

DENNIS V. WALTER JR. | CONSTRUCTION MANAGEMENT

PHASE 2 NEW BUILDING, JOHN TYLER COMMUNITY COLLEGE Midlothian, VA

FINAL REPORT

Thesis Advisor: Jim Faust

4/7/2010



Image courtesy of Burt Hill

[Special thanks to the Gilbane Project Team, Burt Hill, and John Tyler Community College]

Phase 2 New Building

John Tyler Community College, Midlothian Campus

Midlothian, VA

PROJECT TEAM:

Owner:

Virginia Community College
Systems

CM:

Gilbane

Architect:

Burt Hill

Civil Engineer:

Burgess and Niple

Structural Engineers:

Stroud Pence

MEP Engineers:

H.CYU Engineers

Telecommunications/Audio- Visual/Acoustics Engineers:

Shen Milsom Wilke

Cost Estimating Consultant:

Construction Consultants, Inc.

PROJECT OVERVIEW:

Function: Mixed Use Academic Building

Size: 61,000 SF

Height: 3 Stories

Construction Dates: May 2008 – October 2009

Delivery Method: CM @ Risk w/ GMP Contract

LEED® : Pursuing LEED® Silver Certification



STRUCTURAL SYSTEM:

Foundation: Reinforced concrete shallow spread footings, Below grade perimeter cantilevered concrete foundation walls, 4" ground floor slab-on-grade

Framing: Elevated slabs (4" lightweight 4000psi concrete over 1 1/2" x 20 gauge VLR composite deck) and roof deck (4" normal weight 4000psi concrete over 1 1/2" x 22 gauge type B composite deck) supported by typical W16 floor beams and W10 columns.

Façade: Masonry veneer backed up by metal stud and curtain wall glazing, CMU (stair and elevator towers), precast concrete and metal paneling w/ steel stud

MECHANICAL SYSTEM:

- (4) 12,500 CFM AHU's serving Laboratory, Library, Classroom, and others on North End
- (1) 3,750 CFM AHU serving Office/Admin area on South End
- (4) 80 Ton Modular Chillers
- (1) 675 GPM Cooling Tower
- (2) 170 GPM Multi-Zoned Gas Fired Hot Water Storage Heaters
- (2) 1,200 MBH Hydronic Boilers constructed adjacent to Chilled Water Plant

SUSTAINABLE FEATURES:

- Green roof to filter and absorb rainwater, and reduce heat island effect while insulating the building.
- Modular chillers in the mechanical room eliminates the use of oil for the primary cooling equipment in the building
- Recycled content used in building materials such as drywall, fly ash in the concrete, and carpeting
- Natural daylighting sources reduce electrical consumption
- Energy efficient glass and motorized sunshades control solar heat gain, and allow solar shading
- Thermostats in every office to maximize occupants thermal comfort and control

ELECTRICAL SYSTEM:

- 968.2 kW Total Connected Load
- 842.3 kW Total Demand Load
- (1) 150 kW Generator
- 277 V Majority of Lighting System

ARCHITECTURE:

The exterior of the building is a combination of brick, precast concrete accents, metal panels, aluminum windows and an aluminum framed curtain wall complementing existing buildings on the Midlothian Campus. The layout of the building is designed to accommodate the science department, a library, student lounge, bookstore, and multipurpose room. Science labs on the third floor are the driving force for the building shape. The second floor is the primary entrance of the building from the north, and houses the library. The first floor has an entry on the south to accommodate the newly added south parking lot and contains the bookstore, multipurpose room and the student lounge.

Dennis V. Walter Jr. | Construction Management

special thanks to Burt Hill and Gilbane for photos and data

e-Portfolio: <http://www.engr.psu.edu/ae/thesis/portfolios/2010/dxw5004/index.html>



Contents

Acknowledgements.....	5
Executive Summary.....	6
Project Overview.....	7
Client & Building Information	7
Project Delivery System	8
Project Team	9
Project Schedule Summary	10
Detailed Project Schedule	10
Project Location	11
Building Systems Summary.....	13
Introduction to Analyses.....	18
Constructability Challenges:	18
Analysis I – Brick Facade:	20
Problem Statement.....	20
Background	20
Research Method.....	21
Goal	21
Analysis	21
Quality Control Issues	27
Schedule.....	27
Cost	29
Conclusions and Recommendations	30
Analysis II – Roofing System:.....	31
Problem Statement.....	31
Background	31
Research Method.....	31
Goal	32
Master of Architectural Engineering Requirements	32
Analysis	32
Schedule.....	36
Cost	37

Conclusions and Recommendations	37
Analysis III – Electrical System:	39
Problem Statement.....	39
Background	39
Research Method.....	39
Goal	40
Analysis	40
Quality Control Issues	43
Best Practices	43
Conclusions and Recommendations	44
Summary and Conclusions	45
References	47
Appendix A: Project Schedule Summary.....	49
Appendix B: Detailed Project Schedule	51
Appendix C: Precast Panel Takeoffs.....	57
Appendix D: Panel Sizes Summary.....	61
Appendix E: Detailed Project Schedule – Alternative Exterior Façade	63
Appendix F: Detailed Exterior Façade Systems Cost Comparison	69
Appendix G: TPO “Cool” Roof Thermal Properties	71
Appendix H: Detailed Roofing Systems Cost Comparison	73

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Executive Summary

This final thesis report is a result of several analysis conducted over the course of the Spring 2010 semester-long Architectural Engineering capstone project. The subject of analysis is the Phase 2 New Building at the John Tyler Community College's Midlothian Campus in Midlothian, VA just outside Richmond. The Phase 2 New Building is the campuses' most recent and headline project under the Virginia Community College System. This building is part of a new green initiative taken on by the John Tyler Community College and is the first project to be LEED® rated for the Virginia Community College System.

This final report contains three analyses that investigate areas of specific quality and constructability issues associated with this project. The first analysis investigates a high-quality alternative exterior façade taking the place of a hand-laid masonry brick wall and the cost and schedule benefits that occur. The second analysis looks into an alternative roofing system to determine whether a more cost-effective and high-quality system can replace the green roof system and inverted roof membrane assembly while comparing the quality and LEED® benefits of each. The third analysis incorporates research into building transformers and the steps in properly and sizing a safely operating transformer.

It has been determined that, through the first analysis, an alternative architectural precast panel system in lieu of the hand-laid masonry brick wall can provide similar aesthetic quality based on the proper selection of thin brick cast into the concrete panels. Also, it compares similarly in costs, resulting in a \$15,883 reduction in upfront expenditure. Additionally, the building enclosure schedule can be reduced by 16 days and site congestion can be minimized.

The second analysis, dealing with an alternative roofing system, determined that a single-ply thermoplastic TPO "cool" roofing system can offer unique benefits to the owner, but may not stack up in comparison with the originally designed green roof and IRMA systems in terms of energy efficiency and potential LEED® credits. While the single-ply TPO "cool" roof investigated in this analysis is estimated to save \$269,300 in upfront costs, the system does not offer the same long-term energy efficiency benefits as the green roof, resulting in an estimated 37% increase in summer heat gains and 65% increase in winter heat loss through the compared roof systems. Also, the green roof potentially offers 4 to 10 additional LEED® credits beyond what the alternative "cool" roofing system could.

Finally, the third analysis dealt with research into the buildings electrical system transformer. This analysis is mainly research into the building transformer and the process for properly sizing the transformer device to safely handle the predicted building loads. This process involves communication between both the electrical design engineer and the engineer with the electrical power company providing the equipment. Through research, quality issues and best practices were determined for the design, installation and maintenance of the building transformer.

Project Overview

Client & Building Information

The 61,000-square-foot building is the first project in the Virginia Community College System to be registered under the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System. To become LEED® certified, a project must earn credits in key areas that promote human and environmental health, including sustainable site design, water savings, energy efficiency, materials selection, and indoor environmental quality.

The new building, which houses science laboratories, classrooms, an expanded library, a multi-purpose room, and additional commons space for faculty and students, was built to help the College continue to meet rapidly increasing demand for classes at the College. John Tyler Community College's Midlothian Campus, built in 2000, grew so quickly that the campus reached full capacity in 2005. In 2006, the Virginia General Assembly approved construction of the much-needed second academic building. Master plans for the Midlothian Campus eventually call for a bell tower, amphitheatre and possibly sports fields.

The Virginia Community College System had agreed on an original \$18.5 million guaranteed maximum price (GMP) contract that was within their budget, and contained an allowance for owner's contingency that would cover possible changes. In previous Midlothian Campus projects, the Virginia Community College System and the John Tyler Community College were not satisfied with the existing structures built; one of the existing buildings had ended in a legal case against a previous contractor due to leaky building enclosures and also had excessive and bothersome mechanical equipment noise and vibrations. The expected quality of this new building is a water tight enclosure, reduced mechanical noises and vibrations and a project that meets LEED® requirements. There safety requirements by the owner were keeping the students, faculty and public safe during construction, and Gilbane's extensive safety plan was adopted for this project to add additional safety measures.

Since this building is an educational facility on a college campus, there was a requirement set by the owner that substantial completion be prior to the start of a new fall semester. The sequencing of the building had to be planned in order to fulfill the occupancy requirement of a one month owner move-in prior to the new semester. In order for Gilbane to construct a building that the owner is satisfied with, they must produce a quality building with fully a functional, watertight exterior façade, achieve a LEED® rated status, have very minimal mechanical equipment noises and vibrations, and perform within their budgeted plans.

Project Delivery System

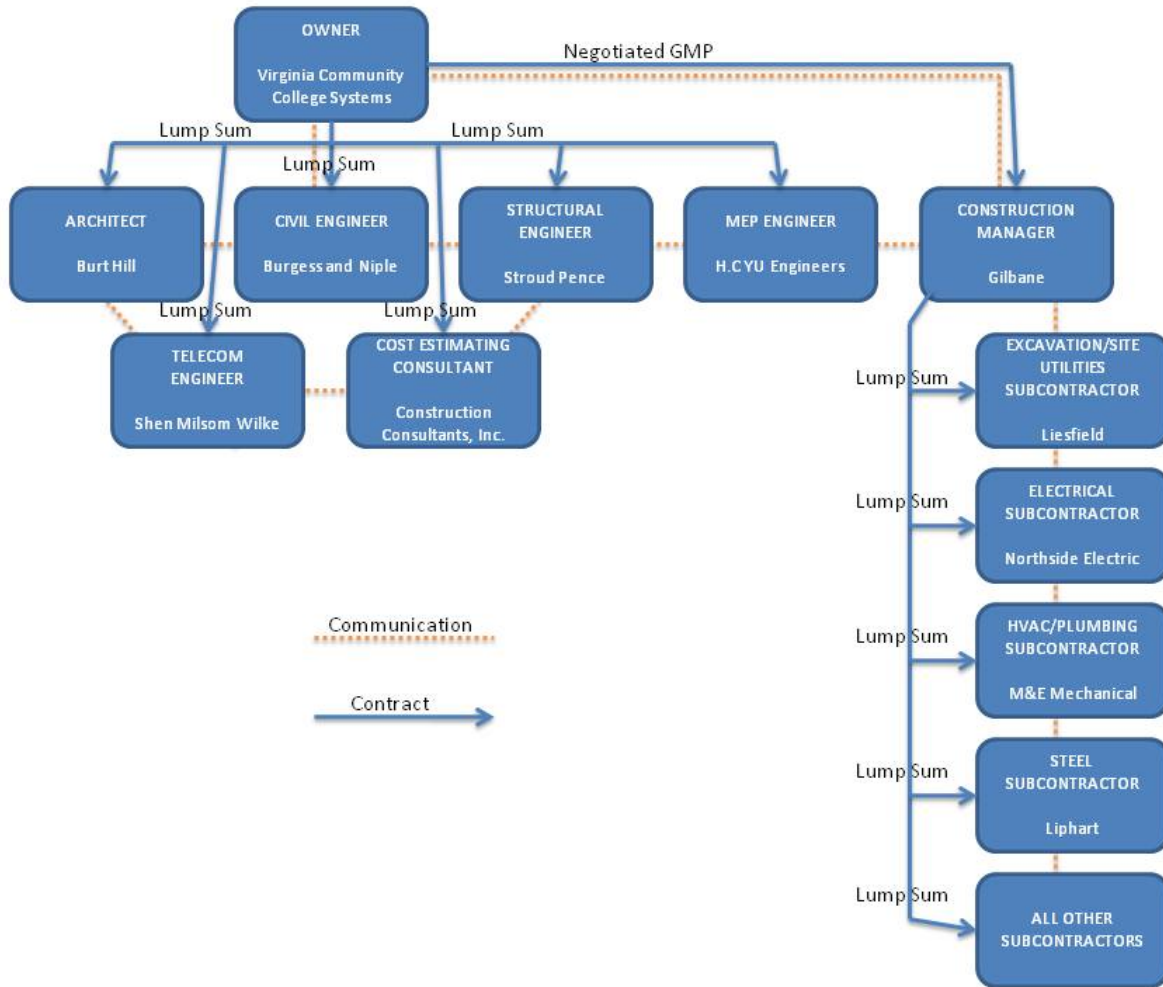


Figure 1, Project Delivery Diagram

The project delivery method is Construction Manager at Risk, with Preconstruction services as a separate prior contract with the owner. Gilbane was on board for preconstruction, and was awarded the contract based on a competitive bid since it is a public project. Gilbane’s contract as a construction manager is a negotiated GMP or guaranteed maximum price. The owner (Virginia Community College Systems) holds the remaining contracts with the architect and other project players as lump sum contracts. The subcontractors are also held at lump sum contracts with Gilbane. This is a typical arrangement of contracting. Gilbane communicates directly with the owner, all of the project team players, and each of the subcontractors. The communication between the architect, construction manager, and owner are the most prominent lines of communication for the overall project’s success followed by the lines of communication between Gilbane and the Subcontractors performing the work.

Project Team

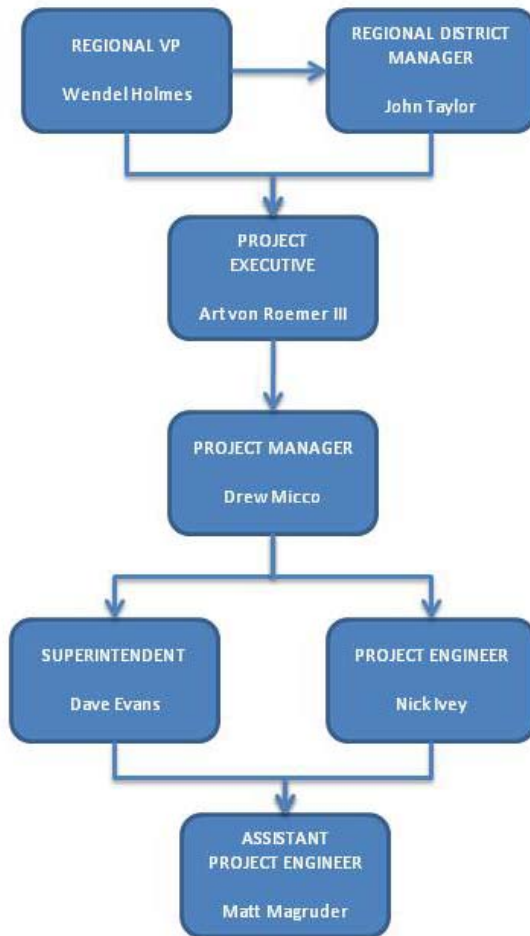


Figure 2, Construction Manager Staffing Plan

Gilbane’s project team is based out of the Mid-Atlantic Regional Office in Laurel, Md. The Vice President of the region is Wendel Holmes. The Richmond District Manager, John Taylor, had overseen the project kickoff and stays in contact with the owner and architect for relations and major problem solving purposes. The Project Executive in charge of the success of the project, including project delivery and client satisfaction is Art von Roemer III.

On-site, the Project Manager, Drew Micco, oversees the daily operations of the construction process to ensure that the building is being built on time and on budget. He also is a key player in solving daily issues that occur within the project. Working under the Project Manager are the Superintendent and Project Engineer. The Superintendent on the project is Dave Evans, who manages and coordinates all the subcontractors working so the project remains on schedule. The Project Engineer, Nick Ivey, is involved with many aspects on the project and assists the Project Manager and Superintendent with all of the daily operations on-site. The Assistant Project Engineer is Matt Magruder, who also assists with the daily operations on the construction site. Also, Brett Thompson, Office Engineer, assists with the project.

Project Schedule Summary

(Actual schedule evaluation is based on a detailed schedule provided by Gilbane. The dates have been slightly altered and simplified for the convenience of this report.)

The design for the Phase 2 New Building at John Tyler Community College began late in 2007 through 2008. Gilbane was brought on board early during the design phase to assist with preconstruction services. The preconstruction activities included assisting the A/E and Owner during the design to keep the building within budget. Gilbane provided the estimating and constructability reviews and value analysis. After a design was finished, the project was put out to bid to multiple trade contractors in bid packages and Gilbane was awarded the contract for construction manager. Construction began shortly after with the Notice to Proceed issued early in 2008. The final completion and handover of the Phase 2 New Building was set for October 30, 2009.

See **Appendix A: Project Schedule Summary**.

Detailed Project Schedule

(Actual schedule evaluation is based on a detailed schedule provided by Gilbane. The dates have been slightly altered and simplified for the convenience of this report.)

Construction sequencing is broken up by floors and areas of the building. After site clearing and excavation, work on the foundation and superstructure began. This is including all piers, footings, grade beams, below grade foundation walls, and slab on grade. MEP work begins rough-in and placement after excavation is completed and continues through the majority of the construction phase. Once the foundation activities were wrapping up, the structural steel and CMU walls began. Steel was able to be fabricated and delivered while the substructure was still being put into place to allow for a smooth transition of work. The masonry and curtain wall façade followed until the building was fully enclosed by the envelope and roofing system. The building skin was broken into sections based on column lines and exterior wall systems. Then, interior trades could begin installations starting with the ground level and working up to floor 3. Once the project was wrapping up with furnishings, equipment and was fully enclosed, the testing, balancing, and commissioning of the building systems could take place. The building had to be substantially complete to provide the owner with a month of move-in activities before the first day of classes on August 24, 2009.

Please see **Appendix B: Original Detailed Project Schedule**.

Project Location

The 117.2 acre site is located west of Charter Colony Parkway within the Midlothian Campus of John Tyler Community College in Chesterfield County, Midlothian, Virginia.

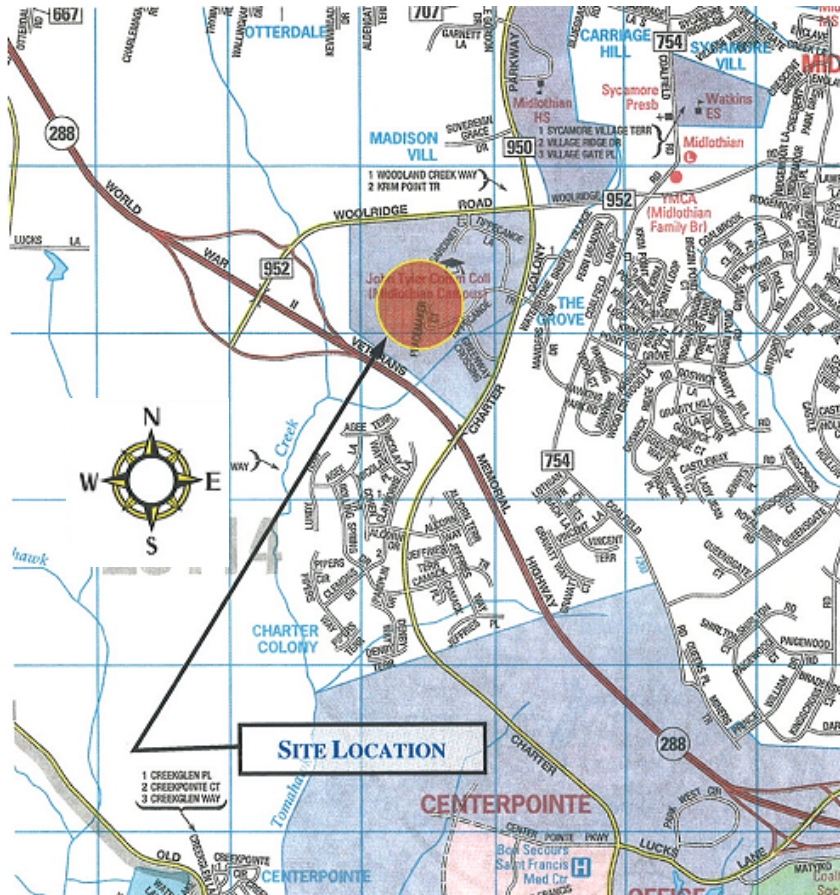


Figure 3, Site Location; Image extracted from ADC Street Map Book, Chesterfield County, Virginia.

The site includes several existing campus buildings and two small tennis courts directly to the north of the building location. The tennis courts will be relocated before construction begins, while the surrounding existing buildings remain open. The relocation of utilities is minimal for this project, because of the presence of existing campus buildings.

Because of the topography of the site and access to existing buildings, the Phase 2 New Building will have entrances to the south on the first floor and to the north on the second floor. The existing plaza connecting the two existing buildings to the east will remain, but will be extended to the west to provide access to the new building.

Only the central portion of the site was developed prior to construction. The campus property was occupied by three buildings connected by nearby access roads, parking lots, and lawn areas. Other parts of the site are heavily wooded and undeveloped. The southwest edge of the site is bordered by a wide power line right-of-way. The north and eastern property boundaries are Woolridge Road and Charter Colony Parkway, respectively.



Figure 4, Aerial view of site prior to construction



Figure 5, Rendering of project site after completion

Building Systems Summary

Work Scope	Yes	No
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 Excavation	x	

Checklist 1, Building Systems Summary Checklist

Structural Steel Frame

The building has typical elevated composite slabs (4" of lightweight 4000 psi concrete topping over a 1 ½" x 20 gauge VLR composite deck) supported by typical W16 floor beams and W10 columns. The roof is a composite slab (4" of normal weight 4000 psi concrete over a 1 ½" x 22 gauge type B composite deck) which is also supported by a typical W16 composite floor beam system.

The crane used to erect the structure was a 70 ton lattice boom crane with jib. The length was 175 ft including the 35 ft jib. The crane was on site for roughly five weeks.

Some of the challenges with steel erection were the sequencing of the pieces coming from the mill. Also, since this project is located in a seismic area in Virginia, the structural engineer had to add pieces of 1" flat plates which were connected in the field on the base of each column in the braced bay areas of the project. The flat plates had to be coordinated with each slab pour to be installed before the concrete was poured.



Figure 6, Steel Erection via Lattice Boom Crane

Cast in Place Concrete

The building sits on a 4", 3500 psi reinforced concrete slab on grade over a vapor retarder and 6" minimum depth of porous fill. The cast in place concrete is also used for the spread footings, column footings and foundation walls and is 4000 psi in these applications. For the elevated floor slabs, a 4" lightweight composite 4000 psi concrete is poured over the metal decking. The roof slab is a 4" normal weight 4000 psi concrete poured over the metal decking. The concrete was placed via pump truck for all of the foundations, slab on grade, and elevated slabs.

Precast Concrete

Some precast concrete was used at the parapet tops and for exterior window sills; however, the building does not contain of any major precast concrete paneling. The precast coping was placed using a boom truck.

Mechanical System

The building's mechanical room is located on the first floor on the northwest end of the building near the loading dock area. The building's five air handling units are located on the roof of the building. The Laboratory, Library, Classrooms, and other areas on the north end of the building are serviced by four (4) 12,500 CFM air handling units, while the remaining Offices and Administration areas on the south end of the building are serviced by one (1) 3,750 CFM air handling unit. The building is also serviced with four (4) 80 ton modular chillers. These chillers have adjustable frequency drives on compressors and sit on magnetic bearings to greatly reduce sound and vibration. The entire building is on a variable air volume (VAV) system. There is a 675 GPM cooling tower located on the roof and has a low noise fan feature. The building has two (2) 170 GPM multi-zoned gas fired hot water storage heaters for hot water. Also, two (2) 1,200 MBH hydronic boilers are constructed adjacent to the chilled water plant to service the building's heating.

The building is serviced with a wet pipe fire protection sprinkler system with pre-action risers servicing the upper floors. It is in accordance with NFPA and local fire codes. The fire stand-pipe connection is on the northwest side of the building near the loading dock area.

Electrical System

The main electrical service feeder enters from a Dominion Power pad mounted transformer into the first floor electrical room in the north end of the building. The emergency power comes from a 150kW generator equipped with an 8-hour operation fuel tank located next to the transformer on the north side of the building. The service is 3 Phase, 5 Wire, 480/277 V with a 2500A Main Switchboard.

Masonry

The exterior walls contain brick and CMU backup in some locations. The entrances to the building are enclosed with large scale ground-faced concrete masonry units. They provide a strong contrast to the predominantly brick masonry building.

Curtain Wall

The curtain wall on the building exists in several locations. It includes a three-story monumental stair on the south side of the building. On the north side, there is two-story curtain wall covering the entrance

to the existing campus upper plaza on the second floor with an open breakout space on the third floor. Modular placement using a snorkel lift was used during the installation of the curtain wall.



Figure 7, Brick and Masonry Facade with Curtain Wall

Support of Excavation

The building pad was mainly excavated and stepped back at a 45-degree angle to allow for soil retention and ease of access around the perimeter of the excavation. The large structural retaining wall on the north side of the building on the ground floor level required dead-men and a kicked back excavation for formwork to be built around the wall and supported during the pouring and curing of the concrete.



Figure 8, Support and forming of north retaining wall

Green Roof

The building is covered with roughly 8,000 SF of green roofing. The green roof was placed on the roof in layers. The roof deck needed to be reworked to meet the roofing manufacturer's flatness requirement. A hot rubberized asphalt waterproofing membrane was installed over the concrete roof deck followed by a modified protection sheet. Then, two layers of 2" extruded polystyrene insulation board was added over the modified protection sheet. A drainage mat was laid over the insulation board. Then, the final growing medium was installed over the drain mat surface. Walkways were also installed around the green roof areas for mechanical systems access and green roof maintenance.



Figure 9, Green Roof Installation



Figure 10, Green Roof Plantings

LEED® Certification

Gilbane has worked closely with the Architect (Burt Hill), MEP Engineer (H.CYU), Structural Engineer (Stroud Pence), Civil Engineer (Burgess and Niple), and Owner (Virginia Community College Systems and John Tyler Community College) throughout the design and construction phase to ensure that the project remain on track to receive the project goal for a LEED® Certification, striving for LEED® Silver.

The project is currently on track to receive a LEED® Certified rating. The project has potential to reach the Silver rating. A Silver rating is achievable if several of the possible additional points are achievable. The building is currently under review for the possible additional points, and a LEED® checklist and plan has been in place since the project's beginning by Gilbane. The building is pending review of credits for Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design. The building may also receive an additional point after one year of operation when the contracted enhanced commissioning agent performs commissioning review of the building systems.

Introduction to Analyses

Constructability Challenges:

Through-Wall Flashing

The construction detail of the through-wall flashing, which appear at brick façade edges on shelf angles and around windows and sills, was one of the most problematic constructability issues. The drip edge termination was detailed and specified by the architect to be stainless steel. The stainless steel detail has an exposed metal drip edge which has typically been found to be aesthetically unpleasing in the past. Also, the installer had tolerances affecting the aesthetics and length of the exposed metal which, once installed, can be extremely costly to remove because cutting is nearly impossible.

The CM decided to hold a meeting to discuss the practicality of this detail, and proposed changing the flashing and drip edge material to be flexible rubber which would ease the constructability and be more aesthetically pleasing. There was a mock-up done of the drip edge detail at a typical sill location. The flexible rubber material was then accepted for use where the stainless steel was originally called for.

This issue was solved prior to any installations and the mock-up was successful in determining the proper detail of the through-wall flashing and drip edge.

Vapor Barrier

Because of the water leakage problems on the Midlothian Campus' existing building facades, the vapor barrier on this building was a major constructability problem. The typical Tyvek vapor barrier was deemed to be unsatisfactory and low budget for this building so the project called for a fluid applied vapor barrier to be applied over the exterior sheathing of the building. The drywall contractor was contracted to perform this. The specs called for applications to be applied at a 120-mil (3.0mm) wet film thickness. The drywall contractor was told by the manufacturer of the fluid applied vapor barrier that rolling the material onto the sheathing would provide acceptable thickness. The project team soon discovered that rolling the vapor barrier was not the correct means of application. The problem was discovered when the product manufacturer's representative did an inspection and found the thickness to be insufficient. A section of wall that was 95% completed with brick veneering had to be torn down to correct the issue.

To solve this issue, the CM brought in every contractor whose scope of work dealt with the building envelope as well as the product manufacturer's representative. They discovered that the specs were calling for way too much material. The CM wrote an RFI and it was accepted to bring the wet film thickness down to 60-mils. The brick mason had to remove the area of wall which they had already completed the brick veneer on. The drywall contractor had to hire a painter to spray on the material at the correct thickness. The product manufacturer's representative inspected the sprayer and the spray-on application before accepting the new application method. The project team had developed an inspection protocol for every area of the building as it became available for the vapor barrier application. The drywall contractor had to pay for the brick mason's time for removing brick on the North elevation which was completed with incorrect application thicknesses.

The project team learned that a benchmark inspection for the first application of the vapor barrier should be completed to determine that the material was being installed correctly at the specified thickness. The schedule was slightly affected due to the inspection criteria, and a recovery schedule was compiled and followed for completing the building envelope on time.



Figure 11, Installation of Vapor Barrier



Figure 12, Vapor Barrier over Exterior Sheathing



Figure 13, Brick Veneer being installed over Vapor Barrier

Analysis I – Brick Facade:

Architectural Precast Concrete Wall Panels vs. Masonry Brick Veneer

Structural Breadth

Problem Statement

The hand-laid utility brick façade is a very common exterior wall type, however caused several problems on site with the detail of the through-wall flashing and drip edge, as well as the application of a spray-on fluid applied vapor barrier. This caused several schedule delays, and had potential for coordination and site logistic issues. Because the exterior enclosure milestone was required to begin interior fit-outs, accelerating the façade construction would keep the interior finishes from being delayed. Using an alternative to the masonry brick veneer such as architectural precast concrete panels may offer the same aesthetic quality and functional performance while increasing the speed of construction.

Background

A hand-laid brick exterior wall system requires a high amount of detail and can be a complex wall system to install. The brick wall may also require a large amount of scaffolding and area near the building envelope during the installation process. Precast systems can eliminate the need for a mortar station and constant re-stocking of brick for installation. There are a large amount of workers required to keep the brick installation moving along, which increases the need for safety and coordination of manpower.

Precast exterior facades reduce labor costs and installation time, despite generally more expensive off-site prefabrication costs. The majority of preparation for a precast façade can be done off-site in a climate controlled environment which can offer a high level of quality control. Additionally, a precast brick exterior façade can take the place of each individual part of the wall, acting as an entire wall system, and can reduce the number of detailing issues and installation issues that could occur in the field.

Some drawbacks to precast wall systems are that they are normally less flexible in design and aesthetic quality compared to a hand-laid brick wall. This means the proper selection of a system which can offer a high level of aesthetic quality is important. The design for the Phase 2 New Building required a match of the existing campus features with an emphasis on a quality appearance and an exceedingly watertight enclosure.

The joints between the precast panels and exterior curtain walls require close attention and quality control. Precast systems have control joints between the panels, which require quality control inspections in the field during construction. To ensure these joints are properly closed with a quality seal, a successful mock-up would need to be constructed and tested for watertight assurance and quality aesthetic appeal.

Additionally, the precast wall panels will change the load to the structure which means checking the existing structure is important, and re-sizing the members might be necessary. The detail of connections to the exterior beams will need to be designed.

Research Method

Research began with gaining a better understanding of different precast brick wall systems available. This is conducted by studying literature and case studies of different systems. Once the appropriate system has been chosen for use and panel sizes are determined, structural calculations will be completed to determine if the precast system is a feasible option, or if the structure would need to be re-sized due to an increased load. A detail of the typical connection at exterior beams will also be determined.

Cost and schedule implications will be determined based on the unit cost of the precast system and erection times. Finally, quality control issues of the selected precast system will be discussed to determine if the precast system can offer similar or better quality than the traditional hand-laid exterior brick wall system.

Goal

The goal of this analysis will be to select an appropriate architectural precast wall system which can offer similar aesthetic quality and watertight functional quality as a hand laid exterior brick wall system. The structural implications will be determined through structural calculations of the load applied to the exterior composite beams connected to the precast panels. This analysis will also determine the resulting cost and schedule implications.

Analysis

To begin the analysis, research had been conducted into appropriate architectural precast wall systems. It was important to select a system that can reduce the number of through wall flashing detailing issues and installation issues that could occur in the field. Because the project called for a fluid applied vapor barrier applied over the exterior sheathing of the building which caused schedule delays, it was also important to select a system that eliminated the need of a fluid applied vapor barrier and exterior sheathing. The following criteria were used for the selection of an appropriate system:

- High Quality appearance
- High weatherproof performance
- Cost-Effective
- Reduced construction schedule
- Proximity of factory to project site

After considering the above criteria in selecting the appropriate system, the following product was selected for use in this analysis.

SlenderWall, by Easi-Set Industries, met all of the mentioned criteria. It is an architectural precast concrete and steel stud panel wall system which composes of an exterior surface of thin architectural

brick veneer cast into 2-inches of high-strength reinforced architectural precast concrete. The inside surface of the panel is composed of 16 gauge, 6-inch galvanized steel studs vertically spaced at 2-foot centers. The architectural concrete is connected to the steel-stud frame with a connection system utilizing insulated, stainless-steel welded Nelson shear stud anchors. This panel's construction as a whole replaces brick veneer, vapor barrier, exterior sheathing, and exterior metal studs.

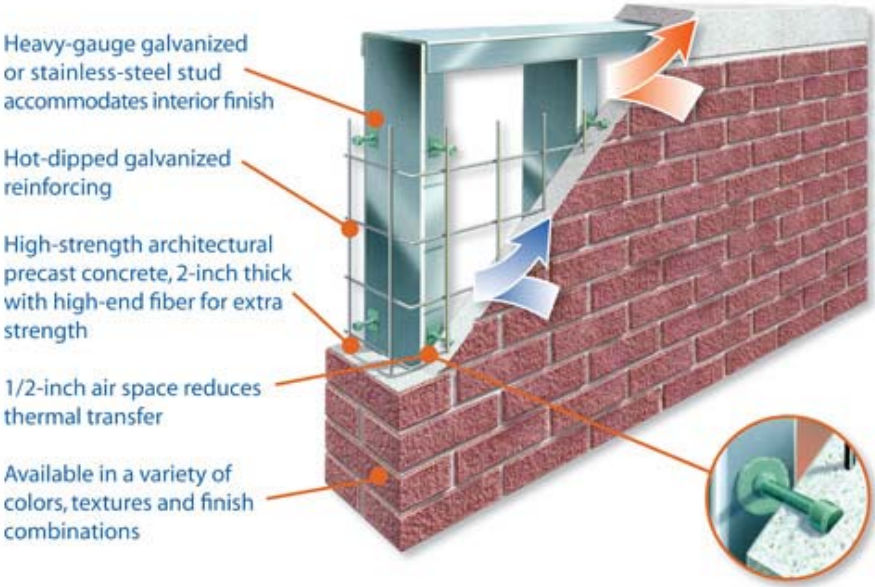


Figure 14, SlenderWall construction, from manufacturer's website <http://www.slenderwall.com>



Figure 15, Epoxy coated, stainless-steel welded Nelson shear stud anchors, from manufacturer's website <http://www.slenderwall.com>

After selecting the SlenderWall product, the panel sizes and layout on the building was first determined. Then a typical exterior beam supporting the exterior precast panel system in one of the heavier design loaded areas of the building will be structurally analyzed taking into account the panel weight. The most

panel load per lineal foot occurs on the third level beams because the second floor story height of 16-feet is the largest; making the second floor panels supported by the third floor beams the heaviest load by the panels.

Determining Panel Sizes

In consultation with the manufacturer of the SlenderWall panel system, and the use of Autodesk Revit, panel sizes and orientations were determined. The orientation of horizontal panels hung from the spandrel beam of the floor above has been determined to best suit the Phase 2 New building. It is recommended that panel sizes be constructed as large as possible, due to costs being on a fixed “per piece basis”. According to the manufacturer, the most economically sized panels are generally 10-feet by 35-feet. Additional shipping fees generally occur when panels larger than 13-feet by 40-feet are being delivered due to delivery truck size restrictions. It is not recommended by the manufacturer to exceed 13-feet by 40-feet panels. Because story heights on the Phase 2 New building are over 13-feet (1st and 3rd story height is 14-feet, 2nd story height is 16-feet), the limiting length of the panels will be 13-feet wide in the horizontal direction.

See **Appendix C: Precast Panel Takeoffs.**

The following table lists a summary of panels per elevation determined for this project:

Panel Summary				
Elevation	QTY	Total SF	Unit Wt (PSF)	Panel Wt (lbs)
South	52	6052.8	30	181583
East	17	2141.7	30	64250
North	26	3972.50	30	119175
West	27	4236.64	30	127099
TOTAL	122	16404	30	492108

Figure 16, Summary of panel sizes per elevation

See **Appendix D: Panel Sizes Summary.**

Connection Detail

Changes to the exterior wall detail will have to be made when incorporating the alternative SlenderWall system. The change will require batt insulation to be installed within the steel framing attached to the SlenderWall panels, and the rigid insulation originally designed in the hand-laid brick system to be removed. The new detail shown below is a section of the typical connection made to the composite exterior spandrel beams provided by the manufacturer. A steel plate or angle is factory welded to the spandrel beam and bolted connections are made by the SlenderWall erection team as the panel is set in place.

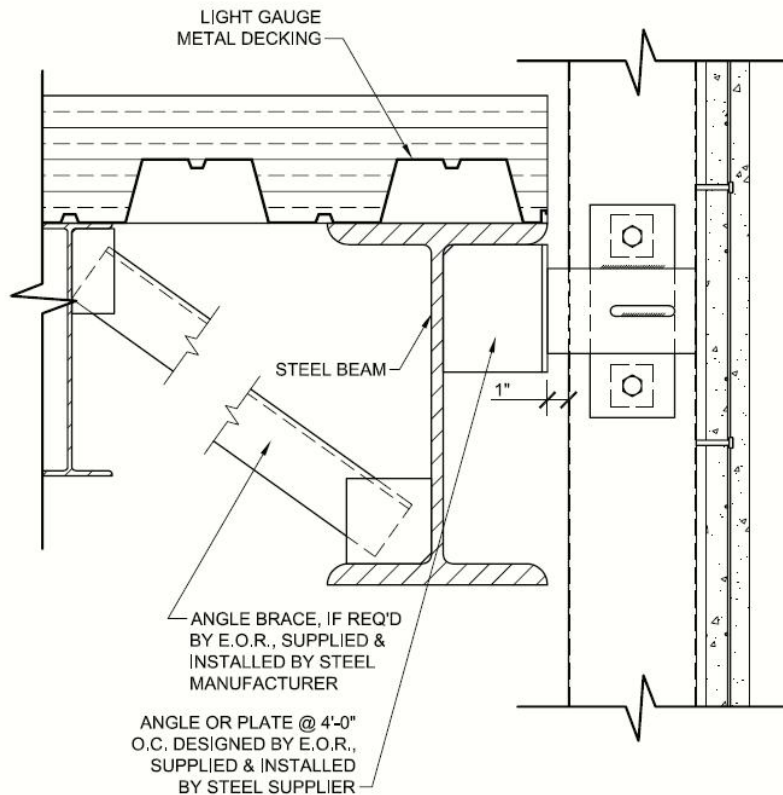


Figure 17, Standard connection detail at typical spandrel beam, from manufacturer's website <http://www.slenderwall.com>

Structural Implications

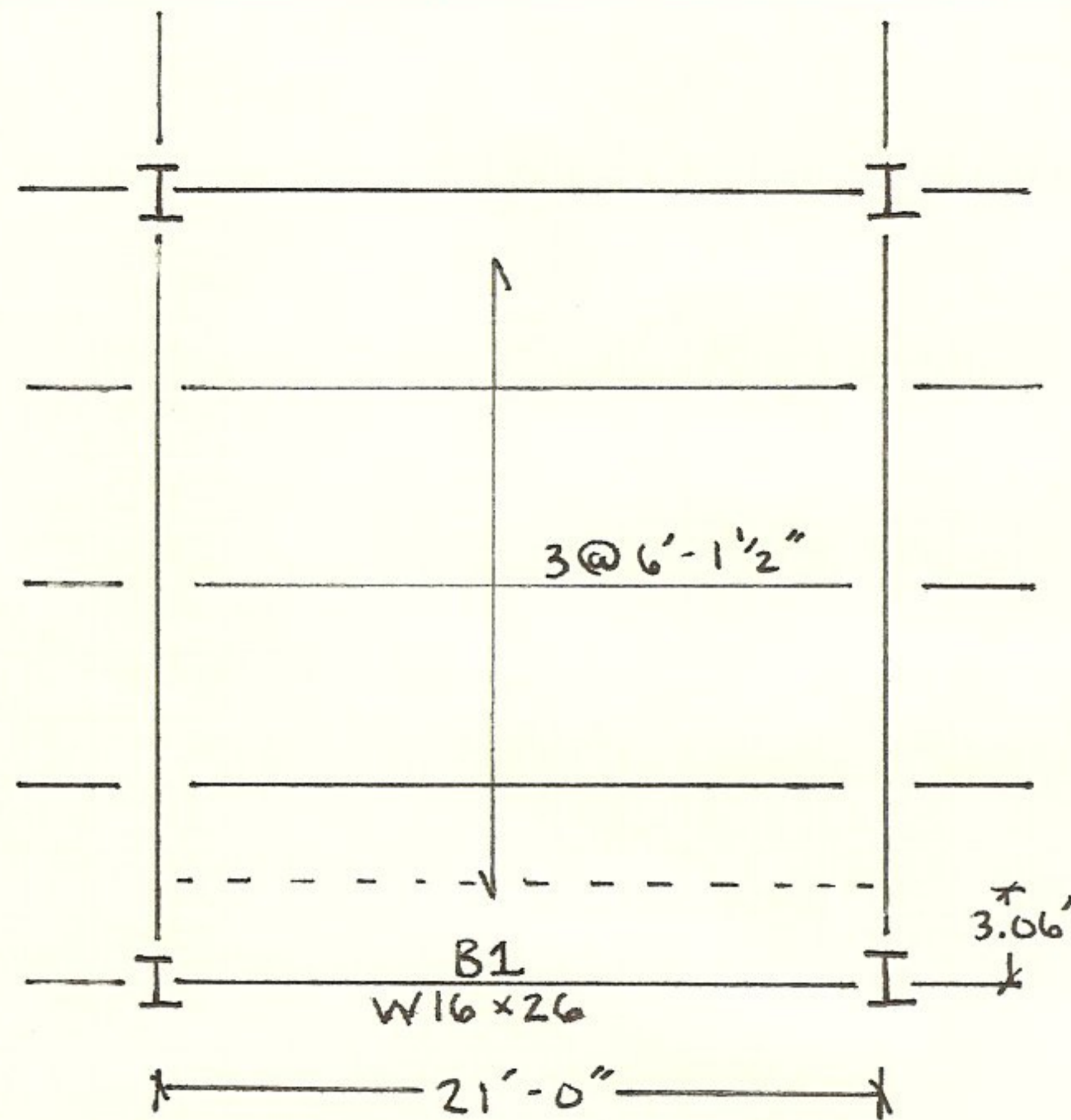
When a new exterior building enclosure system is proposed over the originally designed system, it is important to take into consideration the structural implications this change has on the structural design. Calculations can determine whether the size of the structure is sufficient or if it needs to be increased based on the alternative system weight.

The SlenderWall system is given to be 30 PSF unit weight, and using the second floor story height of 16-feet the system imposes 480 lb per lineal foot over the supporting exterior composite beams at the floor above. Calculations that follow are for a typical 3rd level beam spanning 21 ft supporting the weight of panels on the second floor. It is understood that window units to be installed into the panels will be of lesser unit weight than the wall system, but to be conservative, the panels will be considered solid with no openings.

After performing the calculations for checking the composite beam design and deflection over a typical W 16 x 26 composite beam, it is determined that the beam is adequate in carrying the load of the precast panels. Therefore, it will be assumed by this structural analysis that no changes to the structural system will need to be implemented for supporting the weight of the SlenderWall precast panel system.

Structural Breadth Calculations are as follows:

STRUCTURAL CALCS: CHECK W16x26 DESIGN & DEFLECTION



STORY HEIGHT = 16'

TRIBUTARY WIDTH = 3.06'

4" LW 4000 PSI
COMPOSITE SLAB

1 1/2" 20 GA VLR
METAL DECK

3/4" SHEAR STUDS

DESIGN OF B1

LOADS:

DEAD

$\text{SUPERIMPOSED} = 10 \text{ (PSF)} (3.06') = 30.6 \text{ lb/ft}$
 $\text{SLAB} = 34 \text{ PSF} (3.06') = 104 \text{ lb/ft}$
 $\text{PANEL} = (30 \text{ PSF}) (16') = 480 \text{ lb/ft}$

* FROM VULCRAFT DECK CATALOG

TOTAL DEAD LOAD = 615 lb/ft

LIVE

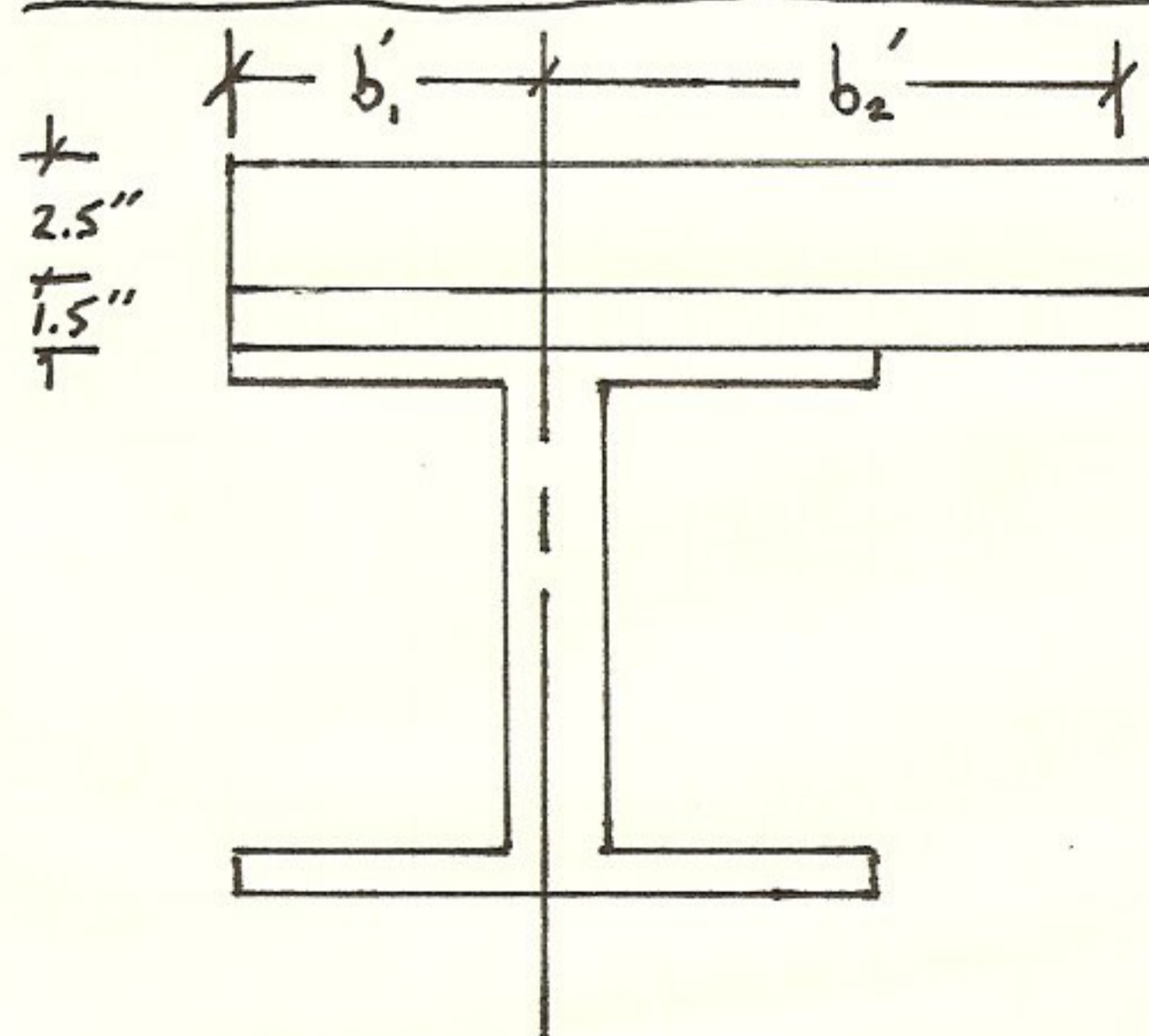
$\text{OFFICES} = (50 \text{ PSF} + 20 \text{ PSF (PARTITIONS)}) (3.06') = 214 \text{ lb/ft}$

FACTORED LOAD

$W_u = 1.2 \text{ (DEAD)} (615) + 1.6 \text{ (LIVE)} (214) = 1080 \text{ lb/ft} = 1.08 \text{ kips/ft}$

$M_u = \frac{1.08 (21')^2}{8} = \frac{W_u l^2}{8} = 59.5 \text{ k}$

DESIGN OF COMPOSITE ACTION BEAM



EFFECTIVE FLANGE

$b_1 = 5.50 \text{ in}$

$b_2 \leq \frac{21'}{8} = 2.63' \leftarrow \text{CONTROLS}$
 $\leq \frac{6.125'}{2} = 3.06'$

$b_{eff} = 2.63' + \frac{5.5''}{12} = 3.09 \text{ ft} = 37.1 \text{ in}$

DESIGN OF COMPOSITE ACTION BEAM CONT'D

ASSUME $a = 1 \text{ in.}$

$$y_2 = 4'' - \frac{1}{2}'' = 3.5 \text{ in.}$$

FROM AISC 13TH EDITION, TABLE 3-21:

$$\frac{3}{4}'' \text{ SHEAR STUD} \rightarrow Q_n = 17.2 \text{ kips}$$

CHECK W16 x 26 : TABLE 3-19:

PNA @ 7 ← TO LIMIT COMPRESSION IN CONCRETE

$$\phi M_n = 234 \text{ k} > M_u = 59.5 \text{ k} \quad \therefore \text{OK } \checkmark$$

$$\Sigma Q_n = 96 \text{ k}$$

CHECK ASSUMPTION $a = 1 \text{ in.}$:

$$a = \frac{96000}{(0.85)(4000)(37.1)} = 0.769 \text{ in} < 1.0 \text{ in} \quad \therefore \text{OK } \checkmark$$

$$\# \text{ OF STUDS} = \frac{96}{17.2} = 6 \text{ SHEAR STUDS}$$

CHECK DEFLECTION IN W16 x 26 :

CONSTRUCTION LOAD :

$$W = W_{D \text{ CONST}} + W_{L \text{ CONST}}$$

SLAB: $W_{D \text{ CONST}} = 0.104 \text{ k/ft}$

20 PSF LL: $W_{L \text{ CONST}} = 0.0612 \text{ k/ft}$

$$W = 0.104 + 0.0612 = 0.165 \text{ k/ft}$$

TABLE 1-1: $I_x = 301 \text{ in}^4$

$$\Delta_{C-LL} = \frac{5 W l^4 (12)^3}{384 E I} = \frac{5 (0.165) (21')^4 (1728)}{384 (29000) (301)} = 0.0827 < \frac{l}{360} = \frac{21(12)}{360} = 0.7 \text{ in} \quad \therefore \text{OK } \checkmark$$

LIVE LOAD :

$$W_L = 0.214 \text{ k/ft}$$

LOWER BOUND: $I_{LB} = 499 \text{ in}^4$ ← TABLE 3-20

$$\Delta_{LL} = \frac{5 (0.214) (21')^4 (1728)}{384 (29000) (499)} = 0.0647 < 0.7 \text{ in} \quad \therefore \text{OK } \checkmark$$

TOTAL LOAD :

$$W = W_D + W_L = 0.165 + 0.214 = 0.379 \text{ k/ft}$$

$$\Delta_{\text{TOTAL}} = \frac{5 (0.379) (21')^4 (1728)}{384 (29000) (499)} = 0.251 \text{ in} < 0.7 \text{ in} \quad \therefore \text{OK } \checkmark$$

Quality Control Issues

Because the previous buildings on the John Tyler Midlothian Campus had extreme weathering and waterproofing issues, as well as problems with the drip edge details and fluid applied vapor barrier, quality control of the exterior wall system is very important to look at. When choosing the proper precast exterior wall system to replace the hand laid utility brick, functional and aesthetic quality is a top priority in this case.

Traditional hand laid systems offer traditional and proven quality in construction, however the Slender Wall Architectural Precast Concrete and Steel Stud Building Panel offers Second Nature Architectural Precast Concrete Brick. This precast concrete brick is Class "A" and is approved by historical societies and architects for use of high profile architectural projects. The benefit to this system is there are no leaking brick joints, because the brick is cast into the precast concrete section. Slender Wall manufacturers work closely with architects, owners and designers to develop custom samples and designs to meet the proper quality requirements of the project. Successful mock-ups are made prior to installing the panels, and this is done to the architect's requirements before accepting the final design of the system.

The Slender Wall system also provides a 100% thermal-break/air barrier. The 2-inch of concrete facing is secured to the steel framing by epoxy-coated stainless-steel Nelson anchors. This provides the concrete with response to thermal gradients independently because a ½ inch air space is left between the precast concrete and the stud frame. This provides a reduction in thermal transfer which could provide additional reduction in heating and cooling costs.

Joints and reveals are areas of big concern for leakage and infiltration of moisture between the panels. The SlenderWall is designed with a ¾-inch joint between panels and reveals can vary in size according to the design needs. The joint between panels can be finished with ¾-inch backer rod covered by a ½-inch layer of caulking to provide a watertight seal. A close quality-control inspection of these joints would need to occur during the construction of the panels in order to guarantee a high quality seal is maintained.

Schedule

The original exterior building enclosure schedule had duration of 79 days. The hand-laid system required exterior studs, exterior sheathing, and the fluid applied vapor barrier to be installed before the masonry contractor could begin setting the hand-laid brick. Additionally, the original building skin schedule required the exterior skin to be installed while the 2nd floor composite slab was being poured and steel framing was still being completed. This causes site congestion and logistical issues when planning material deliveries and unloading.

When incorporating the SlenderWall system into the building skin schedule, durations were obtained from the SlenderWall manufacturer. Panels are typically installed using the precast contractor's crane, which means the precast panels can be erected without major crane interruptions. The manufacturer of SlenderWall estimates an average of 19 minutes from truck to setting and installing per panel. Also,

items such as exterior studs, sheathing, and vapor barrier could be eliminated from the schedule because the SlenderWall already contains these items.

Based on the panel layout and sizes determined in this analysis and utilizing the durations and adding additional time for finishing the joints and caulking, a new schedule for the building enclosure was created. The same erection pattern as the original schedule was incorporated when planning the new schedule, which starts on the western end of the North elevation and moving counter-clockwise around the building.

See Appendix E: Detailed Project Schedule –Alternative Exterior Façade.

The new schedule for the building skin is estimated to take only 48 days, as compared to the original 79 day schedule. This allows for the building skin to begin working a full week after the roof slab deck is poured, which is one of the last activities of the superstructure. This will allow the site congestion to be minimal between trades, and the precast erection crane will have better mobility around the site.

Panel Installation Times			
Elevation	QTY	Output/Panel (min)	Duration (days)
South	52	19	3.00
East	17	19	1.00
North	26	19	2.00
West	27	19	2.00

Figure 18, Installation durations per elevation

Since the building enclosure activities can begin after the superstructure is nearly complete, it is important to look at how many days are saved using this new alternative system. The building skin is not on the critical path for the project, because the Superstructure, MEP and Interior Finishes are the driving force to finish the project in time. However, time can be saved on the building skin allowing the building to be enclosed earlier which reduces the impact of overall schedule delays if problems during the building enclosure schedule were to occur. Site congestion is also minimized by this alternative system schedule. It was determined that the SlenderWall panel system can save 16 days on the overall building skin schedule when compared to the hand-laid system. This is taking into account that the building skin can be started after the superstructure with the SlenderWall system alternative, instead of during the pouring of the elevated floor slabs.

Building Skin Schedule Comparison			
System	Start	Finish	Duration (days)
Hand-Laid System	7/29/2008	11/14/2008	79
SlenderWall System	8/25/2008	10/29/2008	48
Total Days Saved			16

Figure 19, Comparison of schedules

Erection of the SlenderWall panels are plumbed and aligned immediately after the crane unhooks utilizing a lift and release system. The panels are delivered and stored on site prior to the day of erection.



Figure 20, Image of SlenderWall being erected on a project, from manufacturer’s website <http://www.slenderwall.com>

Cost

The cost of implementing the SlenderWall system as an alternative to the hand-laid system is an important factor in determining whether to utilize this alternative for the Phase 2 New Building. The material and labor costs associated with the SlenderWall are determined to be \$40/SF, based on the manufacturer’s cost data. When determining the cost of the hand-laid brick wall system, the cost of the exterior studs, exterior sheathing, fluid applied vapor barrier, utility brick masonry, miscellaneous finishing, and precast window and opening sills were all taken into account because the SlenderWall system includes and replaces all of those items.

Based on contractor’s data and discussions with the masonry contractor, the original hand-laid brick wall system cost roughly \$41/SF for the entire wall assembly. This is relatively close to the cost of the SlenderWall system. A comparison was done to determine the savings when utilizing the SlenderWall alternative system. Savings of roughly \$15,883.00 were estimated when implementing SlenderWall as an alternative exterior façade wall system.

System Cost Comparison				
Wall System	QTY	Unit	Unit Cost	Cost
Hand-laid Brick Wall	16404	SF	\$40.97	\$672,043
Precast SlenderWall	16404	SF	\$40.00	\$656,160
Cost Savings				\$15,883

Figure 21, Cost comparison between systems

See **Appendix F: Detailed Exterior Façade Systems Cost Comparison.**

Conclusions and Recommendations

Based on the information presented in this technical analysis, it has been determined that implementing the alternative SlenderWall architectural precast concrete and steel stud panel wall system in lieu of the hand laid brick system would be a beneficial change to the exterior façade. The SlenderWall system allows the building skin schedule to be reduced by 16 days and begin after the superstructure is completed. When compared to the original schedule with the hand laid brick, which starts while the second floor slab is still being poured, the alternative SlenderWall system will greatly decrease site congestion during the superstructure phase. Also, the decision to use the SlenderWall system has been determined to reduce upfront costs by \$15,883 when compared to using hand-laid brick.

The quality of the SlenderWall precast system would be the other determining factor in the decision to implement this alternative system to the hand-laid brick. While SlenderWall can offer high quality architectural precast brick to match the aesthetic requirements of the architect, it would still be viewed by some to have a “precast” look to the finished product due to joints between panels. However, a successful mock-up of the system can be completed before installation, and closely monitored installation and quality control checks on the finishing of the joints can assure a quality finish. Additionally, the SlenderWall system would offer an exterior enclosure with no leaking brick joints, where the hand laid brick system may have imperfections in the mortar seal between individual bricks.

The decision to implement the alternative exterior façade system would ultimately be up to John Tyler Community College. Depending on the acceptance of quality and aesthetic appeal, the SlenderWall system will provide a 16 day reduction in building skin installation while minimizing site congestion during the superstructure phase and offer an estimated \$15,883 in upfront cost savings.

Analysis II – Roofing System:

TPO “Cool” Roof vs. Green Roof System

M.A.E. Requirements

Problem Statement

The roof system installed on the Phase 2 New Building consists of 19,600 SF of an inverted roof membrane assembly (IRMA) ballasted roof system, with 8,300 square feet of the IRMA covered with an extensive green roof system. An alternative system could be selected with similar thermal properties. There are less expensive roofing alternatives that can potentially provide similar requirements for LEED® and can result in upfront cost savings. The different systems available include a wide variety of green roof systems and also lighter “cool” white roof membranes.

Background

Green roofing systems such as the one installed on the Phase 2 New Building provide many potential benefits in terms of energy and conservation. They provide a substantial amount of storm water runoff control by absorbing the rainwater in the soils for the plantings. They reduce the heat-island effect contributed by buildings with dark roofing membranes. They create a wildlife habitat and improve the aesthetic environment. Also, they add potential energy saving benefits through the reduction of heat transfer through the roof of the building.

There are many alternative and inexpensive roofing systems on the market that can provide excellent thermal insulation and can reduce energy costs as well as minimize impacts on the environment. An alternative roofing system such as a single-ply membrane “cool” roofing system can potentially offer similar requirements for LEED® than that of a green roof.

Thermoplastic single-ply roofing membranes are one of the fastest growing roofing systems that offer performance and installation advantages over green roof systems. They can offer a high heat-reflective and energy efficient roofing surface, and provide exceptional resistance to ultraviolet, ozone and chemical exposure. They can offer a reduction in operational costs and upfront costs because they consist of inexpensive materials and can be installed very quickly compared to a green roof system.

Research Method

Research into the available alternative roofing systems and products will provide a background of roofing knowledge. Consulting the roofing contractor for the Phase 2 New Building to acquire insight and opinion on the best alternative roofing system will help determine what type of system would work best for this project.

Comparing product information and overall quality will be important for choosing the best product. Once a product is chosen as the alternative roofing system, the configuration of this product will be determined to match the suggested R-value of the green roof system. The cost and schedule implications will be analyzed, and a comparison will help determine which system is more economical.

Also, research of the quality issues and comparing between the green roof systems installed and the alternative system will be completed.

Goal

The goal of this analysis will be to determine the impacts associated with removing the designed roof system and utilizing a fully adhered single ply TPO “cool” roof membrane system. The focus of study will be the difference in quality, construction costs, and the LEED® requirements that must be met in order to receive credit for the roof.

Master of Architectural Engineering Requirements

In order to satisfy the M.A.E. research requirements, knowledge learned within graduate level courses are incorporated into this analysis of an alternative roofing system. Knowledge and information gained from AE 542: Building Enclosure Science and Design, which focuses on developing an understanding of the nature, importance, functions, and performance of the building envelope, is shown through calculations and comparison of the thermal properties and heat transfer through the roofing systems. Methods learned for determining the R-value of a system composed of various components and the heat transfer through the system are completed within this analysis.

Additionally, knowledge from AE 597D: Sustainable Building Methods, focusing on strategies and technologies for green building and sustainable construction and understanding how to minimize impacts of buildings on the environment, will help determine appropriate system materials and LEED® implications within this analysis of alternative roofing systems. Comparing the potential LEED® credits of the analyzed roofing systems will be performed within this analysis.

Analysis

After research into various roofing systems and discussions with the roofing contractor for the Phase 2 New Building Project, it has been determined that the best alternative system for incorporation in this analysis is a light colored or white thermoplastic (TPO) singly ply membrane system fully adhered to the composite concrete roof slab. When comparing the systems, it is important to note that energy costs and differences in reductions will not be compared due to limited time and availability, but are important factors when considering these systems.

The green roof system installed on the Phase 2 New Building is estimated to provide an R-30 thermal insulation value, but usually green roof systems actually provide a much greater value. Therefore, it is important to design the alternative TPO “cool” roof system to provide a very similar thermal performance value. Also, in areas which are not covered by green roof, a ballasted IRMA roof system was installed over the hot rubberized asphalt waterproofing membrane. It will be important to remove the hot rubberized asphalt membrane when considering the alternative TPO “cool” roof system. With this in mind, the next step is to configure the roofing construction to provide similar thermal properties as the green roof.

Thermal Properties

Since the green roof system that was installed on the Phase 2 New Building had an expected R-value of R-30, it is important that the design of the alternative roofing system utilizing a single-ply TPO system can provide similar thermal performance. To determine the R-value, a spreadsheet tool was used to configure the proper thickness of materials in order to achieve R-30. The design temperatures for determining the R-Value and heat transfer through the roof were taken from Richmond, VA temperatures.

See **Appendix G: TPO “Cool” Roof Thermal Properties.**

Additionally, a comparison between the heat transfer through an average green roof and the TPO roofing system were compared to determine the difference in expected heat transfer rates. The following table is a summary of the difference in heat transfer, measured in BTU/ft²*hr, through an average green roof and the proposed alternative TPO “cool” roof system. It concludes that when implementing the alternative TPO “cool” roofing system, a 37% increase in heat gains in the summer and a 16% increase in heat losses in the winter should be expected to occur through the TPO system.

Heat Transfer Through Roof			
	TPO "Cool" Roof	Average Green Roof	Difference
	BTU/ft²*hr	BTU/ft²*hr	%
Summer	0.64	0.40	37%
Winter	-1.78	-1.49	16%

Figure 22, Heat transfer increase when implementing the alternative TPO “cool” roofing system

Roofing System Detail

Using the recommendation of the roofing contractor for the Phase 2 New Building, Firestone Building Products were used to determine the configuration of the roof construction. Refer to the following figure for a detail of the roof construction for the TPO membrane system.

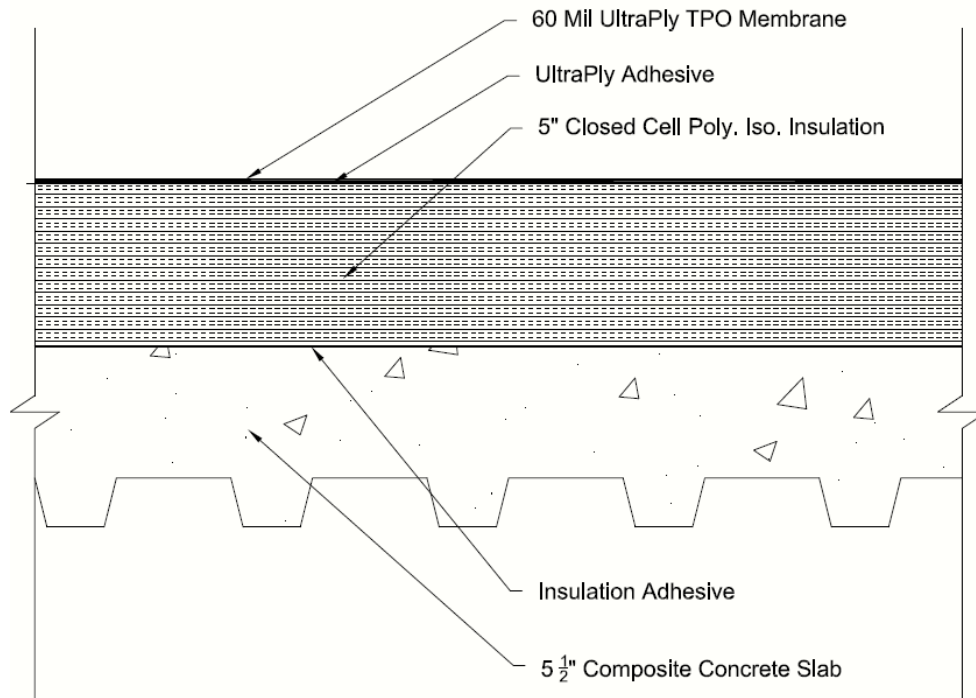


Figure 23, detailed section of TPO “Cool” Roof system

The alternative roof system will be composed of insulation and TPO membrane material. The Firestone ISO closed-cell polyisocyanurate insulation will first be fully adhered to the concrete roof slab using a polyurethane insulation adhesive. The insulation has a thermal insulation property of R-6/inch, so 5-inches will be used to provide an R-30 value. Over the insulation, a 60-mil layer of white Firestone UltraPly TPO “cool” roof membrane will be fully adhered using the recommended UltraPly bonding adhesive. The Firestone UltraPly TPO material is a flexible thermoplastic polyolefin roofing product provided in 10-foot wide rolls. It is overlapped and heat-welded in the seam areas to provide a continuous surface. The UltraPly TPO membrane provides excellent solar reflectance and thermal emittance values. It has been rated by the Cool Roof Rating Council and is Energy Star compliant.

LEED® Credit

Using LEED® 2009 for New Construction, it is important to be sure the alternative roofing system will achieve LEED® points under the Sustainable Sites credit for reducing the heat island effect from the roof. The Sustainable Site credit 7.2 rewards the project a point for reducing the heat islands to minimize the impacts on human and wildlife habitats.

The requirements for SS Credit 7.2: Heat Island Effect – Roof requires the use of roofing materials with a solar reflectance index (SRI) equal to or greater than the values for a low sloped roof of SRI 78 for a minimum of 75% of the roof surface. Roofing materials having a lower SRI value than 78 may be used if the weighted rooftop SRI average meets a minimum criteria calculation. The following tables summarize the independent testing results for solar reflectance properties and thermal emittances.

ENERGY STAR®	White	Tan	Gray	Cool Roof Rating Council (CRRC)	White	Tan	Gray
Initial Solar Reflectance	0.79	0.60		Solar Reflectance Initial	0.79	0.60	
Aged Solar Reflectance (3 years)	0.78	0.54		Solar Reflectance Weathered	0.68	0.55	
Cleaned prior to aged test?	Yes	No		Thermal Emittance Initial	0.85	0.81	
Initial Emittance	0.85	0.81		Thermal Emittance Weathered	0.83	0.84	

LEED	Test Method	White	Tan	Gray
Solar Reflectance	ASTM E903	0.81	0.63	0.37
Thermal Emittance	ASTM E408	0.95	0.95	0.95
Solar Reflectance Index (SRI)	ASTM E1980	102	77	43

Figure 24, independent testing results from Energy Star, the CRRC, and SRI calculator from USGBC. From manufacturer's technical data

Since the alternative roofing material will cover over 75% of the roof surface, and the SRI is rated at 102 for white colored surface which is greater than the required value of SRI 78, the credit for Sustainable Sites Credit 7.2 Heat Island Effect – Roof would be awarded to this alternative system. Therefore, this alternative roofing system would receive a LEED® point like the green roof would in this area.

Additionally, like green roofs, the alternative roofing system could qualify the project for Energy and Atmosphere Credit 1 – Optimizing Energy Performance. Because the roofing systems both could reduce the energy demand of the building and increase efficiency of the cooling systems, 1 to 15 potential points could be credited depending on the total energy reduction levels and other factors.

It is also important to consider additional LEED® credits which could be affected by the change of roofing systems. Green roofs can offer additional credits which may not be acquired through the implementation of a single-ply TPO “cool” roof. The following is a list of additional LEED® credits which can be achieved with the green roof system that the TPO “cool” roof otherwise cannot:

- Sustainable Sites Credit 6 – Stormwater Design:*
 Potential Points: 1 to 2 points
 Green roofs may provide a reduction in stormwater discharge by more than 25% and may be considered as stormwater treatment through their ability to remove solids and other pollutants from rainwater. A stormwater management plan would also need to be incorporated into the design.
- Water Efficiency Credit 1 – Water Efficient Landscaping:*
 Potential Points: 2 to 4 points
 Green roofs can be designed so irrigation is not required. Utilizing drought-resistant plantings or greywater systems can be used to irrigate the plantings. Since green roofs can also filter the rainwater runoff through the soil, this water could be collected and used to irrigate other areas of landscaping without having to pre-treat the water.

- *Innovation and Design Process*

Potential Points: 1 point

Green roofs may qualify for an additional point in this area by improving the workplace environment or by creating an educational laboratory. This depends on the intended uses of the green roof system by the owner.

Quality Issues

There are specific measures that must be taken so the roofing surface is not damaged when it comes to protecting the roofing surfaces after they are installed for mechanical equipment and other MEP work to be installed on the roof without damaging the membrane surfaces. The quality control of the membrane seal and quality construction checks would typically occur during and immediately after the installation to assure that other trades would not be at fault for damages and poor construction. Typically, plywood protection is installed to protect roof surfaces so that other trades can work. Once the project is wrapping up, the plywood protection is removed from protected surfaces. The green roof plantings typically don't occur until after the MEP trades are done working on the roof, late in the project. For quality of the "cool" white surface to be guaranteed, the surface is usually washed and cleaned to be sure that dirt, debris, or any other materials are not taking away from its reflective properties.

Schedule

The original roofing schedule included several activities and mobilizations. The roof membrane was installed in 23 days. The green roof and paver system around the green roof required an additional 10 days to install the growing medium and planting the sedums. This had to be done later in the schedule, which meant an additional mobilization had to occur for the roofing contractor. The original designed roofing membrane consisted of hot rubberized asphalt over the roof deck, with a ballasted IRMA roofing membrane installed over the waterproof membrane. The green roof was also installed over the hot rubberized asphalt waterproofing membrane. A large amount of growing medium and sedum plantings had to be delivered and stored on site prior to the installation.

When incorporating the single-ply white TPO "cool" roof membrane system into the schedule, durations were obtained from discussions with the roofing contractor. The alternative roofing membrane was determined to be able to be installed in the same 23 days as the original roofing membrane. Schedule items such as installing the growing medium for the green roof, installing the pavers around the edge of the green roof, and planting the sedums could be eliminated from the schedule. Based on this reduction, the re-mobilization for installing the green roofing system could be eliminated saving roughly 10 days of installation time.

It is important to note some difficulties and challenges with scheduling and planning the installation of the two roofing systems being analyzed. Mobilization and staging areas are important for green roof systems, because large quantities of soil or growing media must be delivered to site and stored prior to the installation of the plantings. Additionally, coordination issues arise when laying out the plantings that are ready to be transferred from the ground to the roof. Having the proper space is crucial for planning the installation of the green roof. There are many mobilizations that must occur to get all of

the proper components on site and moved to the roof in time for installations. Also, for the installation of the single-ply TPO “cool” roof system, the roofing contractor typically prefers to have a clear working space on the roof. The TPO system components would be installed all within one mobilization, and can all be delivered to the roof for storage until the installation occurs. This creates less staging area on the ground and site congestion is minimized.

Cost

The upfront cost of implementing the single-ply TPO “cool” roof system as an alternative to the original roof membrane and green roof will be a factor in determining whether to utilize this alternative for the Phase 2 New Building. The material and labor costs associated with the TPO roofing system are determined to be \$8.00/SF, based on the roofing contractor’s estimate.

Based on contractor’s data and discussions with the roofing contractor, the green roof was determined to cost roughly \$23.00/SF based on the roofing contractor’s estimate and the IRMA system typically costs around \$12.00/SF. A comparison was done to determine the initial cost savings when utilizing the alternative TPO “cool” roof system. Initial savings of roughly \$269,300.00 were estimated when implementing the alternative roofing system.

System Cost Comparison				
Wall System	QTY	Unit	Unit Cost	Cost
Green Roof & IRMA	19600	SF	\$8.95	\$426,100
Single-Ply TPO	19600	SF	\$8.00	\$156,800
Cost Savings				\$269,300

Figure 25, Cost comparison between systems

See **Appendix H: Detailed Roofing Systems Cost Comparison.**

Conclusions and Recommendations

Based on the information presented in this technical analysis, it has been determined that implementing the alternative Single-Ply TPO “cool” roofing system in lieu of the IRMA and green roof system would have many advantages and disadvantages. The choices between implementing either system each offer unique benefits to the owner.

Implementing the alternative single ply TPO “cool” roof system:

If upfront cost savings is a top priority of the owner, then the alternative roofing system is the best option. The TPO “cool” roof is estimated to save roughly \$269,300 in upfront costs and can shorten the roofing schedule by an estimated 10 days. Additionally, it will reduce the amount of materials being delivered and stored on site prior to installation and requires fewer mobilizations by the roofing contractor for installations. The TPO “cool” roof offers the LEED® credit for reducing the heat island effect, but was determined to not add any additional points in other LEED® categories. Also, the estimated summer heat gains and winter heat losses through the TPO “cool” roofing system was determined to increase by 37% in the summer and 16% in the winter compared to average green roof

thermal properties. This means that additional heating and cooling loads will be needed resulting in increased energy costs.

Implementing the original design of an IRMA and green roof system:

Since the Phase 2 New Building is striving for a LEED® certification level of Silver, it will be important for the owner to choose the green roof system to help achieve this goal. Despite the TPO “cool” roofing system saving \$269,300 and shortening the roofing system schedule by an estimated 10 days, the green roof and IRMA system can be considered a much better option for energy efficiency in reducing heat gain and heat losses and adding additional LEED® credits. The green roof system may potentially add an estimated 4 to 10 additional LEED® credits over the TPO “cool” roof, and positively attracts a better public image in being “green” and environmentally friendly by having a green roof.

Analysis III – Electrical System:

Electrical System - Building Transformer Sizing

Electrical Breadth

Problem Statement

The 300 kVA Transformer specified by the utility company suffered a Phase “A” power loss. This caused severe damage to the building automation system only weeks before occupancy. Many of the contacts for the variable-frequency drives (VFD’s) were fried. This caused several schedule delays prior to the Phase 2 New Building’s first day of occupancy. The removal of the phase protection implies that communication was lost in verifying the building service load and transformer sizing. The power company had to change the 300kVA transformer out for a 750kVA transformer and an insurance claim was filed by the CM. Focusing on the method of sizing the building’s electrical transformer based on the building’s expected power load with quality control of the electrical system design in mind might provide some industry “best practices” that can be used in the future.

Background

The electrical system that is designed for a building must be designed with safety, reliability, and efficiency in mind. The quality control that must be done during the design process is very important for delivering a building system that not only meets standards, but performs to expectations. The electrical system and its components can be assured to be reliable, safe, and efficient through the use of quality control during the design. The incorporation of a high level quality control strategy for the electrical system as it relates to the tie with the electric grid will reduce the risk of component failure and can ensure an improved quality design.

However, electrical systems can be very complex and takes a high level of understanding and experience to properly design a very successful system. The quality control associated with electrical systems and the components, as they relate to the grid tie-in, is an area that may not be well known. This level of quality control may prove to be difficult to guarantee on large complex projects, and the strategy for incorporating this level of QC into the design could be complicated.

Research Method

Research began by collecting information from various publications and industry standards dealing with the quality control and electrical system design. This provides a solid basis of information dealing with the measures and strategies for quality control and electrical design. Consulting electrical engineers within the industry is also important to gain their perspective on these issues. Once several “best practices” can be determined and quality control issues are well defined, calculations for sizing for the building transformer can be completed with the electrical grid and building load in mind.

Goal

Through research and calculations, the building transformer can be sized for the Phase 2 New Building based on the expected building loads. Also, research will determine many quality control issues and provide some industry “best practices” during the design, installation, and maintenance of the electrical system in buildings.

Analysis

To begin analysis, it is important to understand building transformers. A building transformer changes the alternating current (AC) of incoming service voltage to AC of another voltage. They are typically used to step down an incoming 4160-V service to a 480-V distribution within a building. A smaller transformer within the building is then used to step down the 480-V to 120-V for use on the receptacle circuits. In this analysis, the main building transformer will be sized for stepping down the incoming service feed assumed to be a typical 4160-V to the primary distribution 480-V within the building.

After research, it has been determined that standard data should be collected to begin sizing a transformer. It is important to first determine the electrical load, voltage required by load, and if the load is designed to operate on three phase power. Second, it is important to determine the supply voltage or amps. The frequency of the line supply and electrical load must be checked to be the same. A three phase transformer is selected which is designed to operate at the same primary input and supply voltage as the secondary output. The engineer would then need to use calculations to determine the kVA rating based on the known voltage and ampere required. Once the known kVA rating is established, it is important to select a three phase transformer with a standard kVA capacity of equal to or greater than that needed to operate the building loads.

The Phase 2 New Building utilizes a 750 kVA transformer. It has been determined that in buildings with transformer capacities over 300 kVA, it is good practice to complete calculations to compare the operating costs of various types. Assuming normal operating cycles and loading, two transformers were compared. The first transformer, a dry type 750kVA transformer designed for an 80°C (144°F) rise in temperature, and the second for a 150°C (270°F) rise in temperature. Based on a \$0.07/kWh energy cost, the lower energy waste of the more expensive 80°C unit will repay the first-cost in about 4 years. Using a 30-year life, with 8% fixed capital costs, and a 3% annual cost escalation, the life-cycle costs of the 80°C unit is roughly \$10,000.00 less than that of the 150°C unit.

Through the collection of building load estimates and summarizing the electrical load of the building, an electrical calculation could be performed to determine the size of a building transformer to step down the incoming electrical service feed for the Phase 2 New Building. Calculations determined that a 3-phase exterior building transformer should be expected to be sized at 1000 kVA rating. This differs from the transformer that was installed, but could attribute to sizing factors applied by the utility provider that was not accounted for.

Electrical Breadth Calculations are as follows:

ELECTRICAL NOTES:

NORTHSIDE ELECTRIC / VIRGINIA POWER

60,000 SF

UNDERGROUND SERVICE

600 MCM LOAD WIRE SIZE - CU CONDUCTOR TYPE

5 SETS OF LOAD WIRE / PHASE - SWITCH GEAR

SERVICE SIZE 2500 A

3 PHASE, 4 WIRE, WYE 277/480 VOLTAGE

INDOOR METER & SERVICE EQUIPMENT

ELECTRICAL MOTOR LOADS:

<u>PHASE</u>	<u># OF MOTORS</u>	<u>HP</u>	<u>VOLTAGE</u>	<u>HRS OF OPERATION</u>
3	4	20	480	24
3	2	10	480	24
3	2	1 1/2	480	24
3	2	40	480	24
3	7	15	480	24
3	1	30	480	24

OTHERS:

	<u>KW</u>	<u>HRS OF OPERATION</u>
LIGHTING	48	16
CHILLER	200	24
WATER HEATER	10	24
RECEPTACLES	310	16
MOTORS	350	24

BUILDING LOAD SUMMARY :

$$\text{DEMAND LOAD} = 842.3 \text{ kW}$$

$$\text{CONNECTED LOAD} = 968.2 \text{ kW} \leftarrow \text{USE THIS FOR CONSERVATIVE VALUE}$$

CURRENT OF CONNECTED LOAD:

$$I_s = \frac{P}{\sqrt{3}(V_s)(\cos(\text{p.f.}))} \quad \text{ASSUME POWER FACTOR PF} = 1.0$$

$$I_s = \frac{(968200 \text{ W})}{\sqrt{3}(480 \text{ V})(\cos 1.0)} = 1165 \text{ A}$$

TRANSFORMER KVA RATING :

$$\text{3-PHASE : } \text{KVA} = \frac{\sqrt{3}(I_s)(V_s)}{1000}$$

$$\text{KVA} = \frac{\sqrt{3}(1165 \text{ A})(480 \text{ V})}{1000} = 968.6 \rightarrow \text{USE NEXT SIZE UP}$$

\therefore USE 1000 KVA

SPECIFY : 1000 KVA , 3-PHASE TRANSFORMER

Quality Control Issues

An outdoor transformer, which is what the Phase 2 New Building requires, offers many advantages over indoor space transformers. The advantages include no building space used and reduced noise within the building. Also, they are generally lower in cost and have an easier maintenance and replacement value because it is located outdoors. However, costs can increase if long voltage runs are required, or if the transformer is exposed to direct sunlight, which increases the temperature and decreases its rating.

After research, it has been determined that standard data should be collected to begin sizing a transformer. It is important to first determine the electrical load, voltage required by load, and if the load is designed to operate on three phase power. Second, it is important to determine the supply voltage or amps. The frequency of the line supply and electrical load must be checked to be the same. A three phase transformer is selected which is designed to operate at the same primary input and supply voltage as the secondary output. The engineer would then need to use calculations to determine the kVA rating based on the known voltage and ampere required. Once the known kVA rating is established, it is important to select a three phase transformer with a standard kVA capacity of equal to or greater than that needed to operate the building loads.

The utility design engineer will normally calculate the anticipated loads for the building using the National Electric Code (NEC). The designer will have to take into account all estimated loads for motors, lighting, receptacles, any purchased equipment by the client, unknown load factors, and load growth factors. With all of these factors in mind, the distribution system becomes oversized. The electrical designer will contact the utility company to determine the location of the transformer and their recommended size based on these anticipated loads.

Coordination of the selection of the transformer and other electrical system devices are becoming very important issues. If the electrical system design engineer and utility company are not on the same page with building load anticipation, then the transformer is typically provided at an incorrect size. This can cause problems with other components in the electrical system and failures can occur.

Best Practices

After research, it has been determined that several challenges are faced when dealing with electrical system and building transformers. The life span of the electrical equipment has become an important issue. It is important to make sure that transformers that are installed remain operable and in service for as long as possible. This can mean continuous operation over the lifespan of buildings at full loading. There are a large percentage of installed transformers that stay in service for more than 25 years and the health of these are generally unknown unless regular maintenance occurs and log sheets are kept for the specific piece of equipment.

There are many issues that occur in the insulation of the transformers. Many of the transformer faults that occur are caused by temperature and moisture infiltrating the insulation and cause performance to decline. A healthy transformer means regular maintenance programs need to be adopted to periodically test the performance and maintain the originally designed performance levels.

When regular maintenance does occur on a transformer or any other electrical system component, it is important that regular load profiles, locations, and design history is logged. Power factor, percent moisture, and dissolved gas analysis (DGA) are three important measures that should be checked when performing maintenance on a transformer.

The following is a list of tests that should occur on transformers during maintenance or installation testing:

- DGA/Oil Screen
- Power Factors and Capacitance
- Turns Ratio (TTR)
- Leakage Reactance
- Winding Resistance
- Dielectric Frequency Response
- IR

Conclusions and Recommendations

Based on the research and information presented in this analysis, quality issues and best practices in terms of building transformers have been determined. Also, calculations have determined that a 1000-kVA transformer would be appropriate for this project. This differs from the 750 kVA size installed at the Phase 2 New Building, but can be attributed to factors in down-sizing the transformer size that is typically performed by the electrical power company.

Research has determined that there are important steps and processes that must occur between the electrical design engineer and the power company to properly size the building transfer to eliminate any problems with component failures or incorrect sizing. Additionally, there are many quality control issues associated with controlling the selection of the transformer based on anticipated building loads, supply voltages and frequency. Also, best practices have been determined which can be implemented during the installation checks and maintenance checks of the transformer. Since transformers remain in place for long lifetimes, it is important that they can be expected to perform at their designed performance levels and do not suffer and lost efficiency.

Summary and Conclusions

Through the completion of the analyses within this thesis report, ways in which the building exterior façade and roofing system can be changed adding to or offering similar quality as the original design were investigated. Additionally, research into sizing the building's electrical transformer and the quality control issues associated with building transformers was investigated. If the analysis of this report were implemented for the Phase 2 New Building at the John Tyler Community College's Midlothian Campus, the owner would be provided with unique benefits guaranteeing added quality to the project.

The first analysis investigated the use and implementation of an alternative exterior façade system in place of the hand-laid brick wall system. This analysis investigated a product known as SlenderWall which is an architectural precast concrete and steel stud panel wall system comprised of an exterior surface of thin architectural brick veneer cast into 2-inches of high-strength reinforced architectural precast concrete. The inside of the panel is composed of 16-gauge, 6-inch galvanized steel studs vertically spaced at 2-foot centers. This panel's construction enables the brick veneer, vapor barrier, exterior sheathing, and exterior metal studs to be removed from the scope of the project.

By replacing the hand laid brick veneer system with the SlenderWall precast panel system, the project does not lose the aesthetic quality of the exterior façade if the appropriate architectural brick is selected. Also, \$15,883 of upfront cost savings was determined. The SlenderWall system also provides a 16-day reduction in building skin installation time while minimizing site congestion during the superstructure phase.

The second analysis focused on changing the roofing system to an alternative single-ply thermoplastic TPO "cool" roof in lieu of the IRMA and green roof system installed. The analysis investigated a roofing contractor's recommended roofing system produced by Firestone Building Products. The alternative system consisted of 5-inches of closed-cell polyisocyanurate insulation fully adhered to the concrete deck providing an R-30 insulation property. The 60-mil white UltraPly TPO membrane is then fully adhered to the insulation, providing a continuous waterproofing membrane with exceptional reflective properties.

If the priority of the owner is mainly upfront cost savings, the TPO "cool" roofing system offers an estimated upfront cost savings of \$269,300. Additionally, the amount of materials delivered to and stored on site is greatly reduced offering reduced site congestion and reduces the roofing schedule by 10 days. However, the alternative "cool" roofing system would result in an estimated heat transfer increase of 37% summer heat gain and 16% winter heat loss.

Utilizing the green roof and IRMA roofing system instead of the alternative would be a much better option for energy efficiency and adds additional LEED® credits that are not achievable through the alternative "cool" roof. Despite the increase in upfront costs, the green roof system over the IRMA roof has the potential to add 4 to 10 additional LEED® credits, depending on the use and design, as well as creating a "green" public image by incorporating a green roof system.

Finally, the third analysis included the research and calculations involved in properly sizing a building transformer based on anticipated building loads. The research and information presented in the analysis determined quality issues and best practices in building transformers. Through calculations, it was determined that a 3-phase 1000 kVA transformer would be a safe, suitable size for the Phase 2 New Building. This differed from the 750 kVA transformer installed, but can contribute to possible factors in down-sizing the transformer by the electric power company, which has become normal in the industry. Additionally, there are many quality control issues associated with controlling the selection of the transformer based on anticipated building loads, supply voltages and frequency. Also, best practices have been determined which can be implemented during the installation checks and maintenance checks of the transformer. Since transformers remain in place for long lifetimes, it is important that they can be expected to perform at their designed performance levels and do not suffer and lost efficiency.

Overall, the quality of the project can be increased when incorporating the three analysis topics into the design and construction of the Phase 2 New Building at the John Tyler Community College's Midlothian Campus. The incorporation and close attention to the alternative systems and the quality control issues presented in each analysis have the potential to decrease cost, add quality, and lighten the schedule and reduce impacts of delays and site congestion.

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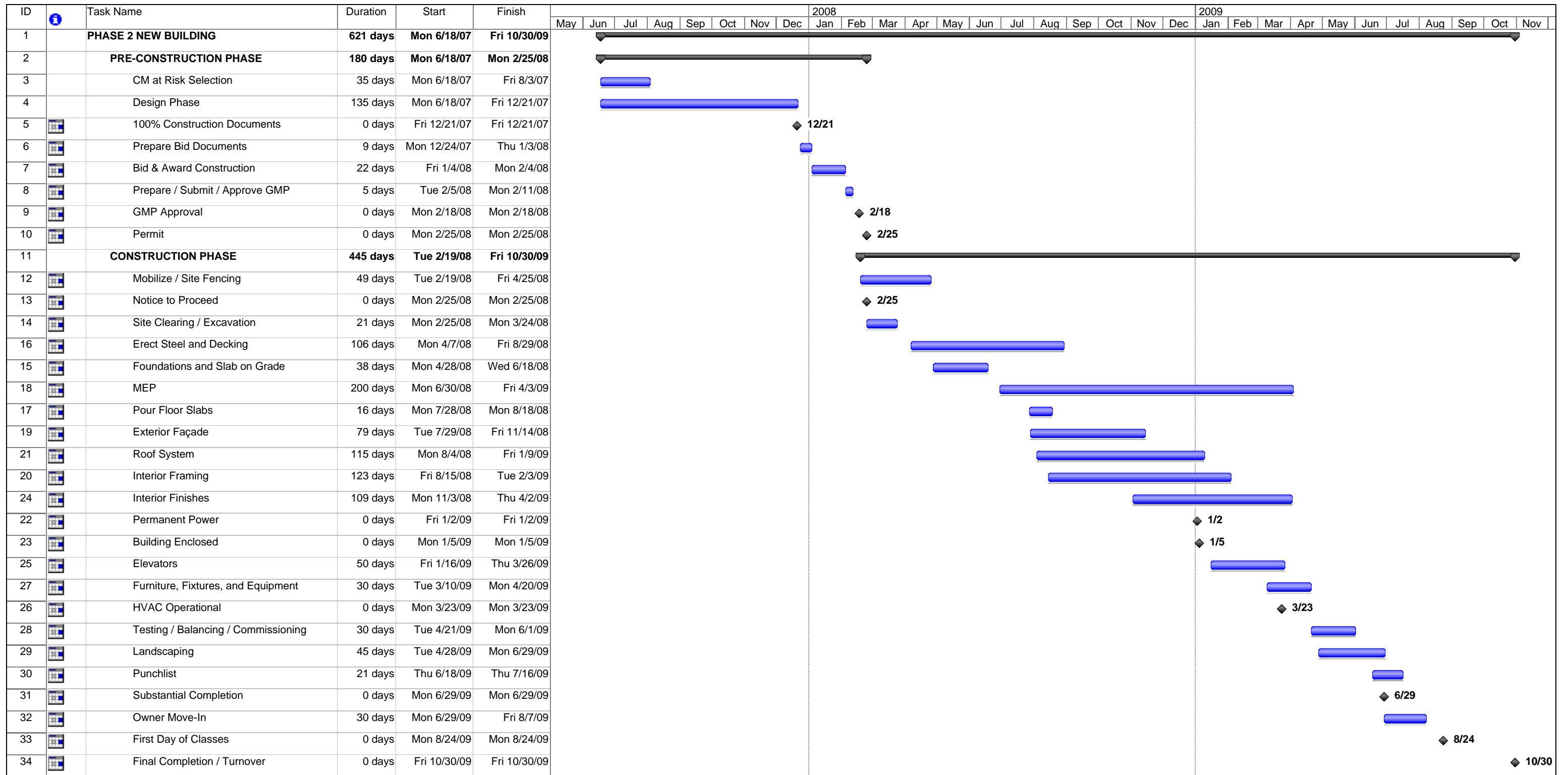
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Appendix A: Project Schedule Summary



Project: Schedule
Date: Mon 4/5/10

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

Appendix B: Detailed Project Schedule

ID	Task Name	Duration	Start	Finish	2008												2009																							
					May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec				
1	PHASE 2 NEW BUILDING	620 days	Mon 6/18/07	Fri 10/30/09	[Gantt bar from 6/18/07 to 10/30/09]																																			
2	PRE-CONSTRUCTION PHASE	180 days	Mon 6/18/07	Mon 2/25/08	[Gantt bar from 6/18/07 to 2/25/08]																																			
3	CM at Risk Selection	35 days	Mon 6/18/07	Fri 8/3/07	[Blue bar from 6/18/07 to 8/3/07]																																			
4	Design Phase	135 days	Mon 6/18/07	Fri 12/21/07	[Blue bar from 6/18/07 to 12/21/07]																																			
5	100% Construction Documents	0 days	Fri 12/21/07	Fri 12/21/07	[Milestone diamond at 12/21/07]																																			
6	Prepare Bid Documents	9 days	Mon 12/24/07	Thu 1/3/08	[Blue bar from 12/24/07 to 1/3/08]																																			
7	Bid & Award Construction	22 days	Fri 1/4/08	Mon 2/4/08	[Blue bar from 1/4/08 to 2/4/08]																																			
8	Prepare / Submit / Approve GMP	5 days	Tue 2/5/08	Mon 2/11/08	[Blue bar from 2/5/08 to 2/11/08]																																			
9	GMP Approval	0 days	Mon 2/18/08	Mon 2/18/08	[Milestone diamond at 2/18/08]																																			
10	Permit	0 days	Mon 2/25/08	Mon 2/25/08	[Milestone diamond at 2/25/08]																																			
11	CONSTRUCTION PHASE	444 days	Tue 2/19/08	Fri 10/30/09	[Gantt bar from 2/19/08 to 10/30/09]																																			
12	MOBILIZATION / SITE CLEARING	49 days	Tue 2/19/08	Fri 4/25/08	[Gantt bar from 2/19/08 to 4/25/08]																																			
13	Mobilize / Site Fencing	5 days	Tue 2/19/08	Mon 2/25/08	[Blue bar from 2/19/08 to 2/25/08]																																			
14	Notice to Proceed	0 days	Mon 2/25/08	Mon 2/25/08	[Milestone diamond at 2/25/08]																																			
15	Strip Topsoil / Excavate To Building Pad	8 days	Mon 3/24/08	Wed 4/2/08	[Blue bar from 3/24/08 to 4/2/08]																																			
16	Re-grade Building Pad	1 day	Fri 4/25/08	Fri 4/25/08	[Blue bar from 4/25/08 to 4/25/08]																																			
17	SUBSTRUCTURE	85 days	Mon 2/25/08	Fri 6/20/08	[Gantt bar from 2/25/08 to 6/20/08]																																			
18	Site Clearing / E&S Controls	19 days	Mon 2/25/08	Thu 3/20/08	[Blue bar from 2/25/08 to 3/20/08]																																			
19	Relocate Dominion Power Line	3 days	Thu 3/20/08	Mon 3/24/08	[Blue bar from 3/20/08 to 3/24/08]																																			
20	Concrete Foundations	13 days	Mon 4/28/08	Wed 5/14/08	[Blue bar from 4/28/08 to 5/14/08]																																			
21	Concrete Retaining Wall - 1st Half	10 days	Wed 5/7/08	Tue 5/20/08	[Blue bar from 5/7/08 to 5/20/08]																																			
22	Masonry Foundations	14 days	Wed 5/14/08	Mon 6/2/08	[Blue bar from 5/14/08 to 6/2/08]																																			
23	Concrete Elevator Pits	5 days	Wed 5/14/08	Tue 5/20/08	[Blue bar from 5/14/08 to 5/20/08]																																			
24	SOG Underground Electrical	9 days	Wed 5/14/08	Mon 5/26/08	[Blue bar from 5/14/08 to 5/26/08]																																			
25	SOG Underground Plumbing	19 days	Wed 5/14/08	Mon 6/9/08	[Blue bar from 5/14/08 to 6/9/08]																																			
26	Concrete Retaining Wall - 2nd Half	9 days	Wed 5/21/08	Mon 6/2/08	[Blue bar from 5/21/08 to 6/2/08]																																			
27	Foundation Drain @ Elevator Pits	1 day	Mon 5/26/08	Mon 5/26/08	[Blue bar from 5/26/08 to 5/26/08]																																			
28	Retaining Wall WP - 1st Lift / 1st Half	1 day	Mon 5/26/08	Mon 5/26/08	[Blue bar from 5/26/08 to 5/26/08]																																			
29	Retaining Wall Backfill - 1st Lift / 1st Half	1 day	Tue 5/27/08	Tue 5/27/08	[Blue bar from 5/27/08 to 5/27/08]																																			
30	Backfill Elevator Pits	3 days	Wed 5/28/08	Fri 5/30/08	[Blue bar from 5/28/08 to 5/30/08]																																			
31	Retaining Wall WP - 2nd Lift / 1st Half	1 day	Mon 6/2/08	Mon 6/2/08	[Blue bar from 6/2/08 to 6/2/08]																																			
32	Retaining Wall Backfill - 2nd Lift / 1st Half	1 day	Mon 6/9/08	Mon 6/9/08	[Blue bar from 6/9/08 to 6/9/08]																																			
33	Retaining Wall WP - 1st Lift / 2nd Half	1 day	Tue 6/10/08	Tue 6/10/08	[Blue bar from 6/10/08 to 6/10/08]																																			
34	Retaining Wall Backfill - 1st Lift / 2nd Half	1 day	Wed 6/11/08	Wed 6/11/08	[Blue bar from 6/11/08 to 6/11/08]																																			
35	Form/Rebar Concrete Slab on Grade	7 days	Thu 6/12/08	Fri 6/20/08	[Blue bar from 6/12/08 to 6/20/08]																																			
36	Retaining Wall WP - 2nd Lift / 2nd Half	1 day	Thu 6/12/08	Thu 6/12/08	[Blue bar from 6/12/08 to 6/12/08]																																			
37	SOG Electrical Floor Box R/I	4 days	Fri 6/13/08	Wed 6/18/08	[Blue bar from 6/13/08 to 6/18/08]																																			
38	Retaining Wall Backfill - 2nd Lift / 2nd Half	2 days	Fri 6/13/08	Mon 6/16/08	[Blue bar from 6/13/08 to 6/16/08]																																			
39	SUPERSTRUCTURE	119 days	Mon 4/7/08	Thu 9/18/08	[Gantt bar from 4/7/08 to 9/18/08]																																			
40	Fab & Deliver Steel	59 days	Mon 4/7/08	Thu 6/26/08	[Blue bar from 4/7/08 to 6/26/08]																																			
43	Erect Structural Steel & Metal Deck	25 days	Mon 6/23/08	Fri 7/25/08	[Blue bar from 6/23/08 to 7/25/08]																																			
50	Pour Concrete Slab on Grade	3 days	Wed 7/16/08	Fri 7/18/08	[Blue bar from 7/16/08 to 7/18/08]																																			
53	Masonry Stair #3 & Elevator Shaft	9 days	Mon 7/21/08	Thu 7/31/08	[Blue bar from 7/21/08 to 7/31/08]																																			
54	2nd Floor Slab R/I - Electrical	9 days	Mon 7/21/08	Thu 7/31/08	[Blue bar from 7/21/08 to 7/31/08]																																			
42	Install Stair #1 - Steel Framing	9 days	Mon 7/28/08	Thu 8/7/08	[Blue bar from 7/28/08 to 8/7/08]																																			
55	Pour 2nd Floor Slab - 1st Half	2 days	Mon 7/28/08	Tue 7/29/08	[Blue bar from 7/28/08 to 7/29/08]																																			
56	Detail Roof Steel	4 days	Mon 7/28/08	Thu 7/31/08	[Blue bar from 7/28/08 to 7/31/08]																																			
49	Pour 2nd Floor Slab - 2nd Half	2 days	Fri 8/1/08	Mon 8/4/08	[Blue bar from 8/1/08 to 8/4/08]																																			
52	3rd Floor Slab R/I - Electrical	9 days	Fri 8/1/08	Wed 8/13/08	[Blue bar from 8/1/08 to 8/13/08]																																			
48	Install Stair #2 - Steel Framing	9 days	Fri 8/8/08	Wed 8/20/08	[Blue bar from 8/8/08 to 8/20/08]																																			
51	Pour 3rd Floor Slab - 1st Half	2 days	Fri 8/8/08	Mon 8/11/08	[Blue bar from 8/8/08 to 8/11/08]																																			
44	Pour 3rd Floor Slab - 2nd Half	1 day	Wed 8/13/08	Wed 8/13/08	[Blue bar from 8/13/08 to 8/13/08]																																			
46	Pour Roof Floor Slab	3 days	Thu 8/14/08	Mon 8/18/08	[Blue bar from 8/14/08 to 8/18/08]																																			
41	Install Stair #3 - Steel Framing	9 days	Tue 8/19/08	Fri 8/29/08	[Blue bar from 8/19/08 to 8/29/08]																																			
47	Spray Applied Fire Proofing	4 days	Tue 8/19/08	Fri 8/22/08	[Blue bar from 8/19/08 to 8/22/08]																																			
45	Set Rooftop Mechanical Curbs	11 days	Thu 9/4/08	Thu 9/18/08	[Blue bar from 9/4/08 to 9/18/08]																																			
57	BUILDING SKIN	119 days	Tue 7/29/08	Fri 1/9/09	[Gantt bar from 7/29/08 to 1/9/09]																																			
58	North Elev (5-1) Ext Studs / Shthg / VB	4 days	Tue 7/29/08	Fri 8/1/08	[Blue bar from 7/29/08 to 8/1/08]																																			
59	Roof: Metal Flashing & Trim - West	1 day	Mon 8/4/08	Mon 8/4/08	[Blue bar from 8/4/08 to 8/4/08]																																			
82	North Elev. (5-1) Brick	9 days	Mon 8/4/08	Thu 8/14/08	[Blue bar from 8/4/08 to 8/14/08]																																			

Project: Detailed Project Schedule1
Date: Mon 4/5/10

Task: [Blue bar] Progress [Grey bar] Summary [Arrow] External Tasks [Grey bar] Deadline [Green arrow]

Split: [Dotted bar] Milestone [Diamond] Project Summary [Arrow] External Milestone [Diamond]

Page 1

Appendix C: Precast Panel Takeoffs

Precast Panel Takeoff

	Panel	Length	Height	Opening SF	SF	Unit Wt PSF	Panel Wt (lbs)	Unit Cost/SF	Cost
South	S101	4.33	14	0	60.62	30	1818.6	\$40.00	\$2,425
	S102	10	14	22	118	30	3540	\$40.00	\$4,720
	S103	10	14	22	118	30	3540	\$40.00	\$4,720
	S104	10	14	0	140	30	4200	\$40.00	\$5,600
	S105	10	14	22	118	30	3540	\$40.00	\$4,720
	S106	10	14	22	118	30	3540	\$40.00	\$4,720
	S107	10	14	0	140	30	4200	\$40.00	\$5,600
	S108	10	14	22	118	30	3540	\$40.00	\$4,720
	S109	10	14	22	118	30	3540	\$40.00	\$4,720
	S110	10	14	0	140	30	4200	\$40.00	\$5,600
	S111	10	14	22	118	30	3540	\$40.00	\$4,720
	S112	10	14	22	118	30	3540	\$40.00	\$4,720
	S113	7.33	14	0	102.62	30	3078.6	\$40.00	\$4,105
	S114	4	14	0	56	30	1680	\$40.00	\$2,240
	S115	3.33	14	0	46.62	30	1398.6	\$40.00	\$1,865
	S116	10	14	22	118	30	3540	\$40.00	\$4,720
	S117	10	14	22	118	30	3540	\$40.00	\$4,720
	S118	10	14	22	118	30	3540	\$40.00	\$4,720
	S119	10	14	22	118	30	3540	\$40.00	\$4,720
	S120	10	14	22	118	30	3540	\$40.00	\$4,720
	S121	10	14	22	118	30	3540	\$40.00	\$4,720
	S122	3.33	14	0	46.62	30	1398.6	\$40.00	\$1,865
	S201	6.66	16	0	106.56	30	3196.8	\$40.00	\$4,262
	S202	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	S203	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	S204	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	S205	6.66	16	0	106.56	30	3196.8	\$40.00	\$4,262
	S206	3.33	16	0	53.28	30	1598.4	\$40.00	\$2,131
	S207	10	16	22	138	30	4140	\$40.00	\$5,520
	S208	10	16	22	138	30	4140	\$40.00	\$5,520
	S209	10	16	22	138	30	4140	\$40.00	\$5,520
	S210	10	16	22	138	30	4140	\$40.00	\$5,520
	S211	10	16	22	138	30	4140	\$40.00	\$5,520
	S212	10	16	22	138	30	4140	\$40.00	\$5,520
S213	3.33	16	0	53.28	30	1598.4	\$40.00	\$2,131	
S301	6.66	14	0	93.24	30	2797.2	\$40.00	\$3,730	
S302	16.66	5	0	83.3	30	2499	\$40.00	\$3,332	
S303	13.33	14	0	186.62	30	5598.6	\$40.00	\$7,465	
S304	16.66	5	0	83.3	30	2499	\$40.00	\$3,332	
S305	13.33	14	0	186.62	30	5598.6	\$40.00	\$7,465	
S306	16.66	5	0	83.3	30	2499	\$40.00	\$3,332	
S307	13.33	14	0	186.62	30	5598.6	\$40.00	\$7,465	
S308	16.66	5	0	83.3	30	2499	\$40.00	\$3,332	
S309	6.66	14	0	93.24	30	2797.2	\$40.00	\$3,730	
S310	3.33	14	0	46.62	30	1398.6	\$40.00	\$1,865	
S311	10	14	22	118	30	3540	\$40.00	\$4,720	
S312	10	14	22	118	30	3540	\$40.00	\$4,720	
S313	10	14	22	118	30	3540	\$40.00	\$4,720	
S314	10	14	22	118	30	3540	\$40.00	\$4,720	
S315	10	14	22	118	30	3540	\$40.00	\$4,720	
S316	10	14	22	118	30	3540	\$40.00	\$4,720	
S317	3.33	14	0	46.62	30	1398.6	\$40.00	\$1,865	
					6052.78			181583.40	\$242,111

	Panel	Length	Height	Opening SF	SF	Unit Wt PSF	Panel Wt (lbs)	Unit Cost/SF	Cost
East	E101	10.66	14	22	127.24	30	3817.2	\$40.00	\$5,090
	E102	4	14	0	56	30	1680	\$40.00	\$2,240
	E103	12.66	14	22	155.24	30	4657.2	\$40.00	\$6,210
	E104	10	14	0	140	30	4200	\$40.00	\$5,600
	E105	10	14	0	140	30	4200	\$40.00	\$5,600
	E201	10.66	16	22	148.56	30	4456.8	\$40.00	\$5,942
	E202	4	16	0	64	30	1920	\$40.00	\$2,560
	E203	12.66	16	22	180.56	30	5416.8	\$40.00	\$7,222
	E204	12.66	16	22	180.56	30	5416.8	\$40.00	\$7,222
	E205	4	16	0	64	30	1920	\$40.00	\$2,560
	E206	12.66	16	22	180.56	30	5416.8	\$40.00	\$7,222
	E301	10.66	14	22	127.24	30	3817.2	\$40.00	\$5,090
	E302	4	14	0	56	30	1680	\$40.00	\$2,240
	E303	12.66	14	22	155.24	30	4657.2	\$40.00	\$6,210
	E304	12.66	14	22	155.24	30	4657.2	\$40.00	\$6,210
	E305	4	14	0	56	30	1680	\$40.00	\$2,240
	E306	12.66	14	22	155.24	30	4657.2	\$40.00	\$6,210
					2141.68			64250.40	

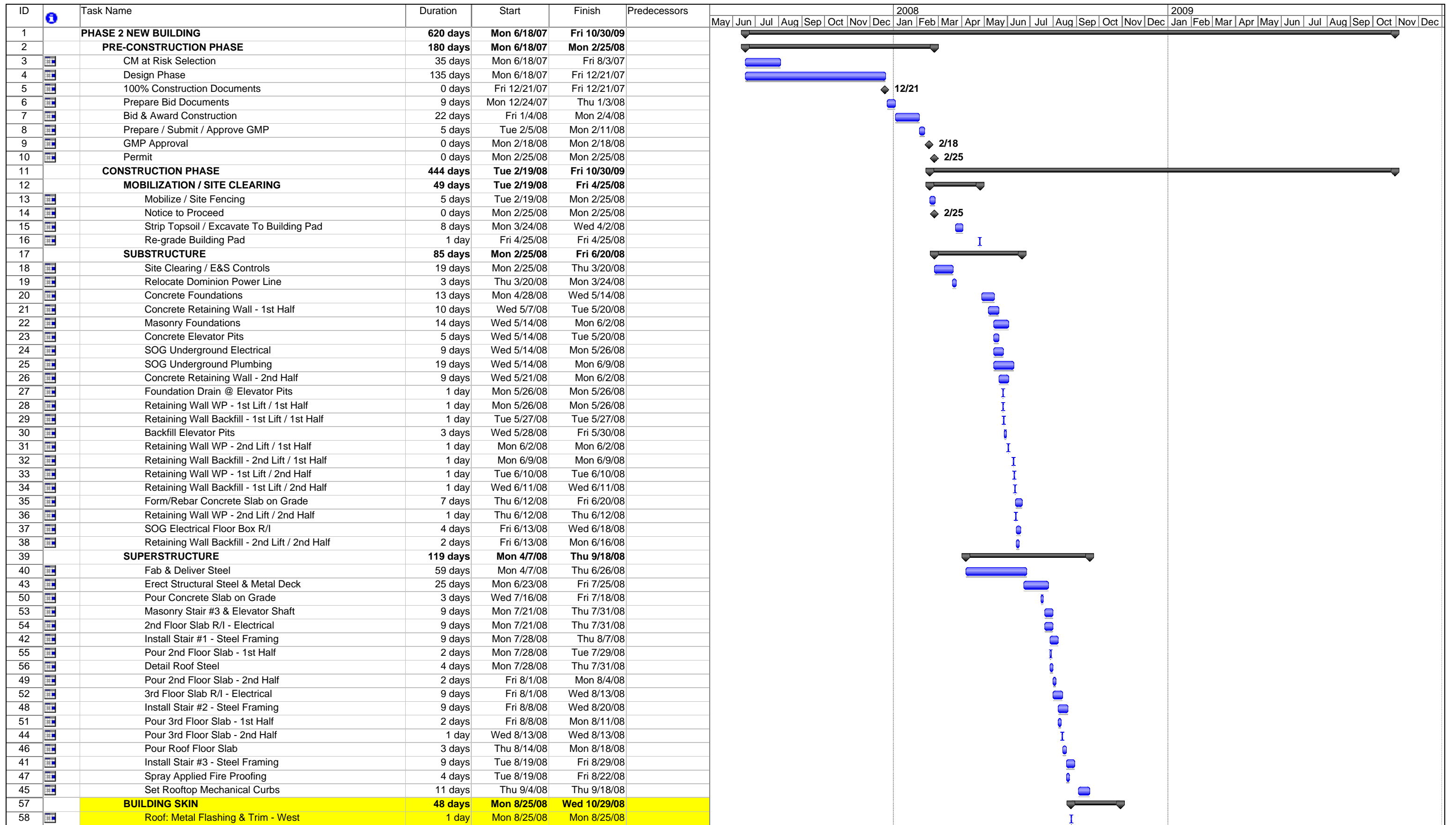
	Panel	Length	Height	Opening SF	SF	Unit Wt PSF	Panel Wt (lbs)	Unit Cost/SF	Cost
North	N201	13	16	0	208	30	6240	\$40.00	\$8,320
	N202	13	16	0	208	30	6240	\$40.00	\$8,320
	N203	13	16	0	208	30	6240	\$40.00	\$8,320
	N204	13	16	0	208	30	6240	\$40.00	\$8,320
	N205	8	16	0	128	30	3840	\$40.00	\$5,120
	N206	8	16	0	128	30	3840	\$40.00	\$5,120
	N207	6.66	16	0	106.56	30	3196.8	\$40.00	\$4,262
	N208	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	N209	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	N210	13.33	16	0	213.28	30	6398.4	\$40.00	\$8,531
	N211	6.66	16	0	106.56	30	3196.8	\$40.00	\$4,262
	N301	13	14	0	182	30	5460	\$40.00	\$7,280
	N302	13	14	0	182	30	5460	\$40.00	\$7,280
	N303	13	14	0	182	30	5460	\$40.00	\$7,280
	N304	13	14	0	182	30	5460	\$40.00	\$7,280
	N305	8	14	0	112	30	3360	\$40.00	\$4,480
	N306	8	14	0	112	30	3360	\$40.00	\$4,480
	N307	6.66	14	0	93.24	30	2797.2	\$40.00	\$3,730
	N308	16.66	5	0	83.3	30	2499	\$40.00	\$3,332
	N309	13.33	14	0	186.62	30	5598.6	\$40.00	\$7,465
	N310	16.66	5	0	83.3	30	2499	\$40.00	\$3,332
N311	13.33	14	0	186.62	30	5598.6	\$40.00	\$7,465	
N312	16.66	5	0	83.3	30	2499	\$40.00	\$3,332	
N313	13.33	14	0	186.62	30		\$40.00	\$7,465	
N314	16.66	5	0	83.3	30		\$40.00	\$3,332	
N315	6.66	14	0	93.24	30	2797.2	\$40.00	\$3,730	
				3972.50			111077.40		\$158,900

	Panel	Length	Height	Opening SF	SF	Unit Wt PSF	Panel Wt (lbs)	Unit Cost/SF	Cost
West	W101	12.33	14	42	130.62	30	3918.6	\$40.00	\$5,225
	W102	11.33	14	0	158.62	30	4758.6	\$40.00	\$6,345
	W103	13	14	0	182	30	5460	\$40.00	\$7,280
	W104	13	14	21	161	30	4830	\$40.00	\$6,440

Appendix D: Panel Sizes Summary

Panel Sizes Summary							
Elevation	QTY	Length (ft)	Height (ft)	Opening (SF)	Panel SF	Unit Wt (PSF)	Panel Wt (lbs)
South	4	3	14	0	46.6	30	1399
	2	3	16	0	53.3	30	1598
	1	4	14	0	56.0	30	1680
	1	4	14	0	60.6	30	1819
	2	7	14	0	93.2	30	2797
	2	7	16	0	106.6	30	3197
	1	7	14	0	102.6	30	3079
	3	10	14	0	140.0	30	4200
	20	10	14	22	118.0	30	3540
	6	10	16	22	138.0	30	4140
	3	13	14	0	186.6	30	5599
	3	13	16	0	213.3	30	6398
	4	17	5	0	83.3	30	2499
52							
East	3	4	14	0	56.0	30	1680
	2	4	16	0	64.0	30	1920
	2	10	14	0	140.0	30	4200
	2	11	14	22	127.2	30	3817
	1	11	16	22	148.6	30	4457
	4	13	14	22	155.2	30	4657
	3	13	16	22	180.6	30	5417
17							
North	2	7	14	0	93.2	30	2797
	2	7	16	0	106.6	30	3197
	2	8	14	0	112.0	30	3360
	2	8	16	0	128.0	30	3840
	4	13	14	0	182.0	30	5460
	4	13	16	0	208.0	30	6240
	3	13	14	0	186.6	30	5599
	3	13	16	0	213.3	30	6398
	4	17	5	0	83.3	30	2499
26							
West	2	7	14	0	102.6	30	3079
	1	7	16	0	117.3	30	3518
	3	9	14	0	130.6	30	3919
	1	9	14	28	102.6	30	3079
	2	9	16	0	149.3	30	4478
	4	11	14	0	158.6	30	4759
	2	11	16	0	181.3	30	5438
	2	12	14	0	172.6	30	5179
	2	12	14	42	130.6	30	3919
	2	12	16	0	197.3	30	5918
	3	13	14	0	182.0	30	5460
	1	13	14	21	161.0	30	4830
	2	13	16	0	208.0	30	6240
27							

Appendix E: Detailed Project Schedule – Alternative Exterior Façade



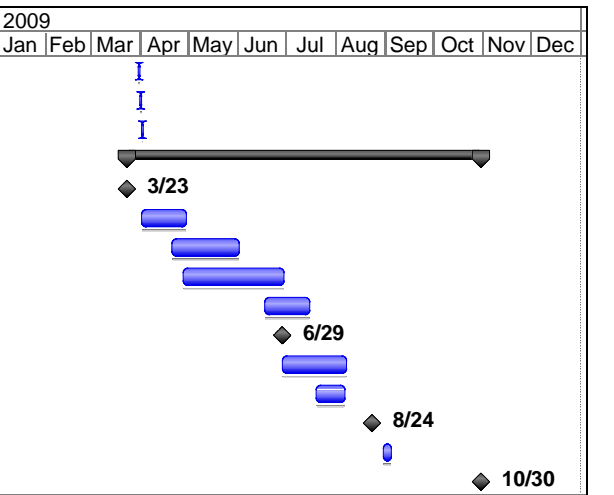
Project: Detailed Project Schedule - P1
Date: Mon 4/5/10

Task: [Blue bar] Progress: [Grey bar] Summary: [Arrow] External Tasks: [Grey bar] Deadline: [Green arrow]

Split: [Dotted bar] Milestone: [Diamond] Project Summary: [Arrow] External Milestone: [Diamond]

Page 1

ID	Task Name	Duration	Start	Finish	Predecessors	2008												2009											
						May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec				
157	Install Bathroom Mirrors 1st Floor	1 day	Tue 3/31/09	Tue 3/31/09																									
158	Install Bathroom Mirrors 2nd Floor	1 day	Wed 4/1/09	Wed 4/1/09																									
159	Install Bathroom Mirrors 3rd Floor	1 day	Thu 4/2/09	Thu 4/2/09																									
239	CLOSEOUT	159 days	Mon 3/23/09	Fri 10/30/09																									
241	HVAC Operational	0 days	Mon 3/23/09	Mon 3/23/09																									
246	Architect's Punchlist	20 days	Thu 4/2/09	Wed 4/29/09																									
242	Testing / Balancing / Commissioning	30 days	Tue 4/21/09	Mon 6/1/09																									
245	Landscaping	45 days	Tue 4/28/09	Mon 6/29/09																									
240	Punchlist	20 days	Thu 6/18/09	Thu 7/16/09																									
247	Substantial Completion	0 days	Mon 6/29/09	Mon 6/29/09																									
248	Owner Move-In	30 days	Mon 6/29/09	Fri 8/7/09																									
250	LEED Building HVAC Flush Out	14 days	Mon 7/20/09	Fri 8/7/09																									
249	First Day of Classes	0 days	Mon 8/24/09	Mon 8/24/09																									
243	Demobilize Jobsite Trailer	5 days	Mon 8/31/09	Fri 9/4/09																									
244	Final Completion / Turnover	0 days	Fri 10/30/09	Fri 10/30/09																									



Appendix F: Detailed Exterior Façade Systems Cost Comparison

Cost Savings - Detailed System Comparison**Additional Costs**

Item	QTY	Unit	Unit Cost	Cost
Precast SlenderWall	16404	SF	\$40.00	\$656,160
Total			\$40.00	\$656,160

Deducted Costs

Item	QTY	Unit	Unit Cost	Cost
Exterior Studs	16404	SF	\$9.51	\$156,000
Exterior Sheathing	16404	SF	\$5.00	\$82,000
Fluid Applied Vapor Barrier	16404	SF	\$2.01	\$32,990
Utility Brick Masonry Veneer	16404	SF	\$16.77	\$275,150
Miscellaneous Finishing	16404	SF	\$1.25	\$20,433
Precast Sills and Headers	16404	SF	\$6.43	\$105,470
Total			\$40.97	\$672,043

Cost Savings	\$15,883
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Appendix G: TPO “Cool” Roof Thermal Properties

TPO "Cool" Roof Thermal Properties				
R-Value				
Material	Thickness (in) L	R-Value per inch °F*ft ² *h/Btu-in	R-Value °F*ft ² *h/Btu	U-Value Btu/°F*ft ² *h
Outside Air Film	-	-	0.17	5.88
UltraPly TPO Membrane	0.060	0.833	0.050	20.00
Poly. Iso Insulation	5.000	6.000	30.000	0.03
Composite Deck	5.500	0.100	0.550	1.82
Inside Air Film	-	-	0.610	1.64
Total:			31.380	0.032
Heat Transfer				
Summer (75°F Indoor , 95°F Outdoor)				
ΣR		ΔT	A	Q
°F*ft ² *h/Btu		°F	ft ²	Btu/hr
31.380		20	8,300	5,290
Winter (70°F Indoor , 14°F Outdoor)				
ΣR		ΔT	A	Q
°F*ft ² *h/Btu		°F	ft ²	Btu/hr
31.380		-56	8,300	(14,812)

Appendix H: Detailed Roofing Systems Cost Comparison

Cost Savings - Detailed System Comparison**Additional Costs**

Item	QTY	Unit	Unit Cost	Cost
Singly-ply TPO "Cool" Roof System	19600	SF	\$8.00	\$156,800
Total			\$8.00	\$156,800

Deducted Costs

Item	QTY	Unit	Unit Cost	Cost
Green Roof System	8300	SF	\$23.00	\$190,900
IRMA System	19600	SF	\$12.00	\$235,200
Total			\$8.95	\$426,100

Cost Savings**\$269,300**