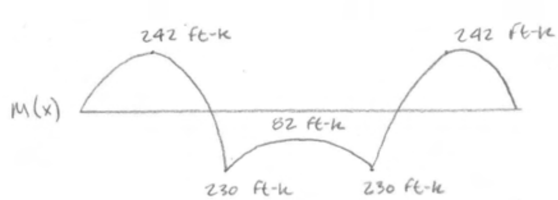




Total Balancing Moments , M_{bal}

$W_b = [1.78(2) + 6.85(1)] / 3 = -3.47 \text{ k/ft}$





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STAGE #1: Stress immediately after jacking (DL + PT) (ACI 18.4.1)

- Midspan Stresses

$f_{top} = (-M_{DL} + M_{Bal})/S - P/A$
$f_{bot} = (+M_{DL} - M_{Bal})/S - P/A$

- Interior Span

$f_{top} = [(-80.0 \text{ ft-k} + 82 \text{ ft-k})(12)(1000)] / (3115 \text{ in}^3) - 251 \text{ psi}$
$= (+8) \text{ psi} - 251 = -243 \text{ psi} < 0.60 f'_{ci}$
$= -243 < 1800 \text{ psi}$ ∴ ok ✓ (compression)

$f_{bot} = [(+80.0 \text{ ft}^k - 82 \text{ ft-k})] / (3115 \text{ in}^3) - 251 \text{ psi}$
$= -6 \text{ psi} - 251 \text{ psi} = -259 \text{ psi} < 0.60 f'_{ci}$
$= -259 < 1800 \text{ psi}$ ∴ ok ✓ (compression)

- End Span

$f_{top} = [(-238 \text{ ft-k}) + (242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251 \text{ psi}$
$= 15 \text{ psi} - 251 \text{ psi} = -236 \text{ psi} < 0.60 f'_{ci}$
$= -236 \text{ psi} \leq 1800 \text{ psi}$ ∴ ok ✓ (tension)

$f_{bot} = [(238 \text{ ft-k} - 242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251 \text{ psi}$
$= -15 \text{ psi} - 251 \text{ psi} = -266 \text{ psi} < 3\sqrt{f'_{ci}}$
$= -266 < 164 \text{ psi}$ ∴ ok ✓ (tension)

- Support Stresses

$f_{top} = (-M_{DL} + M_{Bal})/S - P/A$
$f_{bot} = (M_{DL} - M_{Bal})/S - P/A$

$F_{top} = [(236 \text{ ft-k}) - (242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251 \text{ psi}$
$= -23 - 251 = -274 < 3\sqrt{f'_{ci}}$
$= -274 < 164 \text{ psi}$ ∴ ok ✓ (tension)

$f_{bot} = [(-236 \text{ ft-k} + 242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251 \text{ psi}$
$= 23 - 251 = -228 < 0.60 f'_{ci}$
$= -228 < 1800 \text{ psi}$ ∴ ok ✓ (compression)

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STAGE 2 : Stresses @ Service Load (DL + LL + PT) (18.3.3 & 18.4.2)

· Midspan Stresses

$f_{top} = (-M_{DL} - M_{LL} + M_{BAL}) / S - P/A$
$f_{bot} = (+M_{DL} + M_{LL} - M_{Bal}) / S - P/A$

– Interior Span

$f_{top} = [(-80 \text{ ft-k} - 14 \text{ ft-k} + 82 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= -46 - 251 = -297 \text{ psi} < 0.45 f'c$
$= -297 < 2250 \text{ psi}$ ∴ ok ✓ (compression)
$f_{bot} = [(80 \text{ ft-k} + 14 \text{ ft-k} - 82 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= 46 - 251 = -205 \text{ psi} < 6\sqrt{f'c}$
$= -205 < 424 \text{ psi}$ ∴ ok ✓ (tension)

– End Span

$f_{top} = [(-238 \text{ ft-k} - 42 \text{ ft-k} + 242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= -146 - 251 = -397 < 0.45 f'c$
$= -397 < 2250 \text{ psi}$ ∴ ok ✓ (compression)
$f_{bot} = [(238 \text{ ft-k} + 42 \text{ ft-k} - 242 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= 146 - 251 = -105 < 6\sqrt{f'c}$
$= -105 < 424$ ∴ ok ✓ (tension)

· Support Stresses

$f_{top} = (+M_{DL} + M_{LL} - M_{Bal}) / S - P/A$
$f_{bot} = (-M_{DL} - M_{LL} + M_{Bal}) / S - P/A$

$f_{top} = [(226 \text{ ft-k} + 40 \text{ ft-k} - 230 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= 139 - 251 = -112 < 6\sqrt{f'c}$
$= -112 < 424$ ∴ ok ✓ (tension)
$f_{bot} = [(-226 \text{ ft-k} - 40 \text{ ft-k} + 230 \text{ ft-k})(12)(1000)] / 3115 \text{ in}^3 - 251$
$= -139 - 251 = -390 < 0.45 f'c$
$= -390 < 2250 \text{ psi}$ ∴ ok ✓ (compression)

∴ ALL STRESSES ARE WITHIN THE PERMISSIBLE CODE LIMITS

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ULTIMATE STRENGTH :

- The primary post-tensioning moments, M_1, vary along the length of the span.

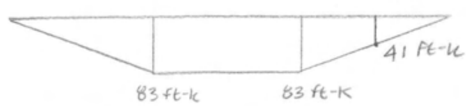
$M_1 = P \cdot e$

$e = 0$ in at the exterior support
$e = 3$ in at the interior support (center of tendon to NA)

$M_1 = (586\text{ k})(3.0\text{ in})/(12\text{ in}) = 147$ ft-k

- The secondary post-tensioning moments, M_{sec}, vary linearly between supports.

$M_{sec} = M_{Bal} - M_1$
$= 230$ ft-k $- 147$ ft-k
$= 83$ ft-k @ interior supports



- Typical load combination for ultimate strength design

$M_u = 1.2 M_{DL} + 1.6_{LL} + 1.0 M_{sec}$

- At midspan $= 1.2(238\text{ ft-k}) + 1.6(42\text{ ft-k}) + 1.0(41\text{ ft-k})$
  $= 394$ ft-k
- At support $= 1.2(-236\text{ ft-k}) + 1.6(-40\text{ ft-k}) + 1.0(83\text{ ft-k})$
  $= -264$ ft-k

DETERMINE MINIMUM BONDED REINFORCEMENT :

- Positive Moment Region

- Interior Span : $F_t = -205 < 2\sqrt{F'c} = 2\sqrt{5000} = 141$ psi ∴ ok ✓
  ∴ NO POSITIVE REINFORCEMENT REQUIRED

- Exterior Span : $F_t = -105 < 2\sqrt{F'c} = 2\sqrt{5000} = 141$ psi ∴ ok

- Minimum positive moment reinforcement required

$y = F_t / (F_t + F_c) h$
$= [+105 / (+105 + 397)](8")$
$= 1.67$ in

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$N_c = (M_{DL} + M_{LL}) / S \cdot 0.5 \cdot y \cdot l_2$
$= [(238 \text{ ft-k} + 42 \text{ ft-k})(12) / (8115 \text{ in}^3)](0.5)(1.67 \text{ in})(24.33')(12)$
$= 263 \text{ k}$

$A_{s\,min} = N_c / 0.5 F_y$
$= (263 \text{ k}) / [0.5 (60 \text{ ksi})]$
$= 8.76 \text{ in}^2$

$A_{s\,min} = (8.76 \text{ in}^2)(24.33')$
$= 0.36 \text{ in}^2 / \text{ft}$

∴ use #5 @ 10 in. O.C. Bottom

$A_s = 0.372 \geq 0.36 \text{ in}^2$ ∴ ok ✓

NOTE: Minimum length shall be 1/3 clear span & centered in positive moment region (ACI 18.9.4.1)

• Negative Moment Region

$A_{s,min} = 0.00075 A_{cf}$ (ACI 18.9.3.3)

Interior Supports:

$A_{cf} = \max. (8 \text{ in})[(28.67' + 18.5')/2](12) = 2{,}264 \text{ in}^2$
$A_{s,min} = 0.00075 (2264 \text{ in}^2)$
$= 1.67 \text{ in}^2$
$= 6$ - #5 Top ($1.86 \text{ in}^2 > 1.67 \text{ in}^2$ ∴ ok ✓)

Exterior Supports:

$A_{cf} = \max (8 \text{ in})[(24'\text{-}4''/2)](12) = 2336 \text{ in}^2$
$A_{s\,min} = 0.00075 (2336 \text{ in}^2)$
$= 1.75$
$= 6$ - #5 Top ($1.86 \text{ in}^2 > 1.75 \text{ in}^2$ ∴ ok ✓)

10/
1(

CHECK MINIMUM REINFORCEMENT : Ultimate Strength

$M_n = (A_s f_y + A_{ps} f_{ps})(d - a/2)$
d = effective depth
A_{ps} = 0.153 in² (number of tendons)
= 0.153 in² (22 tendons)
= 3.37 in²

$F_{ps} = F_{se} + 10{,}000 + (F'_c b d)/(300 A_{ps})$
= 174,000 psi + 10000 + [(5000 psi)(24.33)(12) d] / [(300 (3.37))]
= 184,000 psi + 1444 d

$a = (A_s f_y + A_{ps} f_{ps}) / (0.85 F'_c b)$

- At supports

$d = 8'' - 3/4'' - 5/16'' = 6.9375''$

f_{ps} = 184,000 psi + 1444 (6.9375) = 194,018 psi

a = [(1.86 in²)(60 ksi) + (3.37 in²)(194 ksi)] / [(0.85)(5 ksi)(24.33 x 12)]
= 0.62

ϕM_n = 0.9 [(1.86)(60) + (3.37 in²)(194 ksi)] [7 - 0.62/2] / 12
= [0.9 (765)(6.69)] / 12
= 386 ft-k > 264 ft-k ∴ ok ✓ (use min. reinf.)

$A_{s,req}$ = 1.86 in²

∴ 6 - #5 Top at Interior Supports
6 - #5 Top at Exterior Supports

- At mid-span (end span)

$d = 8'' - 1.5'' - 0.3125'' = 6.1875''$

F_{ps} = 184,000 psi + 1444 (6.1875) = 192934 psi

a = [(8.76 in²)(60 ksi) + (3.37 in²)(193 ksi)] / [(0.85)(5)(24.33 x 12)]
= 0.95

ϕM_n = 0.9 [(8.76 in²)(60 ksi) + (3.37 in²)(193)] [6.1875'' - (0.95/2)] / 12
= [0.9 (1176 k)(5.7125 in)] / 12
= 504 ft-k > 394 ft-k ∴ ok ✓ (use min. reinf.)

∴ Use #5 @ 10'' O.C. Bottom

Appendix E: Detailed Structural System Estimate

Square Foundations (Concrete)							
Mark	Length (ft.)	Width (ft.)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
F80	8.00	8.00	2.67	170.67	2.00	341.33	12.64
F85	8.50	8.50	2.67	192.67	4.00	770.67	28.54
F90	9.00	9.00	2.83	229.50	9.00	2065.50	76.50
F95	9.50	9.50	3.00	270.75	3.00	812.25	30.08
F100	10.00	10.00	3.17	316.67	8.00	2533.33	93.83
F105	10.50	10.50	3.33	367.50	9.00	3307.50	122.50
F110	11.00	11.00	3.50	423.50	2.00	847.00	31.37
F115	11.50	11.50	3.50	462.88	1.00	462.88	17.14
						TOTAL	**412.61**

Combined Foundations (Concrete)							
Mark	Length (ft.)	Width (ft.)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
CF01	27.00	12.00	3.67	1188.00	4.00	4752.00	176.00
CF03	16.00	13.00	4.00	832.00	1.00	832.00	30.81
CF04	14.50	11.00	3.50	558.25	2.00	1116.50	41.35
CF05	12.50	8.00	2.17	216.67	1.00	216.67	8.02
CF06	18.00	9.00	2.83	459.00	4.00	1836.00	68.00
						TOTAL	**324.19**

Grade Beams (Concrete)							
Mark	Length (ft.)	Width (ft.)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
-	132.00	4.00	1.50	792.00	1.00	792.00	29.33
-	31.00	2.00	1.00	62.00	1.00	62.00	2.30
-	129.00	3.00	1.50	580.50	1.00	580.50	21.50
-	162.00	1.50	1.50	364.50	1.00	364.50	13.50
						TOTAL	**66.63**

Mat Foundations (Concrete)						
Mark	Area (sf)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
24"	258	2.00	516.00	1.00	516.00	19.11
34"	597.13	2.83	1691.87	1.00	1691.87	62.66
42"	338.36	3.50	1184.26	1.00	1184.26	43.86
54"	13701.25	4.50	61655.63	1.00	61655.63	2283.54
					TOTAL	**2409.18**

Residential Columns (Concrete)							
Mark	Height (ft.)	Lenght (ft.)	Width (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
101	9.00	2.00	1.33	23.94	6.00	143.64	5.32
102	9.00	2.00	1.33	23.94	6.00	143.64	5.32
103	9.00	2.00	1.33	23.94	6.00	143.64	5.32
104	9.00	2.00	1.33	23.94	6.00	143.64	5.32
105	9.00	2.00	1.33	23.94	6.00	143.64	5.32
106	9.00	2.00	1.33	23.94	6.00	143.64	5.32
107	9.00	2.00	1.33	23.94	6.00	143.64	5.32
108	9.00	2.00	1.33	23.94	6.00	143.64	5.32
109	9.00	2.00	1.33	23.94	6.00	143.64	5.32
110	9.00	2.33	1.17	24.50	3.00	73.50	2.72
111	9.00	2.00	1.33	23.94	6.00	143.64	5.32
112	9.00	2.00	1.33	23.94	6.00	143.64	5.32
113	9.00	2.00	1.33	23.94	6.00	143.64	5.32
114	9.00	2.00	1.33	23.94	6.00	143.64	5.32
115	9.00	2.00	1.33	23.94	6.00	143.64	5.32
117	9.00	2.00	1.33	23.94	6.00	143.64	5.32
118	9.00	2.00	1.33	23.94	6.00	143.64	5.32
119	9.00	2.00	1.33	23.94	6.00	143.64	5.32
120	9.00	2.00	1.33	23.94	6.00	143.64	5.32
121	9.00	2.00	1.33	23.94	6.00	143.64	5.32
122	9.00	2.00	1.33	23.94	6.00	143.64	5.32
123	9.00	2.00	1.00	18.00	3.00	54.00	2.00
124	9.00	2.00	1.33	23.94	6.00	143.64	5.32
125	9.00	2.00	1.33	23.94	6.00	143.64	5.32
126	9.00	2.33	1.17	24.50	6.00	147.00	5.44
127	9.00	2.33	1.17	24.50	6.00	147.00	5.44
128	9.00	2.33	1.17	24.50	6.00	147.00	5.44
129	9.00	2.33	1.17	24.50	6.00	147.00	5.44
130	9.00	2.00	1.33	23.94	6.00	143.64	5.32
131	9.00	2.33	1.17	24.53	6.00	147.21	5.45
132	9.00	2.33	1.17	24.53	6.00	147.21	5.45
133	9.00	2.33	1.17	24.53	6.00	147.21	5.45
134	9.00	2.00	1.33	23.94	6.00	143.64	5.32
135	9.00	2.00	1.33	23.94	6.00	143.64	5.32
136	9.00	2.00	1.33	23.94	6.00	143.64	5.32
137	9.00	2.00	1.33	23.94	6.00	143.64	5.32
138	9.00	2.33	1.17	24.53	6.00	147.21	5.45
139	9.00	2.33	1.17	24.53	6.00	147.21	5.45
140	9.00	2.33	1.17	24.53	6.00	147.21	5.45
141	9.00	2.33	1.17	24.53	6.00	147.21	5.45
142	9.00	2.33	1.17	24.53	6.00	147.21	5.45
143	9.00	2.33	1.17	24.53	6.00	147.21	5.45
144	9.00	2.33	1.17	24.53	6.00	147.21	5.45
145	9.00	2.33	1.17	24.53	6.00	147.21	5.45
146	9.00	2.33	1.17	24.53	6.00	147.21	5.45
147	9.00	2.33	1.17	24.53	6.00	147.21	5.45
148	9.00	2.33	1.17	24.53	6.00	147.21	5.45
149	9.00	2.33	1.17	24.53	6.00	147.21	5.45
150	9.00	2.00	1.33	23.94	6.00	143.64	5.32
						TOTAL	257.24

Residential Columns (Concrete)							
Mark	Height (ft.)	Lenght (ft.)	Width (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
101	9.083	2.00	1.33	24.16	1.00	24.16	0.89
102	9.083	2.00	1.33	24.16	1.00	24.16	0.89
103	9.083	2.00	1.33	24.16	1.00	24.16	0.89
104	9.083	2.00	1.33	24.16	1.00	24.16	0.89
105	9.083	2.00	1.33	24.16	1.00	24.16	0.89
106	9.083	2.00	1.33	24.16	1.00	24.16	0.89
107	9.083	2.00	1.33	24.16	1.00	24.16	0.89
108	9.083	2.00	1.33	24.16	1.00	24.16	0.89
109	9.083	2.00	1.33	24.16	1.00	24.16	0.89
110	9.083	2.33	1.17	24.73	1.00	24.73	0.92
111	9.083	2.00	1.33	24.16	1.00	24.16	0.89
112	9.083	2.00	1.33	24.16	1.00	24.16	0.89
113	9.083	2.00	1.33	24.16	1.00	24.16	0.89
114	9.083	2.00	1.33	24.16	1.00	24.16	0.89
115	9.083	2.00	1.33	24.16	1.00	24.16	0.89
117	9.083	2.00	1.33	24.16	1.00	24.16	0.89
118	9.083	2.00	1.33	24.16	1.00	24.16	0.89
119	9.083	2.00	1.33	24.16	1.00	24.16	0.89
120	9.083	2.00	1.33	24.16	1.00	24.16	0.89
121	9.083	2.00	1.33	24.16	1.00	24.16	0.89
122	9.083	2.00	1.33	24.16	1.00	24.16	0.89
123	9.083	2.00	1.00	18.17	1.00	18.17	0.67
124	9.083	2.00	1.33	24.16	1.00	24.16	0.89
125	9.083	2.00	1.33	24.16	1.00	24.16	0.89
126	9.083	2.33	1.17	24.73	1.00	24.73	0.92
127	9.083	2.33	1.17	24.73	1.00	24.73	0.92
128	9.083	2.33	1.17	24.73	1.00	24.73	0.92
129	9.083	2.33	1.17	24.73	1.00	24.73	0.92
130	9.083	2.00	1.33	24.16	1.00	24.16	0.89
131	9.083	2.33	1.17	24.76	1.00	24.76	0.92
132	9.083	2.33	1.17	24.76	1.00	24.76	0.92
133	9.083	2.33	1.17	24.76	1.00	24.76	0.92
134	9.083	2.00	1.33	24.16	1.00	24.16	0.89
135	9.083	2.00	1.33	24.16	1.00	24.16	0.89
136	9.083	2.00	1.33	24.16	1.00	24.16	0.89
137	9.083	2.00	1.33	24.16	1.00	24.16	0.89
138	9.083	2.33	1.17	24.76	1.00	24.76	0.92
139	9.083	2.33	1.17	24.76	1.00	24.76	0.92
140	9.083	2.33	1.17	24.76	1.00	24.76	0.92
141	9.083	2.33	1.17	24.76	1.00	24.76	0.92
142	9.083	2.33	1.17	24.76	1.00	24.76	0.92
143	9.083	2.33	1.17	24.76	1.00	24.76	0.92
144	9.083	2.33	1.17	24.76	1.00	24.76	0.92
145	9.083	2.33	1.17	24.76	1.00	24.76	0.92
146	9.083	2.33	1.17	24.76	1.00	24.76	0.92
147	9.083	2.33	1.17	24.76	1.00	24.76	0.92
148	9.083	2.33	1.17	24.76	1.00	24.76	0.92
149	9.083	2.33	1.17	24.76	1.00	24.76	0.92
150	9.083	2.00	1.33	24.16	1.00	24.16	0.89
						TOTAL	44.06

Academic Columns (Concrete)							
Mark	Height (ft.)	Lenght (ft.)	Width (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
201	9.00	2.00	1.33	23.94	4.00	95.76	3.55
202	9.00	2.00	1.33	23.94	4.00	95.76	3.55
203	9.00	2.00	1.33	23.94	7.00	167.58	6.21
204	9.00	2.00	1.33	23.94	7.00	167.58	6.21
205	9.00	2.00	1.33	23.94	7.00	167.58	6.21
206	9.00	2.00	1.33	23.94	4.00	95.76	3.55
207	9.00	2.00	1.33	23.94	4.00	95.76	3.55
208	9.00	2.00	1.33	23.94	7.00	167.58	6.21
209	9.00	2.00	1.33	23.94	7.00	167.58	6.21
210	9.00	2.00	1.33	23.94	7.00	167.58	6.21
211	9.00	2.00	1.33	23.94	7.00	167.58	6.21
212	9.00	2.00	1.33	23.94	7.00	167.58	6.21
213	9.00	2.00	1.33	23.94	7.00	167.58	6.21
214	9.00	2.00	1.33	23.94	7.00	167.58	6.21
215	9.00	2.00	1.33	23.94	7.00	167.58	6.21
216	9.00	2.00	1.33	23.94	7.00	167.58	6.21
217	9.00	2.00	1.33	23.94	7.00	167.58	6.21
218	9.00	2.00	1.33	23.94	7.00	167.58	6.21
219	9.00	2.00	1.33	23.94	3.00	71.82	2.66
219	9.00	2.00		28.26	4.00	113.04	4.19
220	9.00	2.00	1.33	23.94	7.00	167.58	6.21
221	9.00	2.00	1.33	23.94	7.00	167.58	6.21
222	9.00	2.00	1.33	23.94	7.00	167.58	6.21
223	9.00	2.00	1.33	23.94	4.00	95.76	3.55
224	9.00	2.00	1.33	23.94	7.00	167.58	6.21
225	9.00	2.00	1.33	23.94	7.00	167.58	6.21
226	9.00	2.00	1.33	23.94	7.00	167.58	6.21
227	9.00	2.00	1.33	23.94	7.00	167.58	6.21
228	9.00	2.33	1.17	24.53	7.00	171.74	6.36
229	9.00	2.00	1.33	23.94	7.00	167.58	6.21
230	9.00	2.00	1.33	23.94	7.00	167.58	6.21
231	9.00	2.00	1.33	23.94	7.00	167.58	6.21
232	9.00	2.00	1.33	23.94	4.00	95.76	3.55
233	9.00	2.00	1.33	23.94	7.00	167.58	6.21
234	9.00	2.00	1.33	23.94	4.00	95.76	3.55
235	9.00	2.33	1.17	24.53	7.00	171.74	6.36
236	9.00	2.33	1.17	24.53	7.00	171.74	6.36
237	9.00	2.33	1.17	24.53	6.00	147.21	5.45
238	9.00	2.33	1.17	24.53	6.00	147.21	5.45
239	9.00	2.33	1.17	24.53	6.00	147.21	5.45
240	9.00	2.33	1.17	24.53	7.00	171.74	6.36
241	9.00	2.33	1.17	24.53	7.00	171.74	6.36
242	9.00	2.00	1.33	23.94	4.00	95.76	3.55
243	9.00	1.50	1.50	20.25	4.00	81.00	3.00
244	9.00	1.50	1.50	20.25	4.00	81.00	3.00
245	9.00	1.50	1.50	20.25	4.00	81.00	3.00
246	9.00	1.50	1.50	20.25	4.00	81.00	3.00
247	9.00	2.00	1.33	23.94	3.00	71.82	2.66
248	9.00	2.00	1.33	23.94	4.00	95.76	3.55
249	9.00	2.00	1.33	23.94	4.00	95.76	3.55
250	9.00	2.00	1.00	18.00	3.00	54.00	2.00
251	9.00	2.00	1.00	18.00	3.00	54.00	2.00
252	9.00	2.00	1.00	18.00	3.00	54.00	2.00
253	9.00	2.00	1.00	18.00	3.00	54.00	2.00
254	9.00	2.00	1.33	23.94	4.00	95.76	3.55
						TOTAL	271.85

Residential Beams (Concrete)							
Mark	Lenght (ft.)	Width (ft.)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
B101	19.00	0.83	1.33	21.06	6.00	126.35	4.68
B102	18.00	0.83	1.67	25.05	4.00	100.20	3.71
B103	20.00	1.67	1.17	38.89	1.00	38.89	1.44
B104	14.00	1.67	1.17	27.22	1.00	27.22	1.01
B105	22.00	1.67	1.17	42.78	1.00	42.78	1.58
B106	22.00	1.67	1.17	42.78	1.00	42.78	1.58
B107	20.00	1.67	1.17	38.89	1.00	38.89	1.44
B108	20.00	1.67	1.17	38.89	1.00	38.89	1.44
B109	22.00	2.00	2.17	95.33	1.00	95.33	3.53
B110	20.00	2.00	1.50	60.00	1.00	60.00	2.22
B111	20.00	2.00	1.50	60.00	1.00	60.00	2.22
B112	28.00	1.00	1.00	28.00	20.00	560.00	20.74
B113	23.00	1.00	5.58	128.42	1.00	128.42	4.76
						TOTAL	50.36

Academic Beams (Concrete)							
Mark	Lenght (ft.)	Width (ft.)	Depth (ft.)	Volume (cu. Ft.)	Quantity	Total	Total CY
B201	19.50	0.83	1.33	21.67	8.00	173.33	6.42
B202	25.00	1.67	1.21	50.35	1.00	50.35	1.86
B203	18.00	1.67	1.21	36.25	1.00	36.25	1.34
B204	24.00	1.67	1.21	48.33	1.00	48.33	1.79
B205	22.00	1.67	1.21	44.31	1.00	44.31	1.64
B206	14.00	1.67	1.21	28.19	1.00	28.19	1.04
B207	41.00	4.00	1.13	184.50	3.00	553.50	20.50
B216	18.00	4.00	2.17	156.00	1.00	156.00	5.78
B220	13.00	0.83	1.33	14.44	12.00	173.33	6.42
B221	12.00	0.83	1.50	15.00	12.00	180.00	6.67
B222	24.00	1.00	1.50	36.00	3.00	108.00	4.00
B223	26.00	1.00	1.50	39.00	14.00	546.00	20.22
B224	14.00	0.83	1.50	17.50	6.00	105.00	3.89
B225	16.00	1.00	2.00	32.00	2.00	64.00	2.37
B226	27.00	2.00	1.00	54.00	6.00	324.00	12.00
B227	85.00	2.00	1.00	170.00	3.00	510.00	18.89
B228	13.00	0.83	1.00	10.83	4.00	43.33	1.60
B229	20.00	0.83	1.33	22.22	2.00	44.44	1.65
B230	16.00	1.33	1.33	28.44	3.00	85.33	3.16
B231	19.50	1.00	2.92	56.88	3.00	170.63	6.32
B233	14.00	1.00	1.50	21.00	3.00	63.00	2.33
						TOTAL	129.90

Structural Slabs (Concrete)					
Mark	**Area (sf)**	**Depth (ft.)**	**Volume (cu. Ft.)**	**Quantity**	**Total CY**
Mud Mat	44882.95	0.17	7480.49	1.00	277.06
G4 Park	40397.00	0.33	13465.67	1.00	498.73
G3 Park	34122.04	0.67	22748.03	1.00	842.52
G3 Res.	11658.00	0.67	7772.00	1.00	287.85
G2 Park	34667.40	0.67	23111.60	1.00	855.99
G2 Res.	11152.00	0.58	6505.33	1.00	240.94
G1 Park	34609.68	0.67	23073.12	1.00	854.56
G1 Res.	11290.00	0.58	6585.83	1.00	243.92
Acad. 1	16503.00	0.75	12377.25	1.00	458.42
Res. 1	11733.84	0.58	6844.74	1.00	253.51
Plaza 1	12200.00	1.00	12200.00	1.00	451.85
Acad. 2	17906.16	0.75	13429.62	1.00	497.39
Res. 2	11735.00	0.58	6845.42	1.00	253.53
Acad. 3	17904.25	0.75	13428.19	1.00	497.34
Res. 3	11735.00	0.58	6845.42	1.00	253.53
Roof Res.	11563.00	0.67	7708.67	1.00	285.51
Roof Acad.	16896.00	0.67	11264.00	1.00	417.19
				TOTAL	**7469.83**

Shear Walls (Concrete)							
Mark	**Height (ft.)**	**Width (ft.)**	**Depth (ft.)**	**Volume (cu. Ft.)**	**Quantity**	**Total**	**Total CY**
SW1	76.00	27.50	1.00	2090.00	1.00	2090.00	77.41
SW2	76.00	18.00	1.00	1242.00	1.00	1242.00	46.00
SW3	76.00	18.00	1.00	1168.50	1.00	1168.50	43.28
SW4	76.00	9.50	1.00	722.00	1.00	722.00	26.74
SW5	77.00	19.50	1.00	1501.50	1.00	1501.50	55.61
SW6	77.00	9.25	1.00	712.25	1.00	712.25	26.38
SW7	77.00	9.25	1.00	712.25	1.00	712.25	26.38
SW8	85.00	9.00	1.00	765.00	1.00	765.00	28.33
SW9	85.00	19.50	1.00	1657.50	1.00	1657.50	61.39
SW11	65.00	27.50	0.67	1081.67	1.00	1081.67	40.06
SW12	85.00	9.00	1.00	765.00	1.00	765.00	28.33
SW13	40.00	18.00	1.00	720.00	14.00	10080.00	373.33
						TOTAL	**833.25**

PT Transfer Beams (Concrete)							
Mark	**Lenght (ft.)**	**Width (ft.)**	**Depth (ft.)**	**Volume (cu. Ft.)**	**Quantity**	**Total**	**Total CY**
B210	42.00	5.00	2.50	525.00	1.00	525.00	19.44
B211	29.00	3.00	2.00	174.00	1.00	174.00	6.44
B212	29.00	3.00	2.00	174.00	1.00	174.00	6.44
B213	22.00	3.00	2.00	132.00	1.00	132.00	4.89
B214	40.00	5.00	2.67	533.33	1.00	533.33	19.75
B215	30.00	4.00	2.17	260.00	2.00	520.00	19.26
B217	36.00	4.00	2.17	312.00	1.00	312.00	11.56
B218	36.00	4.00	2.17	312.00	1.00	312.00	11.56
						TOTAL	**99.35**

Foundation Walls (Concrete)							
Mark	**LF (ft.)**	**Height (ft.)**	**Depth (ft.)**	**Volume (cu. Ft.)**	**Quantity**	**Total**	**Total CY**
0'-8"	58.00	18.00	0.67	696.00	1.00	696.00	25.78
0'-10"	130.50	24.00	0.83	2610.00	1.00	2610.00	96.67
1'-0"	635.92	9.00	1.00	5723.25	4.00	22893.00	847.89
1'-4"	289.33	9.00	1.33	3472.00	4.00	13888.00	514.37
						TOTAL	**1362.26**

Squae Foundations (Rebar)

Mark	Qty.	L (ft.)	W (ft.)	EW Bar	EW qty.	EW (lbs/lf)	NS Bar	NS qty.	NS (lbs/lf)	Wt. (lbs.)	Total (tons)
F80	2.00	8.00	8.00	#8	8.00	2.67	#8	8.00	2.67	341.76	0.34
F85	4.00	8.50	8.50	#8	9.00	2.67	#8	9.00	2.67	408.51	0.82
F90	9.00	9.00	9.00	#9	8.00	3.40	#9	8.00	3.40	489.60	2.20
F95	3.00	9.50	9.50	#9	11.00	3.40	#9	11.00	3.40	710.60	1.07
F100	8.00	10.00	10.00	#9	11.00	3.40	#9	11.00	3.40	748.00	2.99
F105	9.00	10.50	10.50	#9	11.00	3.40	#9	11.00	3.40	785.40	3.53
F110	2.00	11.00	11.00	#10	9.00	4.30	#10	9.00	4.30	851.99	0.85
F115	1.00	11.50	11.50	#10	10.00	4.30	#10	10.00	4.30	989.69	0.49
										TOTAL	12.30

Combined Foundations (Rebar)

Mark	Qty.	L (ft.)	W (ft.)	Bot. S.	Bot. S. qty.	Bot. S. (lbs./lf)	Bot. L.	Bot. L. qty.	Bot. L. (lbs./lf)	Top L.	Top L. qty.	Top L. (lbs./lf)	Total (tons)
CF01	4.00	26.50	11.50	#10	34.00	4.30	#10	16.00	4.30	#10	16.00	4.30	10.66
CF03	1.00	15.50	12.50	#10	16.00	4.30	#10	14.00	4.30	#10	14.00	4.30	1.36
CF04	2.00	14.00	10.50	#9	16.00	3.40	#9	12.00	3.40	#9	12.00	3.40	1.71
CF05	1.00	12.00	6.00	#8	14.00	2.67	#8	8.00	2.67	#8	8.00	2.67	0.37
CF06	4.00	17.50	8.50	#9	18.00	3.40	#9	8.00	3.40	#9	8.00	3.40	2.94
												TOTAL	17.05

Grade Beams (Rebar)

Mark	L (ft.)	W (ft.)	T & B	T &B Qty.	T & B (lbs/lf)	Stir.	Stir. (lf)	Stir. (lbs/lf)	Wt. (lbs)	Total (tons)
-	132.00	4.00	#5	5.00	1.04	#6	3.50	1.50	1382.30	0.69
-	31.00	2.00	#5	3.00	1.04				97.00	0.05
-	129.00	3.00	#9	5.00	3.40	#3	7.00	0.38	2532.53	1.27
-	162.00	1.50	#8	6.00	2.67	#3	5.00	0.37	2892.51	1.45
									TOTAL	3.45

Mat Foundations (Rebar)

Mark	L (ft.)	W (ft.)	L Bar	L Qty	L (lbs/lf)	W Bar	W Qty.	W (lbs/lf)	Qty. (T&B)	Total (tons)
24"	21.50	12.00	#10	12.00	4.30	#10	21.00	4.30	2.00	2.19

Mat Foundations (Rebar)

Mark	Area (sf.)	Area Comparison	T & B (EW)	T & B (EW) Qty	T & B (EW) (lbs/lf)	Wt. (lbs.)	Mult.	Total (tons.)
34"	597.13	100.00	#10	40.00	4.30	1,721.20	5.97	5.14
42"	338.36	100.00	#10	40.00	4.30	1,721.20	3.38	2.91
54"	13,701.25	100.00	#11	40.00	5.31	2,125.20	137.01	145.59
							TOTAL	155.83

Shear Walls (Rebar)								
Mark	Area (sf.)	Area Comparison	T & B (EW)	T & B (EW) Qty	T & B (EW) (lbs/lf)	Wt. (lbs.)	Mult.	Total (tons.)
SW1	2090.00	100.00	#6	40.00	1.50	600.80	20.90	6.28
SW2	1242.00	100.00	#6	40.00	1.50	600.80	12.42	3.73
SW3	1168.50	100.00	#6	40.00	1.50	600.80	11.69	3.51
SW4	722.00	100.00	#6	40.00	1.50	600.80	7.22	2.17
SW5	1501.50	100.00	#6	40.00	1.50	600.80	15.02	4.51
SW6	712.25	100.00	#6	40.00	1.50	600.80	7.12	2.14
SW7	712.25	100.00	#6	40.00	1.50	600.80	7.12	2.14
SW8	765.00	100.00	#4/#5	40.00	0.86	342.20	7.65	1.31
SW9	1657.50	100.00	#4/#5	40.00	0.86	342.20	16.58	2.84
SW11	1787.50	100.00	#4/#5	40.00	0.86	342.20	17.88	3.06
SW12	765.00	100.00	#4/#5	40.00	0.86	342.20	7.65	1.31
SW13	10080.00	100.00	#5/#6	40.00	1.27	509.00	100.80	25.65
							TOTAL	58.64

Residential Columns (Rebar)										
Mark	L (ft.)	Qty.	Bar	Wt. (lbs./lf)	Bars	Stir.	Stir. (lf)	Stir. (lbs/lf	Wt. (lbs.)	Total (tons)
4 Bars	9.00	140.00	#9	3.40	4.00	#3	5.50	0.38	19741.68	9.87
6 Bars	9.00	170.00	#9	3.40	6.00	#3	5.50	0.38	34376.04	17.19
8 Bars	9.00	17.00	#10	4.30	8.00	#3	5.50	0.38	5583.28	2.79
10 Bars	9.00	3.00	#10	4.30	10.00	#3	5.50	0.38	1217.65	0.61
12 Bars	9.00	7.00	#11	5.31	12.00	#4	5.50	0.67	4248.09	2.12
									TOTAL	32.58

Academic Columns (Rebar)										
Mark	L (ft.)	Qty.	Bar	Wt. (lbs./lf)	Bars	Stir.	Stir. (lf)	Stir. (lbs/lf	Wt. (lbs.)	Total (tons)
4 Bars	9.00	140.00	#9	3.40	4.00	#3	5.50	0.38	19741.68	9.87
6 Bars	9.00	108.00	#9	3.40	6.00	#3	5.50	0.38	21838.90	10.92
8 Bars	9.00	32.00	#10	4.30	8.00	#3	5.50	0.38	10509.70	5.25
10 Bars	9.00	12.00	#10	4.30	10.00	#3	5.50	0.38	4870.58	2.44
12 Bars	9.00	18.00	#11	5.31	12.00	#4	5.50	0.67	10923.66	5.46
									TOTAL	33.94

Residential Beams (Rebar)										
Mark	L (ft.)	Qty.	T Bar	Top (lbs./lf)	Bars	Bot. Bar	Bot (lbs./lf)	Bars	Stirrup (lbs)	Total (tons)
B101	19.00	6.00	#7	2.04	2.00	#8	2.67	2.00	3.38	0.73
B102	18.00	4.00	#8	2.67	2.00	#9	3.40	2.00	3.38	0.56
B103	20.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.22
B104	14.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.16
B105	22.00	1.00	#8	2.67	4.00	#10	4.30	4.00	3.38	0.34
B106	22.00	1.00	#9	3.40	4.00	#10	4.30	4.00	3.38	0.38
B107	20.00	1.00	#8	2.67	2.00	#10	4.30	5.00	3.38	0.30
B108	20.00	1.00	#8	2.67	2.00	#10	4.30	5.00	3.38	0.30
B109	22.00	1.00	#9	3.40	4.00	#10	4.30	6.00	3.38	0.47
B110	20.00	1.00	#9	3.40	4.00	#10	4.30	6.00	3.38	0.43
B111	20.00	1.00	#9	3.40	4.00	#10	4.30	6.00	3.38	0.43
B112	28.00	20.00	#7	2.04	2.00	#7	2.04	2.00	3.38	3.24
B113	23.00	1.00	#9	3.40	2.00	#10	4.30	2.00	3.38	0.22
									TOTAL	7.77

Academic Beams (Rebar)										
Mark	L (ft.)	Qty.	T Bar	Top (lbs./lf)	Bars	Bot. Bar	Bot (lbs./lf)	Bars	Stirrup (lbs/lf)	Total (tons)
B201	19.50	8.00	#7	2.44	2.00	#8	2.67	2.00	3.38	1.06
B202	25.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.28
B203	18.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.20
B204	24.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.27
B205	22.00	1.00	#8	2.67	2.00	#9	3.40	4.00	3.38	0.25
B206	14.00	1.00	#8	2.67	2.00	#9	3.40	2.00	3.38	0.11
B207	41.00	3.00	#7	2.44	4.00	#7	2.44	4.00	3.38	1.41
B216	18.00	1.00	#9	3.40	6.00	#11	5.31	10.00	3.38	0.69
B220	13.00	12.00	#8	2.67	2.00	#8	2.67	2.00	3.38	1.10
B221	12.00	12.00	#8	2.67	2.00	#8	2.67	2.00	3.38	1.01
B222	24.00	3.00	#8	2.67	2.00	#8	2.67	2.00	3.38	0.51
B223	26.00	14.00	#8	2.67	2.00	#8	2.67	2.00	3.38	2.56
B224	14.00	6.00	#8	2.67	2.00	#8	2.67	2.00	3.38	0.59
B225	16.00	2.00	#8	2.67	2.00	#8	2.67	2.00	3.38	0.23
B226	27.00	6.00	#8	2.67	2.00	#8	2.67	2.00	3.38	1.14
B227	85.00	3.00	#8	2.67	2.00	#8	2.67	2.00	3.38	1.79
B228	13.00	4.00	#8	2.67	2.00	#8	2.67	2.00	3.38	0.37
B229	20.00	2.00	#7	2.44	2.00	#8	2.67	2.00	3.38	0.27
B230	16.00	3.00	#8	2.67	2.00	#9	3.40	2.00	3.38	0.37
B231	19.50	3.00	#9	3.40	3.00	#10	4.30	3.00	3.38	0.77
B233	14.00	3.00	#8	2.67	2.00	#8	2.67	2.00	3.38	0.30
									TOTAL	15.27

PT Transfer Beams (Rebar)										
Mark	L (ft.)	Qty.	T Bar	Top (lbs./lf)	Bars	Bot. Bar	Bot (lbs./lf)	Bars	Stirrup (lbs/lf)	Total (tons)
B210	42.00	1.00	#8	2.67	8.00	#8	2.67	8.00	3.56	0.97
B211	29.00	1.00	#8	2.67	4.00	#8	2.67	4.00	3.56	0.36
B212	29.00	1.00	#8	2.67	4.00	#8	2.67	4.00	3.56	0.36
B213	22.00	1.00	#8	2.67	4.00	#8	2.67	4.00	3.56	0.27
B214	40.00	1.00	#8	2.67	8.00	#8	2.67	8.00	3.56	0.93
B215	30.00	2.00	#8	2.67	6.00	#8	2.67	6.00	3.56	1.07
B217	36.00	1.00	#8	2.67	4.00	#8	2.67	6.00	3.56	0.54
B218	36.00	1.00	#8	2.67	4.00	#8	2.67	6.00	3.56	0.54
									TOTAL	5.05

Foundation Walls (Rebar)								
Mark	Area (sf.)	Area Comparison	T & B (EW)	T & B (EW) Qty	T & B (EW) (lbs/lf)	Wt. (lbs.)	Mult.	Total (tons.)
0'-8"	1044.00	100.00	#4/#5	30.00	0.79	237.53	10.44	1.24
0'-10"	3132.00	100.00	#4/#6	20.00	1.09	217.00	31.32	3.40
1'-0"	22893.00	100.00	#4/#7/#8/#8	40.00	2.02	807.20	228.93	92.40
1'-4"	10416.00	100.00	#5/#6	40.00	1.27	509.00	104.16	26.51
							TOTAL	123.54

Structural Slabs (Rebar)								
Mark	Area (sf.)	Area Comparison	T & B (EW)	T & B (EW) Qty	T & B (EW) (lbs/lf)	Wt. (lbs.)	Mult.	Total (tons.)
G4 Park	40397.00	100.00	-	-	-	-	-	-
G3 Park*	34122.04	100.00	#5	24.00	1.04	250.32	341.22	42.71
G3 Res.	11658.00	100.00	#5	24.00	1.04	250.32	116.58	14.59
G2 Park*	34667.40	100.00	#5	24.00	1.04	250.32	346.67	43.39
G2 Res.	11152.00	100.00	#4/#5	34.00	0.79	269.20	111.52	15.01
G1 Park*	34609.68	100.00	#5	24.00	1.04	250.32	346.10	43.32
G1 Res.	11290.00	100.00	#4/#5	34.00	0.79	269.20	112.90	15.20
Acad. 1	16503.00	100.00	#5	48.00	1.04	500.64	165.03	41.31
Res. 1	11733.84	100.00	#4/#5	34.00	0.79	269.20	117.34	15.79
Plaza 1	12200.00	100.00	#6	48.00	1.50	720.96	122.00	43.98
Acad. 2	17906.16	100.00	#5	48.00	1.04	500.64	179.06	44.82
Res. 2	11735.00	100.00	#4/#5	34.00	0.79	269.20	117.35	15.80
Acad. 3	17904.25	100.00	#5	48.00	1.04	500.64	179.04	44.82
Res. 3	11735.00	100.00	#4/#5	34.00	0.79	269.20	117.35	15.80
Roof Res.	11563.00	100.00	#5	36.00	1.04	375.48	115.63	21.71
Roof Acad.	16896.00	100.00	#5	36.00	1.04	375.48	168.96	31.72
*epoxy coated Rebar							TOTAL	449.95

Mat Foundations (Formwork)			
Mark	LF	Depth (ft.)	Area (sf)
24"	67.00	2.00	134.00
34"	97.25	2.83	275.54
42"	73.00	3.50	255.51
54"	506.33	4.50	2278.49
		TOTAL	2943.54

Shear Walls (Formwork)			
Mark	LF	Height (ft.)	Area (sf)
SW1	24.00	76.00	1824.00
SW2	24.00	76.00	1824.00
SW3	24.00	76.00	1824.00
SW4	21.33	76.00	1621.31
SW5	24.25	77.00	1867.25
SW6	24.25	77.00	1867.25
SW7	24.25	77.00	1867.25
SW8	24.25	85.00	2061.25
SW9	24.25	85.00	2061.25
SW11	24.25	85.00	2061.25
SW12	17.83	85.00	1515.83
SW13	476.00	40.00	19040.00
		TOTAL	39434.64

Residential Beams(Formwork)				
Mark	**Surface Area**	**Depth (ft.)**	**Quantity**	**Area (sf)**
B101	68.59	1.33	6.00	411.54
B102	77.90	1.67	4.00	311.61
B103	83.89	1.17	1.00	83.89
B104	59.89	1.17	1.00	59.89
B105	91.89	1.17	1.00	91.89
B106	91.89	1.17	1.00	91.89
B107	83.89	1.17	1.00	83.89
B108	83.89	1.17	1.00	83.89
B109	148.00	2.17	1.00	148.00
B110	106.00	1.50	1.00	106.00
B111	106.00	1.50	1.00	106.00
B112	86.00	1.00	20.00	1720.00
B113	291.00	5.58	1.00	291.00
			TOTAL	**3589.49**

Academic Beams(Formwork)				
Mark	**Surface Area**	**Depth (ft.)**	**Quantity**	**Area (sf)**
B201	70.47	1.33	8.00	563.78
B202	106.11	1.21	1.00	106.11
B203	77.53	1.21	1.00	77.53
B204	102.03	1.21	1.00	102.03
B205	93.86	1.21	1.00	93.86
B206	61.19	1.21	1.00	61.19
B207	265.25	1.13	3.00	795.75
B216	167.33	2.17	1.00	167.33
B220	47.72	1.33	12.00	572.67
B221	48.50	1.50	12.00	582.00
B222	99.00	1.50	3.00	297.00
B223	107.00	1.50	14.00	1498.00
B224	56.17	1.50	6.00	337.00
B225	84.00	2.00	2.00	168.00
B226	112.00	1.00	6.00	672.00
B227	344.00	1.00	3.00	1032.00
B228	38.50	1.00	4.00	154.00
B229	72.22	1.33	2.00	144.44
B230	67.56	1.33	3.00	202.67
B231	139.08	2.92	3.00	417.25
B233	59.00	1.50	3.00	177.00
			TOTAL	**8221.61**

Residential Columns (Formwork)				
Mark	LF	Height (ft.)	Quantity	Area (sf)
101	6.66	9.083	7.00	423.45
102	6.66	9.083	7.00	423.45
103	6.66	9.083	7.00	423.45
104	6.66	9.083	7.00	423.45
105	6.66	9.083	7.00	423.45
106	6.66	9.083	7.00	423.45
107	6.66	9.083	7.00	423.45
108	6.66	9.083	7.00	423.45
109	6.66	9.083	7.00	423.45
110	7.00	9.083	4.00	254.32
111	6.66	9.083	7.00	423.45
112	6.66	9.083	7.00	423.45
113	6.66	9.083	7.00	423.45
114	6.66	9.083	7.00	423.45
115	6.66	9.083	7.00	423.45
117	6.66	9.083	7.00	423.45
118	6.66	9.083	7.00	423.45
119	6.66	9.083	7.00	423.45
120	6.66	9.083	7.00	423.45
121	6.66	9.083	7.00	423.45
122	6.66	9.083	7.00	423.45
123	6.00	9.083	4.00	217.99
124	6.66	9.083	7.00	423.45
125	6.66	9.083	7.00	423.45
126	7.00	9.083	7.00	445.07
127	7.00	9.083	7.00	445.07
128	7.00	9.083	7.00	445.07
129	7.00	9.083	7.00	445.07
130	6.66	9.083	7.00	423.45
131	7.00	9.083	7.00	445.07
132	7.00	9.083	7.00	445.07
133	7.00	9.083	7.00	445.07
134	6.66	9.083	7.00	423.45
135	6.66	9.083	7.00	423.45
136	6.66	9.083	7.00	423.45
137	6.66	9.083	7.00	423.45
138	7.00	9.083	7.00	445.07
139	7.00	9.083	7.00	445.07
140	7.00	9.083	7.00	445.07
141	7.00	9.083	7.00	445.07
142	7.00	9.083	7.00	445.07
143	7.00	9.083	7.00	445.07
144	7.00	9.083	7.00	445.07
145	7.00	9.083	7.00	445.07
146	7.00	9.083	7.00	445.07
147	7.00	9.083	7.00	445.07
148	7.00	9.083	7.00	445.07
149	7.00	9.083	7.00	445.07
150	6.66	9.083	7.00	423.45
			TOTAL	**20785.17**

Academic Columns (Formwork)				
Mark	LF	Height (ft.)	Quantity	Area (sf)
201	6.66	9.00	4.00	239.76
202	6.66	9.00	4.00	239.76
203	6.66	9.00	7.00	419.58
204	6.66	9.00	7.00	419.58
205	6.66	9.00	7.00	419.58
206	6.66	9.00	4.00	239.76
207	6.66	9.00	4.00	239.76
208	6.66	9.00	7.00	419.58
209	6.66	9.00	7.00	419.58
210	6.66	9.00	7.00	419.58
211	6.66	9.00	7.00	419.58
212	6.66	9.00	7.00	419.58
213	6.66	9.00	7.00	419.58
214	6.66	9.00	7.00	419.58
215	6.66	9.00	7.00	419.58
216	6.66	9.00	7.00	419.58
217	6.66	9.00	7.00	419.58
218	6.66	9.00	7.00	419.58
219	6.66	9.00	3.00	179.82
219	4.00	9.00	4.00	144.00
220	6.66	9.00	7.00	419.58
221	6.66	9.00	7.00	419.58
222	6.66	9.00	7.00	419.58
223	6.66	9.00	4.00	239.76
224	6.66	9.00	7.00	419.58
225	6.66	9.00	7.00	419.58
226	6.66	9.00	7.00	419.58
227	6.66	9.00	7.00	419.58
228	7.00	9.00	7.00	441.00
229	6.66	9.00	7.00	419.58
230	6.66	9.00	7.00	419.58
231	6.66	9.00	7.00	419.58
232	6.66	9.00	4.00	239.76
233	6.66	9.00	7.00	419.58
234	6.66	9.00	4.00	239.76
235	7.00	9.00	7.00	441.00
236	7.00	9.00	7.00	441.00
237	7.00	9.00	6.00	378.00
238	7.00	9.00	6.00	378.00
239	7.00	9.00	6.00	378.00
240	7.00	9.00	7.00	441.00
241	7.00	9.00	7.00	441.00
242	6.66	9.00	4.00	239.76
243	6.00	9.00	4.00	216.00
244	6.00	9.00	4.00	216.00
245	6.00	9.00	4.00	216.00
246	6.00	9.00	4.00	216.00
247	6.66	9.00	3.00	179.82
248	6.66	9.00	4.00	239.76
249	6.66	9.00	4.00	239.76
250	6.00	9.00	3.00	162.00
251	6.00	9.00	3.00	162.00
252	6.00	9.00	3.00	162.00
253	6.00	9.00	3.00	162.00
254	6.66	9.00	4.00	239.76
			TOTAL	**18481.50**

Foundation Walls(Formwork)			
Mark	**LF**	**Height (ft.)**	**Area (sf)**
0'-8"	116.00	18.00	2088.00
0'-10"	263.00	24.00	6312.00
1'-0"	635.92	36.00	22893.00
1'-4"	289.33	36.00	10416.00
		TOTAL	**41709.00**

PT Transfer Beams (Formwork)				
Mark	**Surface Area**	**Depth (ft.)**	**Quantity**	**Area (sf)**
B210	445.00	2.50	1.00	445.00
B211	215.00	2.00	1.00	215.00
B212	215.00	2.00	1.00	215.00
B213	166.00	2.00	1.00	166.00
B214	440.00	2.67	1.00	440.00
B215	267.33	2.17	2.00	534.67
B217	317.33	2.17	1.00	317.33
B218	317.33	2.17	1.00	317.33
			TOTAL	**2650.33**

Appendix F: LEED NCv2.2 Credit Scorecard

LEED for New Construction v 2.2
Registered Project Checklist

Project Name: Marymount University 26th Street Project

Project Address: 4763 Old Dominion Drive, Arlington, VA 22201

Yes	?	No		
33	13	23	Project Totals (Pre-Certification Estimates)	69 Points
SILVER			**Certified**: 26-32 points **Silver**: 33-38 points **Gold**: 39-51 points **Platinum**: 52-69 points	

Yes	?	No		
10	1	3	Sustainable Sites	14 Points

Yes	?	No			
			Prereq 1	**Construction Activity Pollution Prevention**	Required
1			Credit 1	**Site Selection**	1
1			Credit 2	**Development Density & Community Connectivity**	1
		1	Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation**, Public Transportation	1
1			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
1			Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel Efficient Vehicles	1
1			Credit 4.4	**Alternative Transportation**, Parking Capacity	1
1			Credit 5.1	**Site Development**, Protect or Restore Habitat	1
		1	Credit 5.2	**Site Development**, Maximize Open Space	1
1			Credit 6.1	**Stormwater Design**, Quantity Control	1
	1		Credit 6.2	**Stormwater Design**, Quality Control	1
1			Credit 7.1	**Heat Island Effect**, Non-Roof	1
1			Credit 7.2	**Heat Island Effect**, Roof	1
		1	Credit 8	**Light Pollution Reduction**	1

Yes	?	No		
3	2		Water Efficiency	5 Points

Yes	?	No			
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
	1		Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
1			Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
	1		Credit 3.2	**Water Use Reduction**, 30% Reduction	1

LEED for New Construction v 2.2
Registered Project Checklist

Yes	?	No				
3	5	9	**Energy & Atmosphere**			17 Points
Yes			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**		Required
Yes			Prereq 1	**Minimum Energy Performance**		Required
Yes			Prereq 1	**Fundamental Refrigerant Management**		Required

***Note for EAc1:** All LEED for New Construction projects registered after June 26, 2007 are required to achieve at least two (2) points.

Yes	?	No				
2	4	4	Credit 1	**Optimize Energy Performance**		1 to 10
				Credit 1.1	10.5% New Buildings / 3.5% Existing Building Renovations	1
			-->	Credit 1.2	14% New Buildings / 7% Existing Building Renovations	2
				Credit 1.3	17.5% New Buildings / 10.5% Existing Building Renovations	3
				Credit 1.4	21% New Buildings / 14% Existing Building Renovations	4
				Credit 1.5	24.5% New Buildings / 17.5% Existing Building Renovations	5
				Credit 1.6	28% New Buildings / 21% Existing Building Renovations	6
				Credit 1.7	31.5% New Buildings / 24.5% Existing Building Renovations	7
				Credit 1.8	35% New Buildings / 28% Existing Building Renovations	8
				Credit 1.9	38.5% New Buildings / 31.5% Existing Building Renovations	9
				Credit 1.10	42% New Buildings / 35% Existing Building Renovations	10
		3	Credit 2	**On-Site Renewable Energy**		1 to 3
				Credit 2.1	2.5% Renewable Energy	1
				Credit 2.2	7.5% Renewable Energy	2
				Credit 2.3	12.5% Renewable Energy	3
		1	Credit 3	**Enhanced Commissioning**		1
1			Credit 4	**Enhanced Refrigerant Management**		1
		1	Credit 5	**Measurement & Verification**		1
	1		Credit 6	**Green Power**		1

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Yes	?	No			
3	3	7	**Materials & Resources**		13 Points
Yes			Prereq 1	**Storage & Collection of Recyclables**	Required
		1	Credit 1.1	**Building Reuse,** Maintain 75% of Existing Walls, Floors & Roof	1
		1	Credit 1.2	**Building Reuse,** Maintain 95% of Existing Walls, Floors & Roof	1
		1	Credit 1.3	**Building Reuse,** Maintain 50% of Interior Non-Structural Elements	1
1			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
	1		Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
		1	Credit 3.1	**Materials Reuse**, 5%	1
		1	Credit 3.2	**Materials Reuse**, 10%	1
1			Credit 4.1	**Recycled Content**, 10% (post-consumer + 1/2 pre-consumer)	1
	1		Credit 4.2	**Recycled Content**, 20% (post-consumer + 1/2 pre-consumer)	1
1			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured	1
	1		Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured	1
		1	Credit 6	**Rapidly Renewable Materials**	1
		1	Credit 7	**Certified Wood**	1

Yes	?	No			
9	2	4	**Indoor Environmental Quality**		15 Points
Yes			Prereq 1	**Minimum IAQ Performance**	Required
Yes			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
1			Credit 1	**Outdoor Air Delivery Monitoring**	1
		1	Credit 2	**Increased Ventilation**	1
1			Credit 3.1	**Construction IAQ Management Plan,** During Construction	1
	1		Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
1			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
		1	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
1			Credit 6.1	**Controllability of Systems**, Lighting	1
	1		Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
1			Credit 7.1	**Thermal Comfort,** Design	1
1			Credit 7.2	**Thermal Comfort,** Verification	1
		1	Credit 8.1	**Daylight & Views,** Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views,** Views for 90% of Spaces	1

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Yes	?	No			
5			**Innovation & Design Process**		5 Points
1			Credit 1.1	**Innovation in Design:** Provide Specific Title	1
1			Credit 1.2	**Innovation in Design:** Provide Specific Title	1
1			Credit 1.3	**Innovation in Design:** Provide Specific Title	1
1			Credit 1.4	**Innovation in Design:** Provide Specific Title	1
1			Credit 2	**LEED® Accredited Professional**	1