FINAL REPORT

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Construction Management

Advisor – Ray Sowers

Cardinal Wuerl North Catholic High School

Cranberry Township, PA

Wednesday, April 9th, 2014

Spring 2014

THESIS ABSTRACT

Cardinal Wuerl North Catholic High School — Cranberry Twp., PA

ALEC HANLEY — CONSTRUCTION — SENIOR THESIS BUILDING ABSTRACT

PROJECT INFO

Occupant Name - Catholic Diocese of Pittsburgh
Occupancy Type - Educational – E
Size (GSF) - 177,129 SF
Number of Stories- 2 Above grade, 1 partial below grade (Café, MEP)
Dates of Construction - June 2012 – June 2014
Approximate Cost - $72,500,000
Delivery Method - Design-Bid-Build

PROJECT TEAM

Owner - Catholic Diocese of Pittsburgh
General Contractor - Mascaro Construction
CM Agency - Campayno Consulting
Architect/Engineer - Astorino
Civil Engineer – CEC, Inc.
HVAC/Plumb. Contractor - Renick Brothers
Electrical Contractor - Lighthouse Electric
Site Contractor - Allegheny Excavating, Inc.

ARCHITECTURE

Sustainability - LEED Silver Certification
Façade – Brown Brick, Insulated Metal Panel, Glass
Roofing - TPO, Standing Seam Metal
Phase I - 27 classrooms, chapel, MEP, 1500-person gymnasium, 1000-person auditorium, offices, cafeteria
Phase II - Chapel
Notable – Design reviewed by Vatican

STRUCTURAL SYSTEM

Substructure – footings, caissons, grade beams
Concrete - 5" SOG w/ 5" SOD above cafeteria and MEP rooms & 2nd Floor of Classroom Wing
Superstructure – steel frame
Columns – W10, W12, HSS
Masonry – CMU walls in auditorium & gymnasium
Lateral System – shear walls & moment connections

MECHANICAL SYSTEM

Location – Mechanical Room at SW of building
AHUs – eleven rooftop units (5,000 – 25,000 CFM), chilled water & natural gas
Chillers – 310 & 364 ton units w/ (3) 450 GPM CHWP
Auxiliary Units – split system air conditioners, fan coil units, elec. baseboard heaters, elec. wall heaters
Fire Protection – Wet Pipe System

LIGHTING/ELECTRICAL SYSTEM

Main Switchboard – (1) 3000A
Panel Boards - (42) 120/208V & (32) 480/277V
Backup Power Diesel Generator
Auditorium Lighting – 6" LED down lights
Classroom Lighting – pendant linear fluorescent
Main Elec. Room – Southwest of CWNCHS
Branch Elec. Rooms – (6) along north side

All images are courtesy of Astorino.

http://www.engr.psu.edu/ae/thesis/portfolios/2014/azh5102/index.html

EXECUTIVE SUMMARY

Abstract

This report details four technical analyses that pertain to the means and methods of construction at Cardinal Wuerl North Catholic High School in Cranberry Township, PA. It also focuses heavily on how a project team can positively influence facility management by clearly defining their goals. The building covers 180,000 SF and two stories above grade in the classroom wings, one below grade for the cafeteria and MEP areas, and primarily one story above grade (with varying heights) everywhere else including athletic areas, the auditorium, and the arts wing. The four areas of analysis hope to provide the client with a better final product by reducing costs and schedule duration by prefabricating the exterior skin and improving the effectiveness of turnover to the FM by reducing lifecycle costs of finishes delivering all information efficiently.

Analysis Descriptions

Technical Analysis #1 describes the efforts in implementing prefabricated exterior masonry panels. The original method of stick-built construction from metal studs to brick veneer took roughly six months to complete and was the cause of heavy site congestion and coordination. So, Sto Panel Technologies' Brick Insulated wall panel system was analyzed for integration at CWNCHS. This was the only system considered due to the heavy architectural, thermal, and structural requirements of the exterior skin. The cost proved to be too expensive to work with this building, most likely due to the complicated geometry and relatively shallow wall heights, but all aspects were heavily scrutinized to prove that this would indeed be the case. Regardless of the predicted overall schedule reduction of several weeks, the general conditions reductions would not outweigh the much larger overall cost difference $814,293.86 in favor of the original method. Accompanying this analysis are architectural and structural breadths to determine watertight applications of prefabricated panels and the structural transfer of brick veneer on the foundation to panels bearing on the superstructure.

Technical Analysis #2 describes the methods of lifecycle cost analyses on the finish materials at CWNCHS. The finishes division of the Value Engineering report comprised 19.7% of the total reported cost deductions. This analysis serves to challenge the figures that were reported based on a lifecycle costs based on maintenance, repair, refinishing, replacement, etc. rather than the initial costs of construction alone. The decision to use VCT rather than carpet in the auditorium was changed due to present value lifecycle costs and it was reported that the present value lifecycle cost the analyzed VE items is 69% less than what was projected.

Technical Analysis #3 serves as an industry research topic in the Efficient and Effective Turnover of Facilities Management Information. This topic was presented to me at the PACE Conference and directly relates to CWNCHS since the focal point of BIM applications was record modeling for facilities management utilization. This analysis also provides a matrix for owners to decide on how to go about efficiently and effectively delivering information to a facility manager in order to maintain the building as best as they are able to. For CWNCHS, it was recommended to utilize

Onuma software for facility management as well as to determine training procedures as early as possible to minimize costs.

Technical Analysis #4 analyzed alternative roofing systems to the TPO that was installed at CWNCHS. TPO Roofing that is fully adhered to the substrate causes problems for cold weather installation due to the 25 deg. C temperature threshold that is required by the adhesive. This caused a heavy re-sequencing effort on this project to maintain the substantial completion date of January 31st, 2014. Mascaro was already having issues with keeping this date due to the late turnover of the building pad and these issues came when they were trying to achieve building dry-in. This analysis proposes to use the Duro-Last PVC roofing system product that estimates roughly 75% prefabrication. It can be installed in winter months, is more cost effective than the TPO system that was installed at CWNCHS, and reduces substantial completion date.

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John West – Mascaro Construction Company

Bill Derence – Mascaro Construction Company

Dom Baruffi – Sto Panel Technologies

Jay Monteverde – Duro-Last Commercial Roofing System Company

Vaughn Hanley – Diocese of Pittsburgh

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Chapter 1: PROJECT OVERVIEW

1.1: Project Description

Cardinal Wuerl North Catholic High School (CWNCHS) was designed and built to relocate the original North Catholic High School in Troy Hill, PA (5 minutes outside of downtown Pittsburgh) to a site north of Pittsburgh in Cranberry, PA (20 minutes outside). The original school was outdated and in dire need of either a renovation or a new facility. With the decline of the neighborhood that it was located in, in conjunction with the upheaval of students north of the city attending the school, the Diocese decided to move the school to build a new facility in Cranberry. This high profile project that had its design reviewed by the Vatican broke ground after several years of fundraising and planning in June 2012. CWNCHS is a two-story facility with one partial floor below grade and a gross square footage of 177,129. It will operate as a private Catholic high school and eventually be the home to 1,000 students. The construction of this project was completed in two phases which are outlined in the table below as well as the diagram showing the different areas of the building:

PHASE I	
Area	Description
A	Split between upper and lower level. Serves cafeteria, kitchen, MEP, 1500 person gymnasium, locker rooms
B	Southeast corner of building; serves maintenance, fitness center, athletic/administrative offices
D	1,000 person auditorium, administrative areas. North of A/B, highest roof (53'4"), façade visible from E/W
E	Described as "Arts Wing", serving library & musical education. North of D at northeast corner of CWNCHS
F	Two story classroom wing west of E. Language arts, art edu., science labs, relig. Edu. Classes.
G	Two story classroom wing west of F. English, health, theology, math soc. Studies classrooms. 2nd Floor = Core & Shell
PHASE II	
Area	Description
C	Chapel located in CWNCHS courtyard west of A/D, south of F. Began 8/2013 after funds were raised

Figure 1: Building Sections Description

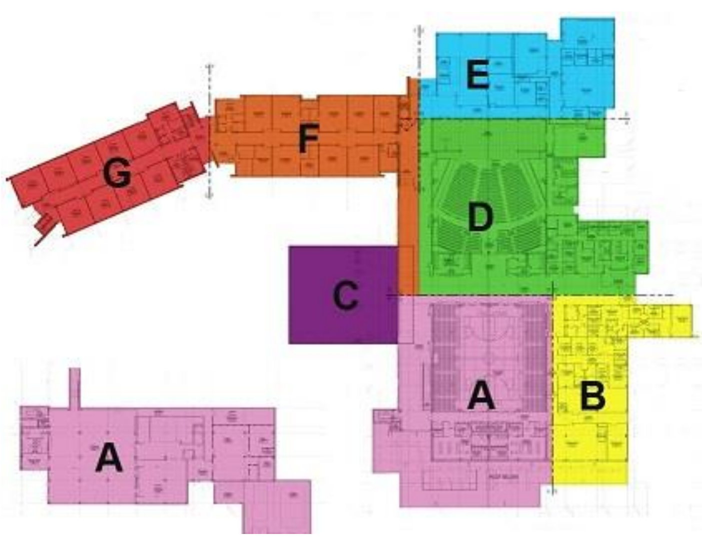


Figure 2: Building Sections Layout (Property of Astorino)

The General Contractor for the project is Mascaro Construction, contracted under a GMP and delivered as design-bid-build. Mascaro did provide some preconstruction services according to the owner. From groundbreaking to the completion of Phase II, the project was scheduled to take 24 months to complete with a total budget of $72.5 million. A further cost breakdown can be found in Section 1.7 or the Appendix A. A schedule breakdown can be found in Section 1.8 or Appendix B.

1.2: Local Conditions

Much of the existing conditions logistical issues were due to land acquisition from longtime land/home owners, removal of a house on the project site & debris from other demolished buildings, extensive tree removal & grading, wetlands mitigation and the removal of one overhead electrical wire. After receiving the Notice to Proceed on June 4th, 2012, three months of wetland mitigation, tree removal and grading delayed the turnover of the building pad to general contractor until September 1st, 2012. Two main problems were encountered in the subsurface investigation of the site. "Redbed" materials were commonplace and are dangerous naturally since they are prone to landslides. They also have a very low internal strength. In areas where this soil will affect the building pad or road conditions, it was over-excavated and filled with engineered soil. The condition of this soil also required temporary excavation safety such as temporary shoring and excavation rigging. Also, some groundwater was found throughout the site. The source of the water was suggested to be from observable seeps, small streams and wet areas. These areas required extensive use of subsurface drainage measures such as rock-fill drains.

1.3: Client Information

The owner of Cardinal Wuerl North Catholic High School is the Catholic Diocese of Pittsburgh. Their Chief Facilities Officer, Mike Arnold, functions as the owner representative between the architects/engineers, CM, and prime contractors. After a considerable amount of time in the construction industry of Pittsburgh, Mike joined the Diocese in 2011 and oversees the maintenance of 1,000 buildings in the area. The primary reason for constructing a new school north of Pittsburgh was population growth in Cranberry Township area. More and more students from Cranberry were enrolling at the original High School while enrollment in the current region had been steadily dropping for years. North Catholic High School was also becoming old & outdated, so the Diocese decided to move the school after years of planning and fundraising.

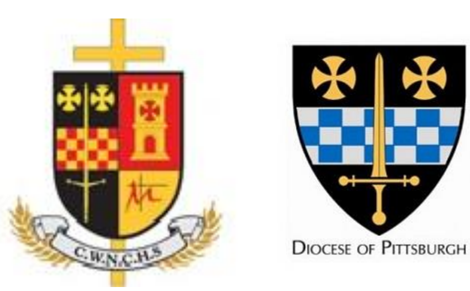


Figure 3: CWNCHS Crest & Diocese of Pittsburgh Crest

1.4: Project Delivery System

Cardinal Wuerl North Catholic High School is considered a design-bid-build project but according to the owner, the Diocese used a hybrid delivery method that incorporated aspects of Integrated Project Delivery while competitively bidding prequalified bidders. Due to his own experience with a variety of delivery systems, Mike Arnold chose the multiple prime, general contractor lead w/ CM Agency structure. He has a wealth of experience in the Pittsburgh area and was selective based on past project performance quality and professionalism. The general contractor was selected based on qualifications, staff & fee structure. Their responsibility as the lead prime on the project was to ensure maintenance of the schedule. As of this moment, Cardinal Wuerl North Catholic High School is scheduled to be complete on time. GMP contracts are in use between the Diocese-architect, Diocese-CM & Diocese-primes. The contracts being utilized (A132-2009. A232-2009 & B132-2009) are in place to ensure that the CM is on the team solely for advising and quality control. Mascaro Construction has lump sum contracts with all of their subcontractors, such as, Cost, D-M, Phoenix Roofing, RAM & SS&E.

1.5: Project Team Staffing Plan

The GC and CM have representatives onsite 5 days/week. Jesse Campayno (CM) can speak directly with Mascaro's VP of Building Operations, Ron Cortes, if necessary, but he will typically communicate with Jon Machen or John West (both of Mascaro) when Mr. West is at the jobsite. Jesse Campayno's foreman, Dan Doyle, is onsite full-time and is in charge of day-to-day QA/QC operations.

Jon Machen (Mascaro Construction) is the onsite Project Manager who delegates to his superintendent Tim Hanna, two project engineers (Nick Depperman & Billy Charles), the administrators (Melanie West & Michelle McCrea), and the BIM/Cost Control departments of Mascaro's corporate office when necessary. Tim Hanna delegates to Mascaro's subcontractors and his two foremen, Paul Hess & Danny Long. They are in charge of all carpentry, general labor/carpentry & cast-in-place concrete. In October 2013, Jon Machen moved on to another project and Billy Charles became the project manager throughout the rest of the project.

1.6: Building Systems Summary

1.6.1: Structural Steel Frame

The primary structure of CWNCHS is its steel frame. The building reaches vertically by utilizing a system of W10, W12 & various HSS columns, and is either covered by TPO or standing seam metal roofing. The frame utilizes shear walls in the stairwells and elevator shafts as well as moment connections on beams throughout the structure for lateral strength. Mobile cranes were used since a lot of horizontal distance needed to be covered during the erection phase. Two mobile boom & jib cranes navigated the perimeter for 1.5 months in order to put the steel skeleton in place. 5.5" thick composite slabs were used in the few areas that required a second floor, while most of the slab construction was on-grade.

Figure 4: Steel Erection Phase (Property of Mascaro Construction)

1.6.2: Cast-In-Place Concrete

Perhaps the biggest undertaking at CWNCHS was the cast-in-place concrete. It took approximately 9 months to complete from the first pour in November 2012 to the last in August 2013. Since most of the school is on one level, a majority of the concrete flooring was poured on grade at 1203'-0". Mascaro self-performed all concrete, which included footers, retaining walls, slab-on-grade, slab-on-deck, cast-in-place stairs, prefabricated steel pan stair cast-in-place concrete, etc. Where it was necessary, the primary formwork used was lumber. In a lot of places, formwork was not necessary due to the two courses of CMU on the footers, which shaped the outer edge of the cast-in-place slab on grade. Power buggies were used for all 1st level concrete placements while a concrete pump truck was necessary for composite slab-on-deck pours at higher elevations.

Figure 5: Auditorium Risers (Property of Mascaro Construction)

1.6.3: Mechanical System

Cardinal Wuerl North Catholic High School is cooled by eleven VAV rooftop air-handling units, two fan coil units, and thirteen split system air conditioners. The primary method of cooling the spaces throughout the building is by providing chilled water to the AHUs, utilizing the chilled water coil in the unit, and delivering conditioned air through overhead ducts at traditional grille, register & diffuser terminals. The aforementioned air-handlers range in size from 10-HP to 40-HP and serve the library, music suite, lower level, administration areas, athletic suite, academic wings, auditorium & gymnasium. All chilled water to these units is returned to the three B&G 1510 36 Model chilled water pumps located in Room A006 (MEP) and are rated at 450 GPM (25-HP; one of these CHWPs must be on standby at all times). From here, the 30% propylene glycol chilled water passes through a glycol fill station and recirculate through one of the two 350-ton chillers in the mechanical yard on the south side of the building. The majority of the chilled water supply feeds the rooftop AHUs but a small portion is delivered to the two fan-coil units for the purposes of providing conditioned air to the academic wing stairwells. Aside from the water-to-air system described, thirteen split system air conditioners are installed at roof level to serve MEP/MDF/machine rooms on lower level A, electrical/IDF rooms through Areas B, E, & F, and the auxiliary/storage rooms (D103/D104) in the auditorium. The SSACs used in CWNCHS supply either 240, 345, or 640 CFM and are necessary to provide constant volume air conditioning to these critical spaces. The rooftop air-handling units also provide heated air through means of natural gas and deliver conditioned air through overhead ducts at traditional grille, register & diffuser terminals. The natural gas service enters North Catholic at the south end of the building in the chiller yard from a 3" pipe at 2-psig/8,702 CFH. The service feeds the ten air-handling units and the three water heaters through branch piping from this single entrance. The natural gas is used as fuel for the AHU's at a max gas inlet pressure of 14 in-wg in each unit and the natural gas burner shall be fully modulating with a minimum turndown ratio of 10:1. Mechanical space is designated in the southeast corner of Area A.

Figure 6: CHWPs & Chiller Yard (Mascaro Property)

1.6.4: Electrical System

The underground electrical utility service enters the building at the south side in the mechanical yard into the utility transformer. The primary service power then travels to an exterior current transformer cabinet and inside the building to the main switchboard (3,000 Amps). Power is distributed from here to the 41-208/120V & 30-480/277V panel boards. EMT conduit runs the length of the building from here, feeding power to the entire complex. Classrooms utilize pendant linear fluorescent lighting while the auditorium utilized 6" pendant LED down lights. There is also a diesel generator in the mechanical yard of the building, which serves emergency power and has an optional standby power. Branch electrical and IDF rooms are located in many areas throughout the school. The main electrical rooms are located in the southeast corner of lower Level A.

Figure 7: 3,000A Main Switchboard (Mascaro Property)

1.6.5: Masonry

CMUs were used to construct shear walls in the staircases & elevators. They were also used in areas such as the locker rooms, kitchen, MEP rooms etc. as the finished wall material. A brick veneer is used on almost 65% of the exterior. Traditional scaffolding was used on most elevations other than the Area E north elevation. A hydraulic scaffolding lift was used here since it was the largest & simplest scope of brick veneer work for efficiency's sake.

Figure 8: Brick Masonry Construction on Area E East (Mascaro Property)

1.6.6: Support of Excavation

Earthwork and site clearing were the focuses of construction early on in the project. The extensive tree clearing and excavating that needed to occur drove the project during summer 2012. Temporary excavation support (shoring & rigging) was needed during excavation due to reported groundwater and the possibility of landslide due to excessive redbed soil. Onsite roadwork and earthwork changes caused for a change in the site's entrances/exits several times.

1.6.7: LEED

The Catholic Diocese wanted to incorporate the best practices of sustainability that were possible with LEED options. The LEED certification was important to the Diocese but overall goals of sustainability were more important than "point chasing", or going after points that did not make sense based on the owner's goals. Other considerations included cost, needs and mission of Cardinal Wuerl North Catholic High School, environmental stewardship, and energy costs. After the initial planning took place, the following matrix was developed to determine what type of LEED Certification would be attainable:

	Very Likely	Somewhat Likely	Not Likely	Not Attempting
Sustainable Sites	10	0	1	13
Water Efficiency	9	0	0	2
Energy & Atmosphere	9	0	0	24
Materials & Resources	7	0	0	6
Indoor Environmental Quality	11	0	1	7
Innovation & Design Process	4	2	0	0
Regional Priority	3	0	0	1
TOTALS	53	2	2	53

Figure 9: LEED Matrix (Astorino Property)

The matrix shows that the project will attempt to achieve anywhere between 53-57 points. If this goal is met the project will receive a LEED Silver Certification. The project team held meetings to track LEED progress weekly and the team is confident that they will fulfill LEED goals. The major points of emphasis were the indoor environment, water efficient landscaping, sustainable sites, recycled/regional materials, and construction waste management.

1.6.8: BIM

The major Building Information Modeling goals at CWNCHS were to reduce change orders due to the possibility of poorly coordinated drawings, assist with visualization of design so the owner's input could be obtained earlier in the process, logistics/schedule/asset management, and so that the Diocese could use rendered images for marketing purposes. Models were transferred from design to construction in order to track any as-built changes and coordinate between the general contractor and any other primes. All models were continuously updated as needed and coordination meetings were held as necessary throughout construction between the owner, CM, GC, architect and primes. At the time of substantial completion, a Federated Model populated with As-Built information from the A/E, primes and subs will be delivered to the owner in .NWD (NavisWorks) or .DWF format. The Chief Facilities Officer for the Diocese plans to use this model for Facility Management purposes. The table below displays the BIM Uses planned for CWNCHS:

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	Programming	X	Design Authoring		Site Utilization Planning		Building Maintenance scheduling
	Site Analysis	X	Design Reviews		Construction System Design		Building System Analysis
		X	3d Coordination	X	3d Coordination		Asset Management
			Structural Analysis		Digital Fabrication		Space Management / Tracking
			Lighting Analysis		3d Control and Planning		Disaster Planning
		X	Energy Analysis	X	Record Modeling	X	Record Modeling
		X	Mechanical Analysis				
			Other Eng. Analysis				
		X	Sustainability (LEED) Evaluation				
			Code Validation				
	Phase Planning (4d Modeling)	X	Phase Planning (4d Modeling)	X	Phase Planning (4d Modeling)		Phase Planning (4d Modeling)
	Cost Estimation	X	Cost Estimation	X	Cost Estimation		Cost Estimation
	Existing Conditions Modeling		Existing Conditions Modeling		Existing Conditions Modeling		Existing Conditions Modeling

Figure 10: BIM Uses at CWNCHS (Mascaro Property)

1.7: Project Costs & Estimates

1.7.1: Actual Construction Costs

The actual building construction costs and CC/SF are reported (excluding site work, site acquisition/permitting, etc.) as $43,027,573.00 and $242.92/SF respectively. This is based around the building GSF of 177,129. Total project cost is reported at $72,525,969.00, $13.91/SF. The large drop in cost/SF can be attributed the extent of land that was acquired (71 acres). At the request of the owner, the MEP/FP system costs are not listed individually, but the combined cost is $8,860,010.00 and $49.99/SF. The structural system cost was reported from the GC as $6,017,485.00 and $33.97/SF.

ACTUAL BUILDING COSTS		
	Construction Cost	**Cost/SF**
Actual Building Construction Costs (CC)	$43,027,573.00	$242.92
Total Project Cost (TC)	$72,525,969.00	$13.91
MEP/FP Systems Total Cost	$8,860,010.00	$49.99
Structural Systems Cost	$6,017,485.00	$33.97

Figure 11: Actual Building Costs

1.7.2: Square Foot Estimate

The CC/SF cost given by RS Means for face brick w/ concrete block back up (no exterior studs/sheathing provided) at the interpolated value for 177,129 GSF is $162.92/SF. After using their provided formulas for adjustments, it was shown that the final CC/SF was $181.58/SF. Additives such as telescoping bleachers, clock system, elevators, flagpoles, kitchen equipment, lockers, auditorium/classroom seating & sound system were added in an attempt to get the estimate figure closer to the actual building construction cost.

The $9 million difference in price between the estimate and the actual number can be attributed to a lot of ideas. First of all, the building pad and perimeter of this building are very large in comparison to other schools that RS Means would evaluate. It is also a private school, which tend to be more expensive. CWNCHS did not always take the low bidder either. Also, RS Means did not provide the proper wall construction. Finally, there wasn't much repetitive work that occurred, which most likely drove down production rates and drove labor costs up. MEP costs were very high due to the length their branches needed to travel from the southeast corner of the building.

Square Foot Estimate		
Appraisal Information		
Gross Floor Area (SF)		177,129
Perimeter (LF)		3,136
Average Story Height (LF)		20'-1"
Building Estimate		
Adjusted Base Cost/SF		$181.58/SF
Building Cost Estimate	$	32,163,083.82
Additives	$	1,481,640.00
FINAL TOTAL COST	**$**	**33,644,723.82**

Figure 12: RS Means Square Foot Estimate

1.7.3: System Assemblies Estimates

The combined costs of the MEP/FP systems at CWNCHS account for the largest cost component of the building. MEP/FP systems were estimated at $9,125,341.15 or $51.52/SF. Each system required a different quantification for each take-off to arrive at a reasonable cost. All systems were adjusted with a location modifier of 1.02 (Pittsburgh, PA) after developing a subtotal. The combined cost values came within 3% of the real project costs. This accuracy was helpful when researching alternative MEP systems for Cardinal Wuerl North Catholic High School. By determining accurate costs based on components it makes it much easier to determine what parts are expensive and what can possibly be value engineered out of the system.

The plumbing estimate required all fixtures to be accounted for in order to develop a cost. Fixtures included water closets, urinals, lavatories, kitchen sinks, lab sinks, service sinks, showers, cup sinks, electric water cooler & electric water heaters. A 75% multiplier was added to the fixture costs in order to account for distribution piping, drains, waste pipes, and vents.

The mechanical system estimate required calculating the quantity of SF that the split system air conditioners serve (27,000) compared the SF that rooftop air-handling units serve (153,000). Applying these areas to the unit cost based on the building type and unit capacity (tons) determined the cost. The electrical system estimate required all lighting fixtures, receptacles, panel boards and light switches to be taken off as well as the underground electrical service, main switchboard and all branch wiring. The fire protection system consists of a 4" wet pipe configuration, mostly on one floor. This situation provides a unit value based on SF from RS Means. A cost reduction was calculated in order to develop a more accurate systems cost (since the floor area is not 50,000 ft^2 as stated in RS Means). All takeoffs and full estimates can be found in Appendix C.

MEP/FP ESTIMATE COMBINED TOTAL	$	9,125,341.15
REAL MEP/FP COST	$	8,860,010.00
% Difference		97%

Figure 13: MEP/FP Estimate Totals

1.7.4: General Conditions Estimate

The General Conditions cost for Cardinal Wuerl North Catholic High School was estimated to be $2,871,341 over the 21 month schedule. The period that General Conditions costs were counted was from September 2012 – June 2014 since the general contractor was on site during that time period. The site contractor's fees were not counted in this estimate (they began activity in June 2012). My estimate puts General Conditions at 6.67% of the actual building construction costs (~$43 million) and $136,730.52/month. GC costs were slightly high, which can be largely attributed to high temporary structure costs needed for the large onsite staff. The project team reported an approximate value of $3,000,000 for their general conditions services. Therefore, most if not all of the actual resources, temporary structures and miscellaneous items have been accurately reported. A full estimate can be found in Appendix D.

1.8: Project Schedule

CWNCHS's site was turned over to Allegheny Excavating, INC. on June 4th, 2012 in order to begin earthwork. Due to delays from the site contractor, the building pad turnover to the GC was delayed roughly three weeks. Regardless of the late start, foundation work began on 9/24/2012 and did so in a very quick fashion. The three weeks that were lost from the original schedule were completely recovered by June 2013. Completion of the superstructure frame & detailing took slightly over 2 months and made way for roof/building enclosure work. The building exterior is slotted to finish at the end of September 2013, giving the project team 4 months to finish the building interior. Perhaps the most critical scheduling item outside of the late start was the late design & construction of the chapel. This design had been in the original plan but the funds for it were not available until the beginning of summer 2013. Once they were available, Astorino went into the design phase and prepared 100% completed drawings by mid-July. One month later on August 12th, 2013, Mascaro broke ground. Phase 1 (main building) finished on time (1/31/14) and the chapel will be completed by May 30th, 2014. The table below shows the project milestones:

MILESTONES	
NTP - Site Earthwork	4-Jun-12
Building Pad Ready for Foundation Installation	1-Sep-12
Obtain Building Permit - Diocese	20-Sep-12
Structural Steel - Begin	12-Nov-12
Structural Steel - Complete	18-Jan-13
Building Exterior - Complete	26-Sep-13
Substantial Completion - Main Building	30-Jan-14
Substantial Completion - Chapel	30-May-14

Figure 14: CWNCHS Project Milestones

1.9: Site Layout Planning

All excavation, superstructure, and enclosure/finishes site layout plans can be located in Appendix E. The following descriptions serve as the corresponding narratives for said site plans:

1.9.1: Excavation

The primary concern during the beginning phase of the project was to clear all of the trees and overgrowth on the Cardinal Wuerl North Catholic High School property in order to grade the soil to the correct elevations. This was done in order to provide a clean building bad to the GC. Identification & removal of the existing overhead electrical wire during this time was critical. The existing house on the property was demolished, shoring was required in “redbed” soil areas during excavation due to redbed’s tendency to slip, wetland mitigation and underground utilities/storm water management did not begin yet. Site access is only from Old Mars Crider Road (North). Neither route 228 nor Franklin Road was ready for site access yet.

1.9.2: Superstructure

The primary concern during this phase of the project was structural steel erection. All foundations were installed, the site was cleared, and the building pad was turned over from the site contractor. Material laydown areas, dumpsters & temporary toilets were moved closer to the temporary parking areas in order to not interfere with the two crawler cranes on site. By reducing foot traffic around the cranes, it reduces the risk of an accident. Rental cranes are very expensive to rent and it would not be beneficial to waste time because there are too many obstacles for the crane. Also, any areas in the cranes erection sequence for a given time period were considered “restricted access areas”. Other important logistics of the site during this time included gained access from Route 228, the beginning of permanent underground utilities’ construction, site gates were added at the entrances and exits to protect developing assets, a temporary transformer and electricity were added behind the temporary trailers on the NW side of the site, and storm water management reservoirs’ development began. To protect them from breaking under the weight of the crawler cranes, underground storm piping and permanent water piping were not installed around the immediate building perimeter during this phase.

1.9.3: Enclosure

The primary concern during this project phase was demobilization and opening up the site for owner occupation. In order to do this, it was necessary to reduce the number of dumpsters, transition material laydown areas to parking areas, and demobilize/reduce temporary structures & toilets. At the conclusion of the project, the project site team will consist of the GC and CM Agency. Primes with trailers should have demobilized. Active work during this phase primarily consisted of interior finishes, chapel construction, and main building punch list. Temporary parking became permanent. Laborers were parking in the permanent lots on the southeast corner of CWNCHS. Finally, all permanent utilities are shown and installed.

Chapter 2: PREFABRICATION OF EXTERIOR MASONRY PANELS

2.1: Problem Identification

Offsite prefabrication is becoming more and more popular in the construction industry. Considering the multiple levels of wall construction that were a cause of heavy coordination and schedule congestion at North Catholic, I believe it is worth evaluating the possibility of a prefabricated façade for the masonry sections. The Insulated Metal Panels were prefabricated and were often waiting on the completion of the masonry work to move forward. Not to mention, glass could not be installed until the brick was completed, which tied up interior finishes such as drywall installation, taping and finishing. A better coordinated process could mitigate these issues regarding the schedule and offsite prefabrication may also provide cost savings. Also, the spray-applied air barrier contractor often displayed poor workmanship and required an extraordinary amount of QA/QC management from the project team. This issue could have been averted under controlled conditions. Possible cost savings, schedule accelerations, and logistical considerations can be evaluated by this concept.

2.2: Research Goals

The research goals are as follows:

1. Explore the effects of prefabricated panels as opposed to the stick-built method.
2. Analyze all aspects of construction that would influence the decision to prefabricate including cost, schedule, quality, safety, constructability, delivery, manufacturing, and the erection logistics & sequence.
3. Produce a cost/schedule comparison vs. the original method of construction in order to choose the most practical method.
4. Analyze the materials used in the prefabricated alternatives to ensure watertight design practices are implemented properly.
5. Determine structural implications of utilizing this method of construction.

2.3: Application Methodology

1. Research case studies using this technique/investigate off-site prefabrication and delivery. Develop costs/durations from this
2. Research if any current project members have experience with this method
3. Determine subcontractor availability in Pittsburgh
4. Determine actual construction costs and durations from Mascaro pertaining to stick-built method used currently
5. Design several alternative approaches to paneling building
6. Research on-site prefabrication and locate laydown/production area
7. Determine sequencing of panel erection
8. Develop site plans/logistics, safety concerns
9. Explore savings/losses associated with prefabrication (schedule, cost, quality, safety) compared to original method
10. Develop a recommendation for or against prefabrication

2.4: Background Information

The use of prefabricated brick wall panels is becoming more and more popular in the construction industry. Whereas they were more widely used in southern states such as Florida, Texas, and California originally, they are spreading all over the country. The reason for this can be attributed to their cost savings, schedule reductions, and a reduction in onsite congestion. Most critics of prefabricating masonry wall panels claim that a lot of variation in design is a sign that this method should be avoided. Other professionals in the masonry industry claim that there are advantages in using this method for unique exteriors because each panel is custom made and can all be different. These varying industry views will be put to the test in this analysis. It may be difficult to develop a steady flow of work with unique panels like those that would be used at CWNCHS, which might drive up labor costs. Attempts must be made to limit the variations in design and stress must be placed on panel-to-panel joint design.

2.5: Preliminary Analysis

Prefabricated exterior wall panels require a wealth of research and the implementation of said panels takes an incredible planning and coordination effort. While this method of construction is most often used in Design-Build project delivery systems because it is coordination and planning intensive, it could have been implemented at CWNCHS. This project used a Design-Bid-Build delivery system, but Mascaro claimed to provide preconstruction services to the owner and A/E. So, a suggestion for a panelized system could have occurred if they deemed it was fitting.

While there is an enormous planning effort that is required by the general contractor, the design and engineering phases are critical. There are three important design characteristics of prefabricated masonry panels; architectural, structural, and mechanical. First of all, architectural design must be considered overall for aesthetic. Manufacturers will often work with the project team to achieve the appropriate aesthetic design that they desire. If the owner and architect are not in favor of the exterior finish, they will most likely not be happy with the building in general. Following that, the design team must consider that once panel fabrication begins, that design changes will be extremely costly, so façade design and dimensions should be finalized as early as possible. Also, the infiltration of fluids such as air and water must be considered. Ensuring the watertight design of this system will be the focal point of my first breadth. Finally, a panel area (ft^2) must be chosen to walk the line between minimizing the number of joints and designing it efficiently for structural considerations (also has bearings on construction management considerations). Prefab panels operate differently in a structural aspect than the stick-built method. The stick-built method bears directly on the foundation (footings) while prefabricated panels bear on the steel superstructure. So, the structural engineer must work directly with the architect to design a lightweight, yet energy efficient panel system. The connections to the superstructure must be analyzed to determine how much additional weight is added so it can be designed to ensure structural integrity. Footings must be redesigned to represent how much load has been taken off of them. This will be the focus of my second breadth. In the process of designing a lightweight system, thin bricks are often used. The use of a more lightweight thin brick may sacrifice a component of the R-value, which has a direct effect on the mechanical system. The R-value of the wall assembly should match that of the original assembly as closely as possible; otherwise room heating/cooling load calculations should occur to resize the corresponding mechanical equipment if necessary. For this analysis, I will attempt to match the R-value of the system so that a mechanical redesign and additional mechanical design breadth are not necessary.

The general contractor should have a direct input in prefabrication design to ensure construction practices are considered. For the GC, schedule and cost considerations ultimately drive the decision whether or not to use prefabricated panels, with a plethora of considerations falling under those categories. Panel sizes should be coordinated with the manufacturer or GC to determine that supply chain logistics are considered. For example, if the panels are designed too largely, they won't fit under highway overpasses, through tunnels, or on a flatbed semi-trailer (8'6" wide and 48'-53' long). It is also critical to find a manufacturer relatively close to the project to reduce shipping costs. Also, the final panel design should be approved with time considered so that warehouse construction can begin. Lead time to design, build all panels in the warehouse, and ship at a time that effectively reduces site storage and congestion is vital. There also needs to be a plan for site laydown and an erection plan. This usually involves labeling the panels at the warehouse and coordinating with the GC where they would like them to be laid down on the site. Laydown is obviously planned according to proximity from where the panel will be placed on the building façade. Placement of panels requires a crane to erect, which involves determining crane capacity based on weight of panels, incorporation of panel erection into a site specific safety plan, mobilization/demobilization of a crane, and scheduling considerations.

An accurate and well-executed schedule is vital to the success of utilizing prefabrication because it can greatly reduce the time necessary for the stick-built method by 85% and greatly reduce your critical path. An erection plan with corresponding graphical representations can reduce confusion and provide a better sequence of façade installation at CWNCHS. If it is coordinated directly after steel erection, crane costs can be reduced. To mitigate the higher cost/SF of prefabricated panels, most of the additional cost savings directly correlate with a reduction of the critical path since general conditions costs can be reduced. Additional cost savings may occur from a structural redesign. General conditions costs are very high on this GMP project ($6,835/day) and can save the owner money if the project team can finish ahead of schedule, regardless of the fact that there is no rush to get the project done quickly. Appropriate standards and codes must also be considered, including:

- ASTM C109-10 – Standard Specification for Prefabricated Masonry Panels
- ASTM E119 – Exterior Wall Rating (fire)
- NFPA 285 – Non-Combustive Wall with Combustible Components
- ANSI/UL 2079 – Perimeter Joint

2.6: Current Façade Assembly

The current façade that is being studied required three separate subcontractors and roughly 6 months to construct from initial cold-formed metal framing installation to the final curing and wash-down of masonry. These multiple layers of wall construction were the cause of many hours of quality control supervision, months of site congestion and restrictions on the beginning of interior activities/finishes. A wall section displaying the installed exterior brick veneer façade is shown below:

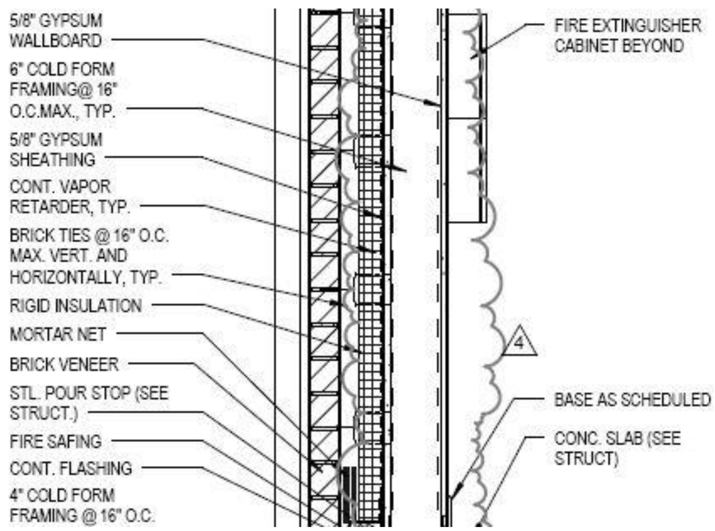


Figure 15: Actual Wall Assembly (Astorino Property)

The 6" cold-formed metal framing and 5/8" gypsum sheathing were completed first by RAM Corporation, the continuous vapor barrier was spray applied by Tom Brown Contracting, and the rigid insulation and masonry veneer were installed by Cost Company. During the 6 months that these multiple trades took to finish the façade, they followed the two flows of work around the large perimeter of Cardinal Wuerl North Catholic High School. In the beginning of February 2013, two separate crews began working on two different sections of the building. Façade construction started on the north and south elevations of Area F on February 6, 2013 and worked west towards area G until the last cure/wash-down occurred at the west elevation of Area G on July 29, 2013. Work began in Area A on February 13, 2013 and worked north on Area B, Area D, and Area E, where work completed for the entire façade on August 8, 2013 at the north elevation. This progression can be seen in the graphic to the right:

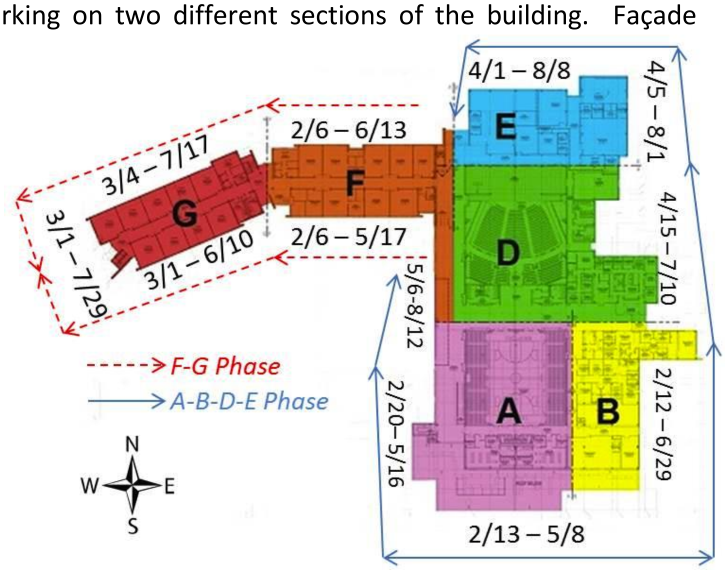


Figure 16: Original Wall Construction Sequence (Astorino Property)

While investigating the current assembly, it was also necessary to determine the R-value in order to compare it against other systems. R-values were found using ASHRAE 90.1 for the entire assembly and summed in the table below:

CWNCHS Wall Assemby Total R-Value	
1. Exterior Air Film	0.17
2. 3-5/8" Brick	0.44
3. 1" Air Space	1.00
4. Thermax 3" Rigid Insulation	19.00
5. Continuous Air Barrier	-
6. Glass Mat Exterior Gypsum Wall Sheathing	0.57
7. Interior Air Space	1.62
8. 1/2" Interior GWB	0.45
TOTAL R-VALUE	***23.25***

Figure 17: Original Wall Assembly R-Value Calculation

It is also necessary to determine loading for the wall assembly. First, the brick veneer that bears directly on the footing foundation weighs approximately 50 PSF. When considering prefabrication, this load will be dismissed. This is because the prefabricated panels are welded to the steel superstructure via nelson studs and all loading is transferred to the columns. The metal studs are mechanically attached to the slab below and steel frame above. All sheathing and insulation are fastened to cold-formed metal studs and are accounted for in design calculations of the studs. Air barrier is spray-applied over sheathing. Bricks are mechanically fastened to the insulation through the use of brick ties for lateral stability. The transfer of the brick veneer load from the foundation in the stick-built method to the steel superstructure in the prefabricated panel method may cause a redesign of exterior columns as well as footings. As a side note, brick assemblies at Cardinal Wuerl North Catholic High School that do not have this exact assembly will not be considered in this analysis. For example, walls at the mechanical yard are 16" CMU on 4" face brick and there are several areas that use wing walls for aesthetic purposes that are 12" CMU on 4" face brick. These areas will be built on site and have not been factored into the actual costs of the current system. In order to compare costs with the alternative system being proposed, an estimate was prepared for actual costs of the current system. It is shown below:

CWNCHS Brick Takeoff	
A - South	4772
A - West	3455
B - East	2922
B - North	843
B - South	3400
D - East	6214
D - North	637
D - South	866
E - North	6027
F - North	4661
F - South	2992
G- North	3846
G - South	2573
G - West	1449
TOTAL (SF)	**44657**

Actual Façade Costs		
	Material	**Labor**
Brick	$220,000	$510,000
Insulation	$180,000	-
Air-Barrier	$170,000	
Metal Stud	$127,000	$215,000
Sheathing	$37,000	$57,000
TOTAL	**$1,516,000**	
Total Wall Assembly Cost/SF	***$33.95***	

Figure 18: Brick Takeoffs & Actual Costs

All figures were reported from the project team and rounded within reason for privacy purposes. The important figures are the total cost of materials and labor as well as the assembly cost/SF. $33.95/SF was used while researching alternatives to gauge what would be an acceptable price range for a prefabricated panel system.

2.7: Prefabricated Alternatives

Only one system will be analyzed for the sake of this report. Through my rounds of initial research, many manufacturers and contractors were eliminated based on the extensive qualifications and requirements that are necessary to implement prefabrication. For example, Brick-It™ Thin Brick & Installation Systems were one of the leading systems to be used but it was realized during researching them that they would not be a viable product based on the size of their panels. They recommend very small panels (48” x 11-1/2”) that would require a lot of joints. This would increase the time it takes to erect panels, drive up costs due to a larger number of smaller panels, and have a negative aesthetic appearance. Also, other assembly types such as thin brick on concrete did not work because of their lower R-values, which would have caused a mechanical redesign. For this reason, it was necessary to look into another option. Sto Panel Technologies offers a Brick Insulated prefabricated panelized system as a solution to the stick-built method at CWNCHS. Their Brick Insulated wall assembly is very similar to that of the wall construction at CWNCHS. From inside to out, it uses cold-formed metal framing, glass mat gypsum sheathing, waterproof air barrier membrane, Sto Insul X® (rigid insulation that sits between Z-channels), a slip sheet, Sto Cast Bed Reinforced®, thin set adhesive, and 5/8” thin brick and grout. The image on the bottom left shows the current wall assembly with the image on the bottom right being the proposed wall assembly for prefabricated construction:

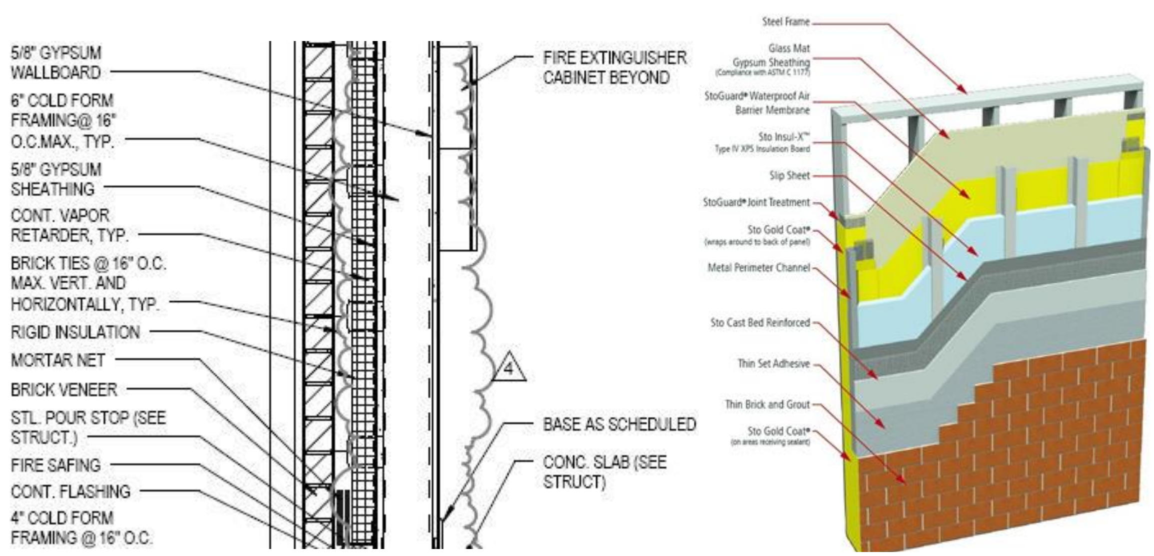


Figure 19: Current Assembly vs. Proposed Assembly (Astorino Property; Sto Panel Technologies Property)

The almost exactly similar wall assembly of Sto Panel compared to the original assembly was one of the primary reasons that it was chosen as the system to analyze. According to Dom Baruffi, it is supremely energy efficient with an R-Value close to 30. This value is acceptable when compared to the R-23 assembly used currently at CWNCHS and will not be further analyzed (over-insulating principles will be disregarded). Since the project team at CWNCHS was required to put a lot of time into quality control for the spray-applied air barrier to ensure its integrity, waterproofing and airproofing were very important in the panel system selection process to ensure that damages were not caused to any part of the wall. This will help in ensuring that HVAC inefficiencies are as minimal as possible. Other advantages of the Sto Panel Brick Insulated system are:

- *Speed* – carefully controlled installation time is pre-determined. Schedule compression is guaranteed.
- *Reduced site congestion*:
    - Storage of studs, sheathing, air barrier product, insulation, and brick for long periods of time is cut in place of several days for panel laydown.
    - No scaffolding required.
    - Heavy manpower only needed for several weeks compared to months.
    - Equipment to move bricks and mix grout is minimized.
- *Quality* – precisely engineered and manufactured in environment controlled conditions. Extensive shipping protection prevents damage. There is also a single source of warranty for this product rather than several with the stick-built method.
- *Lightweight* – easier installation and lower structural requirements (20 PSF)
- *Finishes* – several different styles of thin brick are available (two different brick colors at CWNCHS)

After doing as much research as possible from internet resources, I spoke with the Executive Director of Sto Panel Technologies, Dominick Baruffi. He was able to answer a lot of lingering questions. First of all, Sto Panel has several certified manufacturers around the country. J&B Acoustical Inc. in Mansfield, OH is the closest manufacturer to Pittsburgh, PA and is a viable option for shipping since it is only 154 miles away (3 hour drive). Next, he was able to inform me that costs for this system are typically \$58/SF - \$62/SF depending on the complexity of the system's design and the overall height. For conservative purposes I will use \$62/SF since CWNCHS is not a very tall building at all and has a very complex geometry with very little repeatability. This figure includes engineering, fabrication, supply/shipping, erection, and caulking. Also, he recommended designing panels at a size range between 200 – 300 ft^2 for weight and erection time purposes. The weight aspect of this issue will be considered in Chapter 4 in my structural breadth. In order to determine the scheduling impact, Dominick informed me that erection crews put up an average of ten panels per day. This figure includes laydown, erection, and tune-ups (caulking and detailing). After erection, the panels are ready to receive batt insulation and interior GWB. The assembly should also be fire caulked at the interior to pass code inspection.

2.8: Investigation of Chosen Alternative

While Sto Panel's Brick Insulated system passes all the prerequisite tests of aesthetics, thermal performance, and quality of workmanship, it is necessary to put cost, schedule, constructability, safety and site logistics to the test in the following sections to determine if it is of value to the owner.

2.8.1: Schedule/Cost

To analyze if there will be a cost savings involved with using prefabricated panels, a critical path evaluation must be considered. The panels are more expensive by $/SF, so general conditions savings are the most likely area to see reduced a cost on the project's GMP contract. The following table shows where the façade activities that would be reduced by panelized construction are located on the critical path and their corresponding durations:

Current Critical Path Activities	
Area F - North Elevation (Feb 5th - Feb 25th)	
Cold-Formed Metal Studs	10 days
Exterior Sheathing	10 days
Area G - North Elevation (Feb 26th - March 15th)	
Cold-Formed Metal Studs	14 days
Area D - East Elevation (May 15th - June 20th)	
Cold-Formed Metal Studs	5 days
Exterior Sheathing	10 days
Spray-Applied Air Barrier	3 days
Brick Veneer	10 days
TOTAL CP DURATION	**62**

Figure 20: Current Facade Critical Path Activities & Durations

After determining how many days that façade activities are on the critical path, a panelized system should be designed for those areas to determine how long installation would take. According to the table above, erection should be ready to start by February 5th, 2013 and travel west towards the west end of the north elevation of Area G to gain critical path reduction benefits. It should be noted that all steel superstructure activities were completed by January 18th, 2013, so all panels are available to be erected and welded to the steel skeleton by this date. The following images and tables show how the F North, G North, and D East panels will be designed and erected:

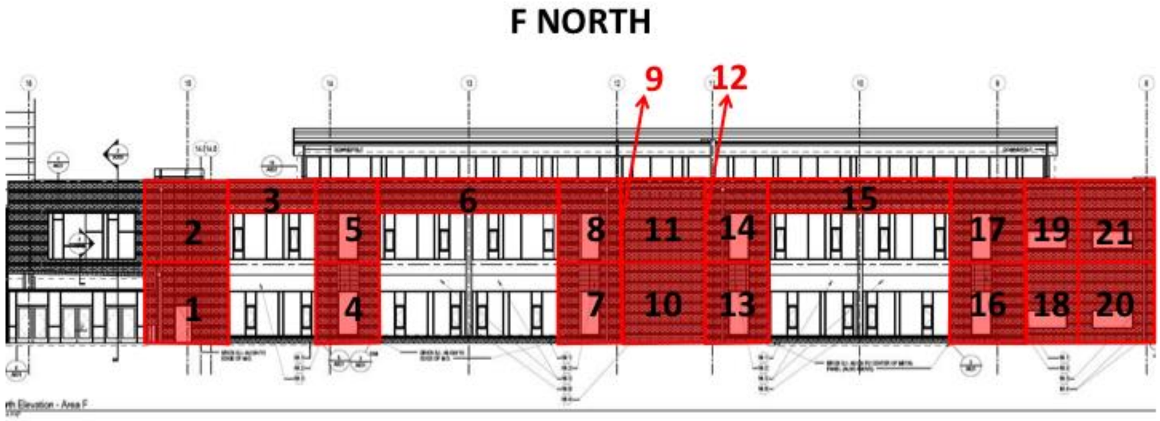


Figure 21: Area F North Elevation - Panel Design and Erection Sequence (Astorino Property)

F North - Panel Design Sequence					
Panel No.	Height (ft)	Width (ft)	Area	Punch-Out Area	Total Panel Area
1	16	16.5	264	25	239
2	16	16.5	264		264
3	6.25	17.7	111		111
4	16	12.5	200	40	160
5	16	12.5	200	40	160
6	35.4	6.25	221		221
7	16	12.5	200	40	160
8	16	12.5	200	40	160
9	32	4	128		128
10	16.5	16	264		264
11	16.5	16	264		264
12	32	4	128		128
13	16	12.5	200	40	160
14	16	12.5	200	40	160
15	35.4	6.25	221		221
16	16	15	240	40	200
17	16	15	240	40	200
18	16	14.5	232	40	192
19	16	14.5	232	40	192
20	16	14.5	232	40	192
21	16	14.5	232	40	192
		Total SF	**4473**	***Total Gross SF***	**3968.125**
		AVG Panel Size	**213**	***AVG Gross Panel Size***	**189**

Figure 22: Area F North Panel Takeoffs

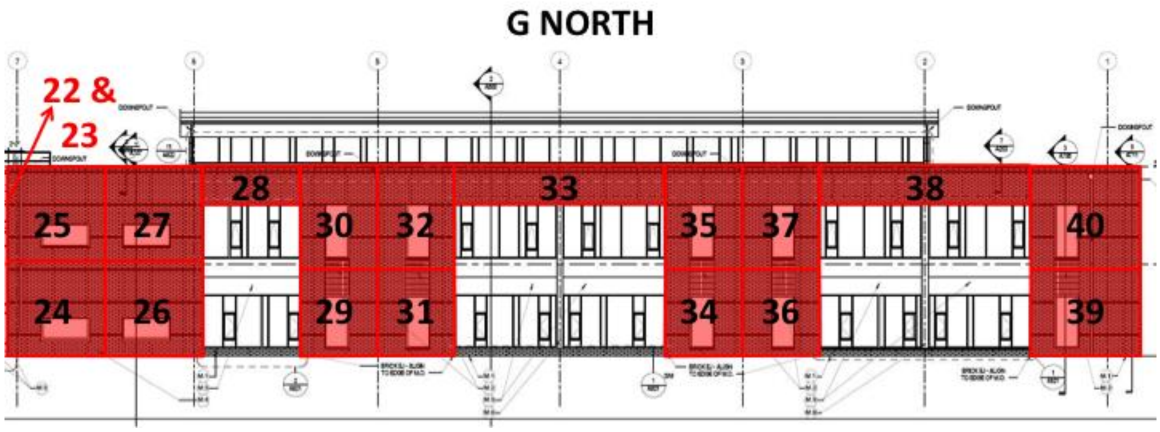


Figure 23: Area G North Elevation - Panel Design and Erection Sequence (Astorino Property)

G North - Panel Design Sequence					
Panel No.	**Height (ft)**	**Width (ft)**	**Area**	**Punch-Out Area**	**Total Panel Area**
22	16	10	160		160
23	16	10	160		160
24	16	16	256	32	224
25	16	16	256	32	224
26	16	16	256	32	224
27	16	16	256	32	224
28	6.25	16.67	104		104
29	16	13	208	38	170
30	16	13	208	38	170
31	16	13	208	38	170
32	16	13	208	38	170
33	36	6.25	225		225
34	16	13	208	38	170
35	16	13	208	38	170
36	16	13	208	38	170
37	16	13	208	38	170
38	36	6.25	225		225
39	18.75	16	300	38	262
40	18.75	16	300	38	262
		Total SF	**4162**	***Total Gross SF***	**3654.1875**
		AVG Panel Size	**219**	***AVG Gross Panel Size***	**192**

Figure 24: Area G North Panel Takeoffs

Figure 25: Area D East Elevation - Panel Design and Erection Sequence (Astorino Property)

D East - Panel Design Sequence					
Panel No.	Height (ft)	Width (ft)	Area	Punch-Out Area	Total Panel Area
41	17.25	5.5	95		95
42	3	12.5	38		38
43	17.25	9	155		155
44	3	5.5	17		17
45	17.25	9	155		155
46	3	13.5	41		41
47	3	10	30		30
48	17.25	12	207		207
49	3	15	45		45
50	17.25	6	104		104
51	3	15	45		45
52	17.25	9	155		155
53	3	13.5	41		41
54	17.25	3	52		52
55	17.25	7	121		121
56	17.25	12.25	211		211
57	17.25	12.25	211		211
58	17.25	12.25	211		211
59	17.25	12.25	211		211
60	8.83	26.5	234		234
61	8.83	26.5	234		234
62	8.83	26.5	234		234
63	13.25	16	212		212
64	13.25	16	212		212
65	18.17	9	164		164
66	26.5	10	265		265
67	13.25	15.5	205	25	180
68	13.25	15.5	205		205
		Total SF	4109	*Total Gross SF*	**4084**
		AVG Panel Size	147	*AVG Gross Panel Size*	**146**

Figure 26: Area G North Panel Takeoffs

For the purposes of this analysis, the total panelized system was not designed. Only the areas on the original project's critical path were designed to determine how many days could be saved, since these were the only areas that could have reduced the overall schedule duration. Dom Baruffi from Sto Panel informed me that panels could be erected at an average rate of 10 picks/day for sizes of 200 – 300 ft^2 panels. Considering that the panels on Areas F & G north are on the lower end of this range and the panels on Area D East are considerably smaller than that on average, it can be safely and conservatively assumed that the milestone of ten picks/day can be achieved.

After designing roughly 25% of the building's proposed panelized façade, an average panel size was determined in order to estimate the likely number of panels that will be manufactured at CWNCHS. This process is shown below:

1. 11,707 GSF of Panels designed in 160 panels
2. Average panel size is 172 SF
3. 44,627 Total SF of Brick Wall
4. Projected 260 Panels @ 10 panels/day erection rate
5. Estimated 26 raising days (laying, erecting, tune-up/detailing)

Weather permitting, panel erection will begin on Tuesday, February 5th, 2013 and conclude on Tuesday, March 12th, 2013. This is more than enough time to get the maximum critical path benefit possible. The schedule of façade activities is therefore reduced from roughly 6 months to a little over 5 weeks. By starting at the F North elevation, wrapping around the building counterclockwise, and concluding at the E North Elevation, panel erection finishes all original activities before their initial critical path dates were scheduled. This is outlined in the table below, which shows exactly how the cost difference will be compared between the stick-built method and prefabrication of masonry panels:

PREFABRICATED EXTERIOR MASONRY PANELS ESTIMATE		
Stick-Built Construction Costs	$	1,516,000.00
Cost/SF of Prefabricated Panels	$	62.00
Gross Square Feet of Panel Area		44,657
Estimated Cost of Prefabrication	$	2,768,734.00
Current Façade Critical Path Duration (days)		62
Prefabrication Critical Path Duration (days)		2
Critical Path Reduction (days)		60
General Conditions Cost/Day	$	6,835.00
General Conditions Savings	$	410,100.00
Structural Redesign Costs		
Footing Redesign Difference	$	28,340.14
Column Redesign Difference	$	-
TOTAL COST OF PREFABRICATED PANELS	$	2,330,293.86
STICK BUILT vs. PREFAB COST DIFFERENCE	$	(814,293.86)

Figure 27: Masonry Panels Estimate

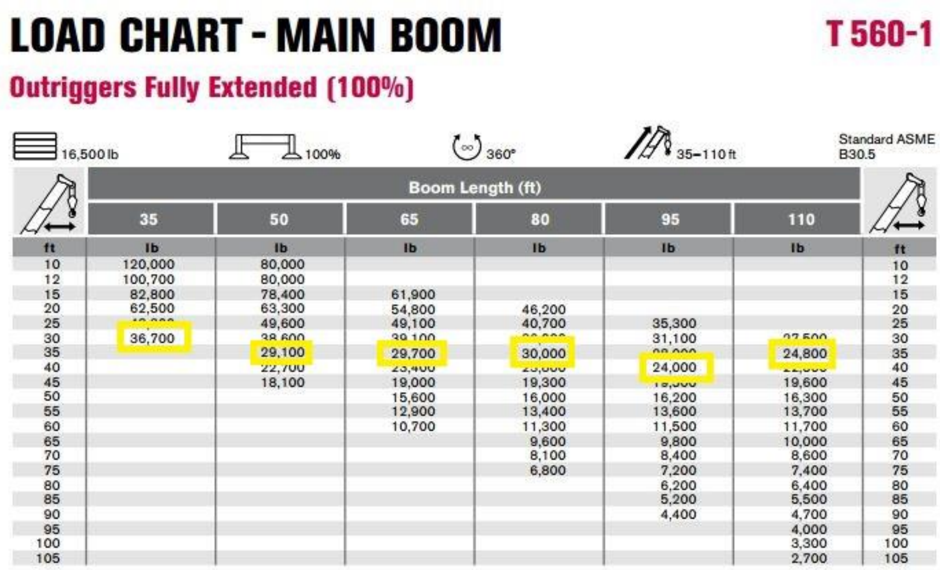
First of all, the larger cost/SF in the range of \$58/SF - \$62/SF that was given to me by Dom Baruffi was used due to the irregularity and lack of repeatability in panel design/construction. Even if the \$58/SF figure were used to attempt to drive costs down the difference would still be roughly \$636,000 in favor of the original method of construction. Secondly, since the critical path activities dealing with façade construction begin on February 5th on the F North Elevation, this is the only time that prefab erection coincides with the original critical path. If erection follows the sequence detailed in section 2.8.3, it will beat all originally scheduled dates and theoretically take 60 days off of the schedule. The likelihood of this large of a reduction is grim, but for the purposes of this analysis, a detailed critical path analysis using P6 would not have been beneficial anyways since the cost savings are not even close to viable. Also, as a side note, the scope of the flashing that was suggested to be added in my architectural breadth was very cheap relative to the cost difference observed above and assumed to be negligible. Clearly, cost is the bottom line in this analysis. Therefore, it has been proven that prefabrication is most likely not a good course of action to pursue.

2.8.2: Constructability

There are a multitude of constructability issues that can be described for prefabricated masonry panels. The level of detail that goes along with this analysis can go as far as you'd like to take it. Since many of the constructability issues have been described throughout this analysis and are described in the logistics plans and both breadth studies, I will outline several other areas of concern that do not fit well in other subtopics. First of all, to maintain the critical path savings, a float path analysis should be determined to see if the maximum benefit is attainable. 60 days of critical path savings is roughly 3 months and there are a lot of other activities that may join the critical path in that time. Based on logic, other exterior finishes would most likely come next in line on the critical path since the building's exterior dry-in milestone relies on all exterior finishes to be complete. Glass, insulated metal panel, and roofing installation may hold the prefabricated masonry panels from achieving the full critical path reduction benefit. It is ultimately difficult to tell without the aid of a scheduling program such as P6 where the critical path will specifically go next since CWNCHS is very irregularly shaped and geometrically complex. Secondly, the manufacturer that would be used (J&B Acoustical Inc. in this circumstance) needs to submit progress reports to ensure that all panels are on track to be completed and shipped to the CWNCHS site on time. Another constructability concern deals with safety. The deletion of scaffolding makes the risk of accidents lower but there are different risks associated with panel erection by crane. All safety concerns should be clearly identified in a site specific safety plan (SSSP). Next, fire caulking should be accounted for on the panels' interiors to achieve code requirements. Sto Panel does not perform this task and recommended that it should be considered before closing up the wall. All MEP penetration concerns are outlined in Chapter 3. The structural change proposed should require that the bottom of the footing's elevation be raised 4" higher to achieve the originally planned 1203'-0" FFE. Finally, the implementation of prefabricated masonry panels is no small undertaking. It should be considered at the beginning of a project and carefully coordinated with all parties, including architects/engineers, general contractor, construction management agency, and the owner. All parties who have a stake in the building façade need to be involved to ensure proper execution otherwise problems in the field will most likely arise at a bad time.

2.8.3: Site Logistics

Since the superstructure erection finished two weeks prior to the projected beginning of panel erection, it was decided to leave the smaller of the two crawler cranes onsite to erect all panels. The model being used is a Terex T560-1 crawler crane. The other crawler crane had a much larger capacity and was unnecessary to still be on site after steel erection. Keeping this crane on site will save on mobilization/demobilization costs of another crane. After a quick analysis, it has the ability to quickly erect all panels. The largest panel design was 300 GSF. Since Sto Panel Brick Insulated weighs 20 PSF, the heaviest potential panel is 6,000 lbs. According to ASTM C901-10 – Standard Specification for Prefabricated Masonry Panels, lifting devices should be equipped with 4x dead weight capacity of the panel. So, the crane should have a capacity of 24,000 lb. at its extended length of erection. Since all erections are at the perimeter of the building, the crane's capacity should be of little concern because the maximum extension of the boom will only need to be 20 ft. in most cases. The following table shows the maximum loading conditions for the Terex T560-1 highlighted:



LOAD CHART - MAIN BOOM T 560-1

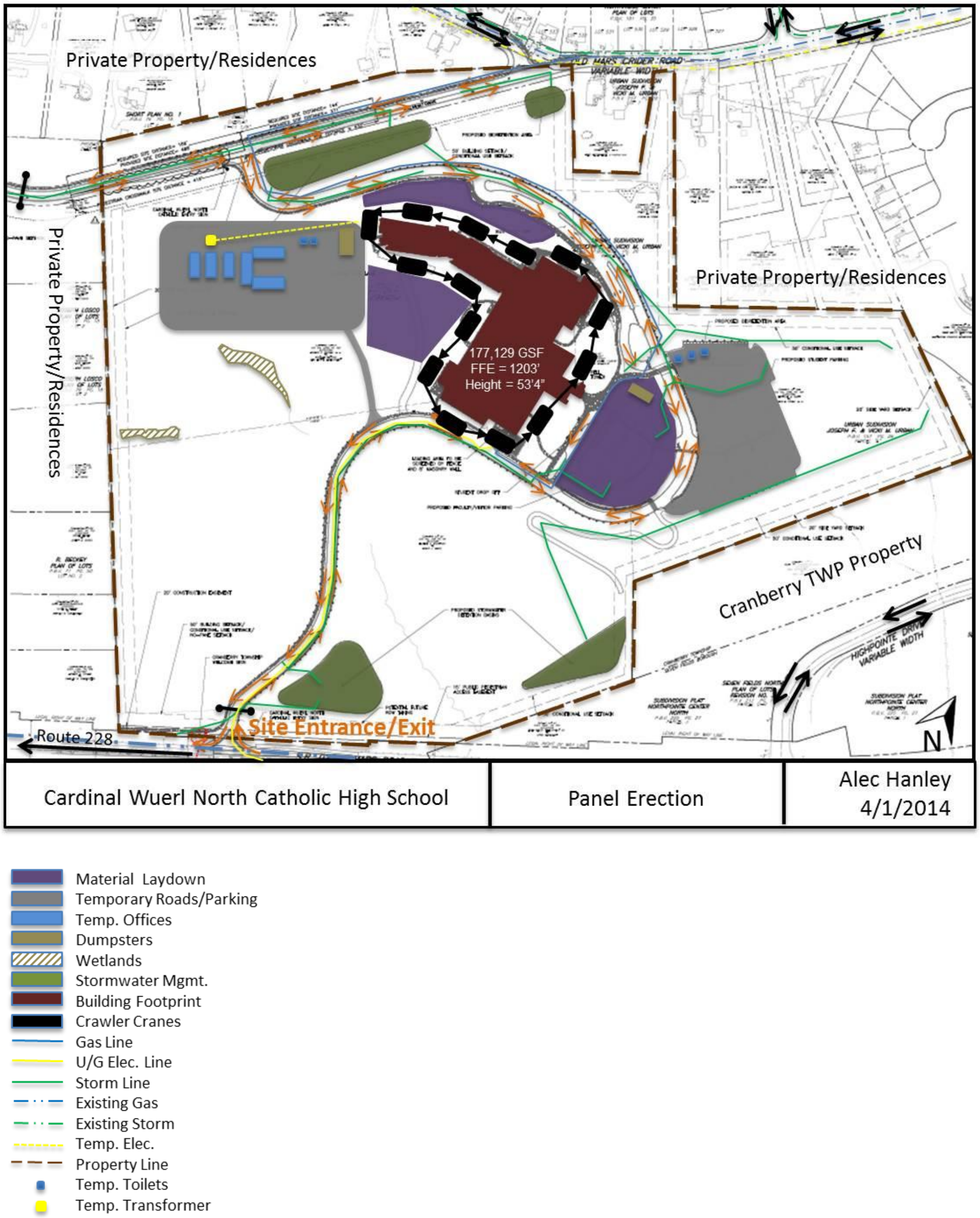
Outriggers Fully Extended (100%)

16,500 lb | 100% | 360° | 35–110 ft | Standard ASME B30.5

	Boom Length (ft)						
	35	50	65	80	95	110	
ft	lb	lb	lb	lb	lb	lb	ft
10	120,000	80,000					10
12	100,700	80,000					12
15	82,800	78,400	61,900				15
20	62,500	63,300	54,800	46,200			20
25	[illegible]	49,600	49,100	40,700	35,300		25
30	36,700	38,600	39,100	[illegible]	31,100	27,500	30
35		29,100	29,700	30,000	[illegible]	24,800	35
40		22,700	23,400	[illegible]	24,000	[illegible]	40
45		18,100	19,000	19,300	[illegible]	19,600	45
50			15,600	16,000	16,200	16,300	50
55			12,900	13,400	13,600	13,700	55
60			10,700	11,300	11,500	11,700	60
65				9,600	9,800	10,000	65
70				8,100	8,400	8,600	70
75				6,800	7,200	7,400	75
80					6,200	6,400	80
85					5,200	5,500	85
90					4,400	4,700	90
95						4,000	95
100						3,300	100
105						2,700	105

Figure 28: Terex T560-1 Load Chart (Property of Terex)

A specific site plan should also be developed for the amount of time that erection will take place. This is to make sure that the crane can fit into all necessary areas and to show that there is adequate space for panel laydown. The following image shows a panel erection site plan with the crane shown in black around the building perimeter and panel laydown areas in purple along with a legend for all other items shown:



Cardinal Wuerl North Catholic High School did not often encounter issues with site congestion, so the adequate laydown space shown above as well as the erection sequence should have no issues. The erection sequence begins on the north side of the building in Area F and wraps around the building counterclockwise, concluding at the north elevation of Area E.

2.8.4: LEED Evaluation

Sto Panel Brick Insulated has added credits in Energy & Atmosphere and Innovation-In-Design. First of all, after consulting with Mascaro's project manager and engineers who are certified LEED APs, a point can be added for optimizing energy performance. The building has achieved 15.54% improvement over ASHRAE 90.1's standards and the additional R-7 in the wall assembly should be able to reach the benchmark of 16% improvement for an extra point. While this is a rough estimate, it is a very safe one at that. Also, only 4 of the 6 available points were achieved in Innovation & Design Process. The implementation of highly energy efficient prefabricated masonry panels that minimize construction waste by manufacturing in factory controlled conditions can provide another point. Overall, 2 points can be added to change the total from 53 points to 55. While this doesn't change the certification value of the building from Silver to Gold per say, it certainly is an added benefit of the system that should be recognized.

2.9: Conclusion/Recommendation

Despite the many advantages that prefabricated masonry panels offer, such as schedule reduction, quality control, reduction in site congestion, safety improvements, structural savings, LEED benefits, and the very energy efficient design due to effective insulation/air barrier, I am recommending against using them on this project. The bottom line in this circumstance is that the cost savings are not there. There are no long term tangible benefits of using this system so costs of construction are the only cost that matters. I had heard many times that this system was better for taller, more regular shaped buildings based on the high cost/SF and this analysis proved that hypothesis to be correct. Using this system in geometrically complicated circumstances should only be considered when schedule reduction is of the utmost importance. There is little repeatability in design of panels on CWNCHS' short structure, which may contribute to even higher costs. Perhaps a cheaper system exists that would have been beneficial to use, but it is not likely. The ultimate bane in this analysis was that this system's principles of use do not fit the geometry of my building. To even begin to see a cost benefit would require a cost/SF for masonry panels on this project to be roughly $43. Even that is unlikely due to the fact that the very generous estimate of a 60 day schedule reduction is highly unlikely and factored into the $43/SF figure. Sto Panel Brick Insulated offers a great product, but on a project where the building is very irregularly shaped and the schedule did not require a large reduction, I would recommend against using it.

Chapter 3: BREADTH #1 – WATERTIGHT DESIGN OF PREFABRICATED EXTERIOR MASONRY WALL PANELS

3.1: Problem Identification

Prefabricated walls' biggest issues are typically directly related to infiltration of water through their joints. For this reason, it is suggested that they be designed with a minimal number of joints. Details at corners, parapets, top of wall, etc. typically have the highest risk of infiltration. Prefabricated panels should be designed with the proper water-stopping materials to ensure performance and durability. Forces that cause infiltration will be researched to determine where additional components should be added to stop the infiltration of water. It should be researched where on the exterior of CWNCHS is at high risk of infiltration and the necessary water-stopping equipment will be added. It is necessary to fully develop details at transitions, wall corners and penetrations, and to develop dependable panel-to-panel joints. All considerations will be quantified and designed with respect to ASTM C901-10 – Standard Specification for Prefabricated Masonry Panels as well as an ASTM case study, "Prefabricated Brick Wall Panels: Economy or Nightmare?", written by Michael J. Louis.

3.2: Research Goals

Research goals are as follows:

1. Research issues with water infiltration in prefabricated wall panels.
2. Determine materials/methods to mitigate issues.
3. Locate high risk areas on CWNCHS façade and determine what materials would reduce or eliminate risk.
4. Show new materials in details/wall sections.
5. Determine cost impact.

3.3: Preliminary Research

Prefabricated panels lend themselves to cutting construction schedules substantially and reducing overall costs. They also offer advantages in quality since they are constructed in controlled factory environments. Panel construction is not affected by weather, uniformity is improved in factory conditions, quality control is easier to monitor, and cost savings can be gained. There are several risks associated with prefabricated panels though, including discontinuity of flashing and internal weather barriers, damages from transportation, and the possibility of corrosion and premature deterioration from increased steel reinforcing. The following paragraphs will discuss different waterproofing techniques, the principles behind those techniques, and specific case study that outlines how to design against different forces of water infiltration.

There are two different types of prefabricated wall panels based on water protection. First of all, there are "barrier wall panels". These panels are treated with water repellents in the form of additives in mortar in hopes that no infiltration will occur at all. Barrier wall panels cannot have any deficiencies in fabrication that would result in cracks and hairline cracks that develop from settlement over time must be considered. The other type of panel is a "cavity drainage panel". Cavity drainage panels incorporate an air space behind the veneer wall ties, a waterproofing barrier, flashing at the bottom of the air space, and gravity clips to transfer wind and dead load to the steel superstructure. In comparison with barrier wall panels, cavity drainage panels serve to accommodate rather than prevent water infiltration altogether. Complete prevention of water penetration over time is nearly impossible and the air space and drainage system incorporated into the wall assembly are vital.

There are six forces that can affect water flow through a prefabricated panel. These forces include gravity, kinetic energy, surface tension, capillary action, air currents, and pressure differences. These are the six fundamental forces that must be considered in brick masonry construction to protect against the infiltration of water. These six forces are displayed in the picture to the right.

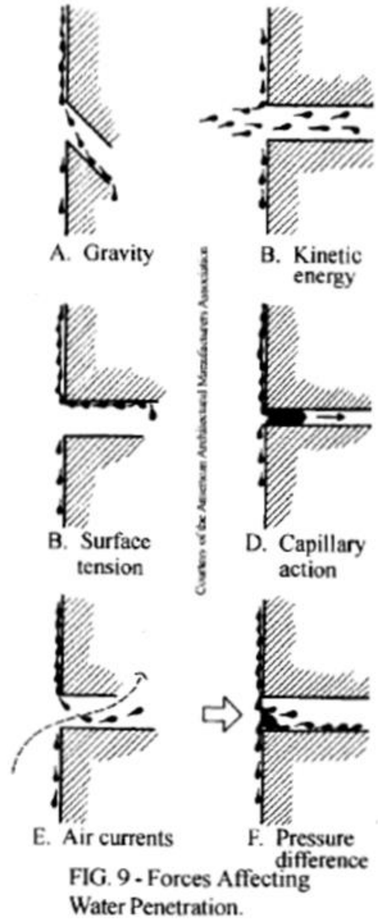


Figure 29: Forces Affecting Penetration of Water on Masonry (ASTM Property)

3.4: ASTM Case Study

"Prefabricated Brick Wall Panels: Economy or Nightmare" written by Michael J. Louis details the problems with water infiltration into prefabricated masonry panels and one specific case study. The lessons learned on this project are instrumental to anyone implementing a panelized system on their building façade. The case study describes the process from the beginning of design through a few years of the life of the building on a major corporate headquarters building with over 100,000 ft^2 of exterior wall area. The design team was under the impression that they were innovative in their water-tight design of the prefab assembly, but in reality they only considered pressure differences through the introduction of a rain screen design. The rain screen prevents air flow through the panel through the use of air vents in the cavity. Pressure differences on the face of the wall due to wind are reduced because of this. There are nine major components in the wall assembly being analyzed in this case study (next page):

1. Water Collection Pan with drainage hole
2. Perimeter Air Seal with gap at drainage holes
3. Foil Faced GWB with foil taped joints
4. Insulated Steel stud wall
5. Masonry tie-backs
6. Rigid insulation spacer
7. Reinforced brick panel
8. Pressure equalized air chamber and drainage cavity
9. Vent slots in head joints in masonry

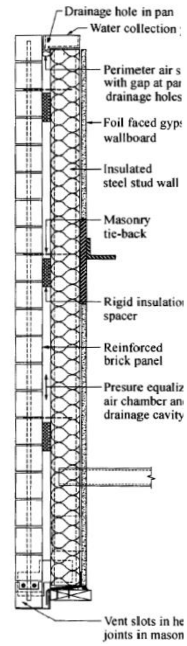


Figure 30: Case Study Wall Section (ASTM Property)

All of these individual components are seen in one wall assembly show above. While it appears that these components address a lot of water problems, such as adjoining panels and punched windows, there are clear deficiencies. The major problem associated with the wall panel's design was associated with the water collection pan. The pan was intended to collect water that may penetrate through or around window corners and from small panels between windows. From there, water that gathers in the collection pan should travel through the air cavity and exit at the sill flashing at the base of the wall. Problems occurred where water gathered on the inboard and outboard sides of the air cavity. Surface tension caused collection at mortar joints and at studs while masonry tie-backs and rigid insulation spacers served as a bridge for water to enter to the interior wall assembly. Batt insulation took on water, which was then transmitted to the metal framing. This causes rust on framing, a reduction of thermal transmittance in batt insulation, weak and moldy interior GWB, and water collection on the interior of the building. In summation, the panel system does not fully contain water within the air chamber and direct it to the base flashing. This problem could have been alleviated with a water/vapor barrier within the system. Several other issues on this project in the case study include, weather seals, panel termination, through-panel penetrations, and parapet wall panels. These issues are attributed to a lack of ability to easily modify special field detailing. The designers of prefabricated masonry panels should accurately

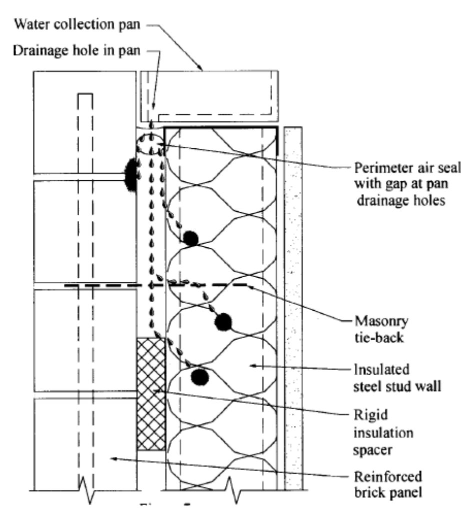


FIG. 7 - Water draining from collection pan at top of panel wets insulation and steel wall studs.

Figure 31: ASTM Study's Wall Section Flaws (ASTM Property)

anticipate all field conditions and develop specific detailed solutions. For example, the weather seals at joints between panels are often the weak point of prefab systems. Joints should be paid careful attention by surface cleaning/priming, providing sufficiently smooth bonding surfaces, proper geometry and tolerances, durability of the sealant, and chemical compatibility with adjacent materials. Dom Baruffi at Sto Panel assured me that their sealant is durable through the life of the warranty and is compatible with the prefabricated insulated metal panels used at CWNCHS. Also, panel termination is an issue where brick panels overlap at inside wall corners where it extends beyond the outboard face of the curtain wall. This does not occur at CWNCHS, but this situation should be handled by cutting of flashing at the corner so that water does not infiltrate to the interior. Through panel penetrations such as louvers, duct, structural elements, conduit, etc. were addressed with one layer of sealant at the exterior, but the interior element that traverses through the air chamber became a risk to water penetration to the interior since it is not sealed where it introduces itself to batt insulation. Finally, there is no insulation at parapet walls extended over the roof surface. So, water penetrates the brick veneer above the roof surface and is evaporated during daytime temperatures. When the temperature cools off during the night, the infiltrated water condenses on the interior face of the brick veneer and can transmit into the interior batt insulation and GWB since there is no insulation or waterproofing membrane present. Most of these are problems that could have been solved by the proper implementation of an effective vapor barrier and proper sealant/caulking techniques.

In conclusion, there are several principles that ASTM offers as a part of this case study when designing water control systems that can greatly improve the systems performance and durability. First of all, all details should be fully developed. Details for transitions, corners, and penetration should be fully detailed and designed for on construction drawings. Optimize the size of panels to reduce the overall number of joints and to provide better waterproofing integrity. Also, the wall assembly should avoid diverting water towards moisture sensitive materials. Secondly, all forces of water penetration should be considered, not just some. Finally, reliable panel-to-panel joints must be considered. ASTM recommends to use interlocking panel perimeters or to use dual joints with air gaps between seals. The air gap should have a weep at the bottom that leads to the exterior. Sufficient space should be provided to install and reinstall both joints from the outside.

3.5: Conclusions and Recommendations

From what has been gathered from the ASTM case study, detailing, ensuring that the proper materials are chosen, and a coordinated layout of the wall assembly are the most important aspects of making sure that your prefabricated wall system is watertight. First of all, utilizing a vapor barrier and sufficient flashing is very important. The spray-applied air barrier was the product that required the most quality control time at Cardinal Wuerl North Catholic High School with respect to the wall assembly. While assuring that the millage of the membrane was continuous and 1/16” thick in all areas was very important, detailing seemed to give the project team the most problems. Flashing at windows, penetrations, doors, expansion joints, parapet walls, and other areas of concern were watched very closely to ensure that no water/air would penetrate to the interior of the building. This is shown in the pictures below from CWNCHS:

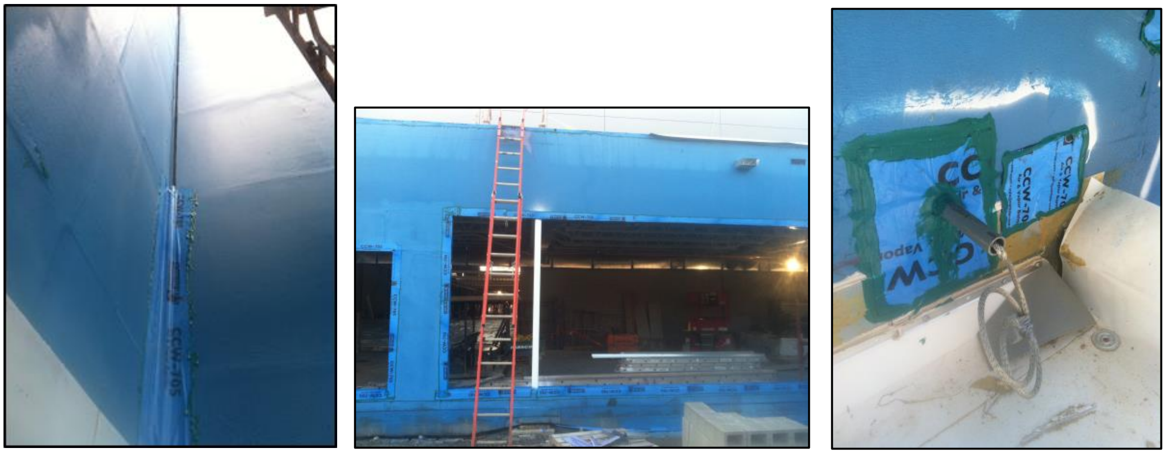


Figure 32: Air Barrier at CWNCHS (Mascaro Property)

The picture in the top left shows the expansion joint between the Area F classroom wing and the Area D main corridor. The middle picture shows the large windows in the main corridor in the D wing (auditorium). The picture to the top right shows an electrical penetration that was sufficiently flashed and caulked to ensure that no water/air penetration occurred. The continuous air barrier was a major point of emphasis at CWNCHS and when using a prefabricated panel it should be a very strong product. This was one of the primary reasons Sto Panel was chosen as the manufacturer to analyze. Their StoGuard® Waterproof Air Barrier Membrane and Sto Gold Coat® are excellent water protection systems. StoGuard® acts on the same principles that the system utilized at CWNCHS does. All penetrations must be sealed effectively and the millage must be 1/16". The major area of concern is between panels. Sto Gold Coat® serves to provide a shield for panel-to-panel joints so that water does not transmit to the interior or damage the wall assembly components. At said panel-to-panel joints, it is coated over the entire assembly from the cold-formed metal studs to right before the thin bricks. A weep hole is placed at the bottom of the joints so that water does not build up inside joints and infiltrate to the interior. Also, the fire sealant applied to the inside edge of the panel serves as a water resistor also. This is not done by the caulking/finishing team that Sto Panel contractors employ and should be accounted for by the GC. Also, MEP penetrations should be coordinated with all responsible contractors to ensure proper flashing/caulking around those penetrations. For example, if a conduit is necessary to penetrate to the exterior for a receptacle, it needs to sealed and flashed at the air barrier membrane. This can only be done by slipping a piece of conduit through the wall assembly at the time of prefabrication and sealing it at that point. This can become a problem if union electricians are being used because only union contractors can place conduit. This is why all penetrations should be coordinated and considered at the very

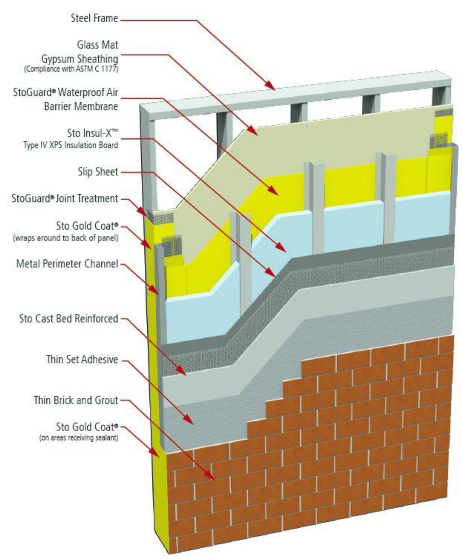


Figure 33: Brick Insulated Assembly (Sto Panel Property)

early stages of planning and design. An image of the Sto Panel wall assembly for their Brick Insulated system is shown above. The two images shown below are wall sections showing how detail oriented Sto Panel is when installing their air barrier. The one directly below shows how they guard against penetration through the metal perimeter channel as well as behind the Z-channel that holds the rigid insulation in place. The section directly below that shows how Sto Panel flashes between wall panels with Sto Gold Coat®.

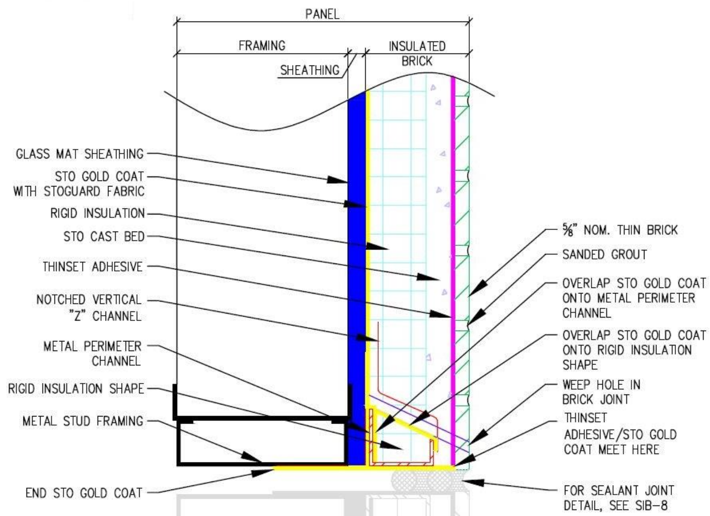


Figure 34: Sto Gold Detail at Metal Perimeter Channel (Sto Panel Property)

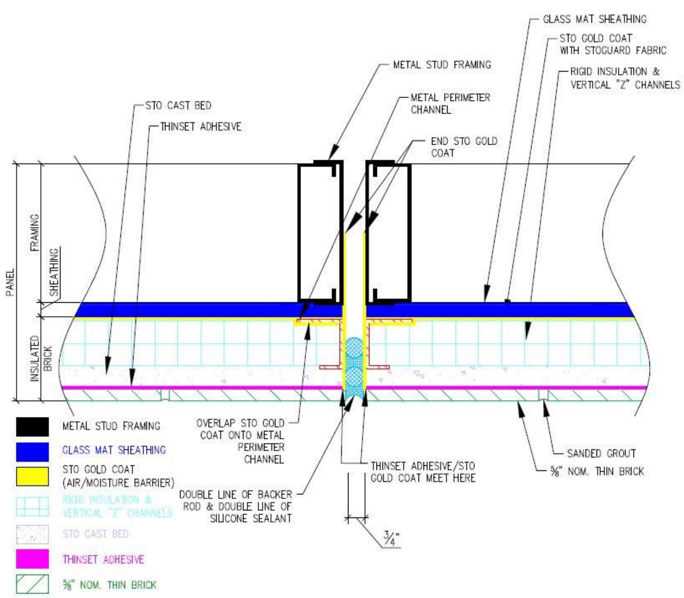


Figure 35: Sto Gold Detail at Joint (Sto Panel Property)

While Sto Panel's waterproofing system seems to be adequate to protect against many of the lessons learned in the ASTM case study that was referenced earlier, there is one area of deficiency in the system. At interior corners where the wall assembly can be transmitted into the interior, flashing is vital to protect against water infiltration. In the image above showing the expansion joint at CWNCHS, this is one example that should be protected against. If not flashed against properly, water may infiltrate, ruin the expansion joint, and cause mold on the interior GWB. The proper way to flash this detail is shown in the image below (provided by ASTM study):

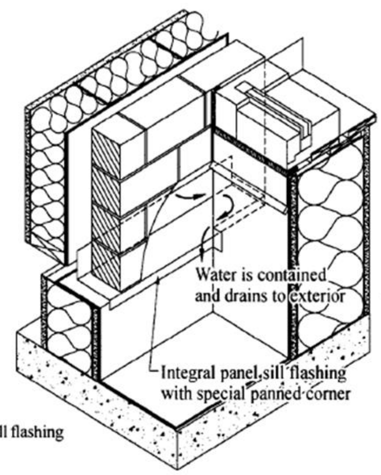


FIG. 14 - Panned sill flashing design.

Figure 36: Panned Sill Flashing (ASTM Property)

In conclusion, based on how well the vapor barrier is designed by Sto Panel Technologies at details and between joints, it is mostly sufficient for waterproofing. The above detail for flashing at interior corners should be added to protect against infiltration in that circumstance. A cost evaluation for this will not be provided since it is a relatively cheap detail to add and in the scope of the total prefabricated masonry panel estimate it would not make a large difference at all (especially since I recommended against them). Also, MEP penetrations should be coordinated with contractors to ensure they are properly waterproofed. Parapet walls are not an issue as long as they are properly flashed since the air barrier membrane and rigid insulation travel the entire way to the top of the wall. There are also no details where water is diverted towards the interior of the wall.

Chapter 4: BREADTH #2 – REDESIGN OF COLUMNS/FOOTINGS DUE TO PREFABRICATED MASONRY PANEL CONNECTION CHANGES

4.1: Problem Identification

Prefabricated exterior masonry panels are welded to the building's steel superstructure. In the stick-built method, the primary load to be considered is the brick veneer's 50 PSF dead load on the building's foundation. This causes a reduction on the buildings foundation and an additional load on the superstructure. These issues require design checks and possible redesigns. Since Area F's North Elevation was the primary focus of the analysis pertaining to this breadth and has the closest configuration to a typical bay on this irregular building as well as two stories, it will be the section of the structure analyzed and possibly redesigned.

4.2: Research Goals

The research goals are as follows:

1. Determine difference between stick-built loading of brick veneer and prefabricated panel loading on steel superstructure
2. Consider redesign of steel superstructure
3. Consider redesign of footing
4. Evaluate costs of redesigns and project over the entire building's structure
5. Direct costs back to overall panel estimate to make final decision

4.3: Preliminary Research

One huge advantage to the Sto Panel Brick Insulated system is its lightweight design. The original brick veneer weighed 50 PSF on the footings while the Sto Panel system weighs 20 PSF and bears on the steel superstructure. After speaking with Dom Baruffi at Sto Panel, he informed me that a design angle is with a nelson stud is welded to the pour stop at the edge of a slab or roof member. There is a 1" nominal dimension between the panel and the member that it is welded to, to allow for workability. This load then transfers to columns and requires a redesign since it was not accounted for in the original design. As stated above, the area that will be considered for purposes of this analysis is half of the north elevation of Area F. This elevation is shown below:

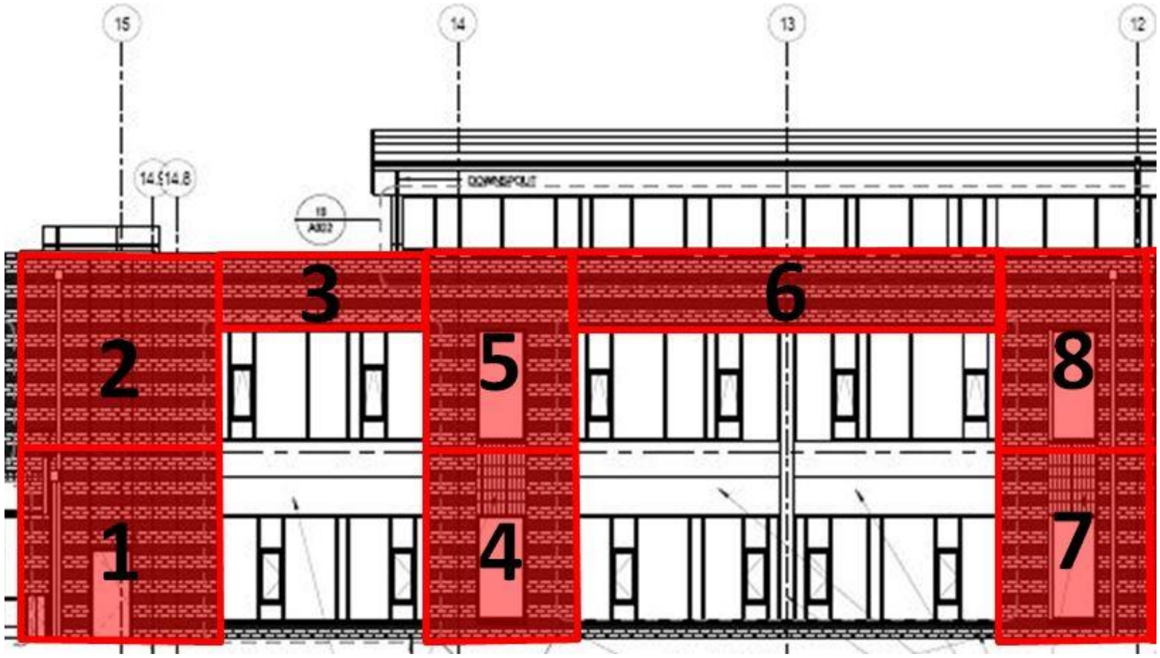


Figure 37: Structural Breadth Panel Design (Astorino Property)

The bays being considered are between column line 14.8 and column line 12 (shown above). This requires consideration of the weights associated with the panels influencing those columns. This area was chosen simply for the reasons that it has a two story structural design, caissons are not found in this location (out of my scope of knowledge), and it is simply designed in general. The weights and gross areas associated with the panels above are outlined the table below:

Panel No.	Gross Panel Area (SF)	Weight (lbs)
1	239	4780
2	264	5280
3	111	2220
4	160	3200
5	160	3200
6	222	4440
7	160	3200
8	160	3200

Figure 38: Panel Areas and Weights

The foundation, first floor framing, and roof framing plans (respectively) are shown below and the areas highlighted in red show where the panels will be erected:

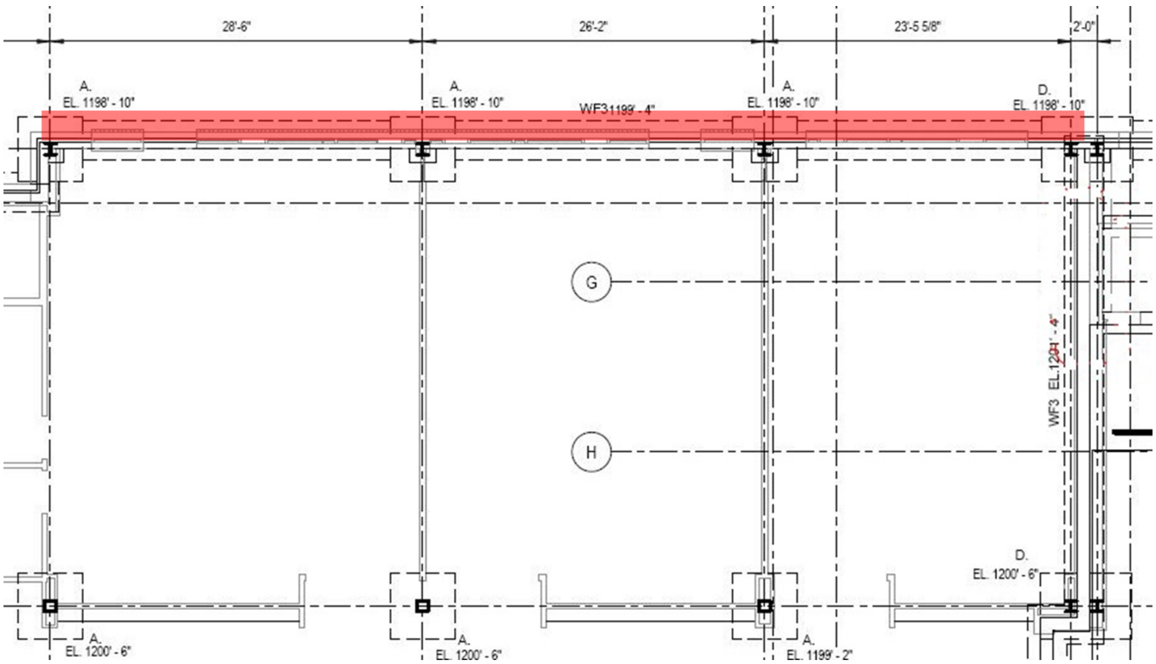


Figure 39: Foundation Plan (Astorino Property)

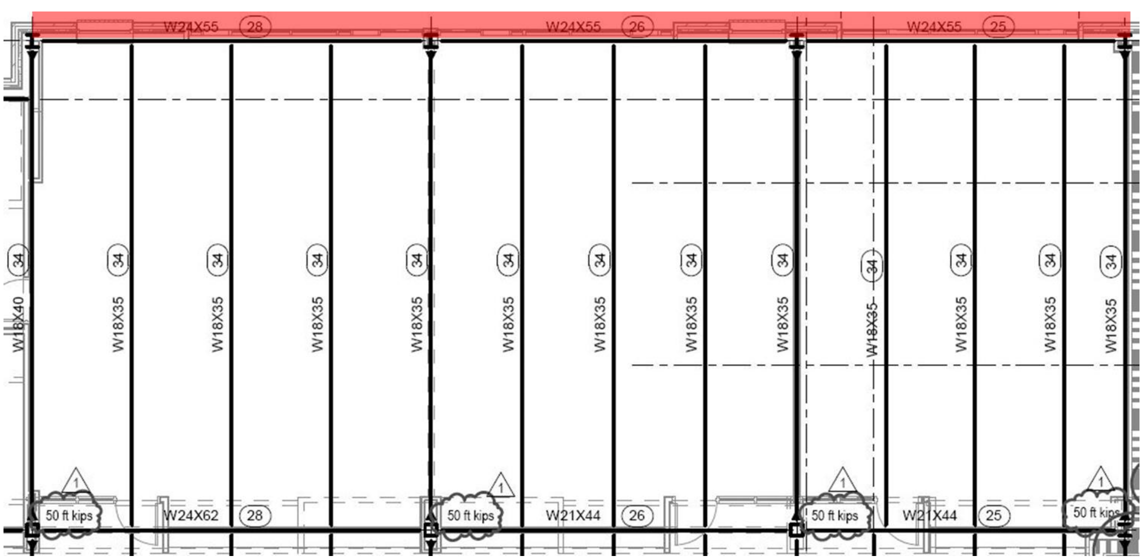


Figure 40: First Floor Framing Plan (Astorino Property)

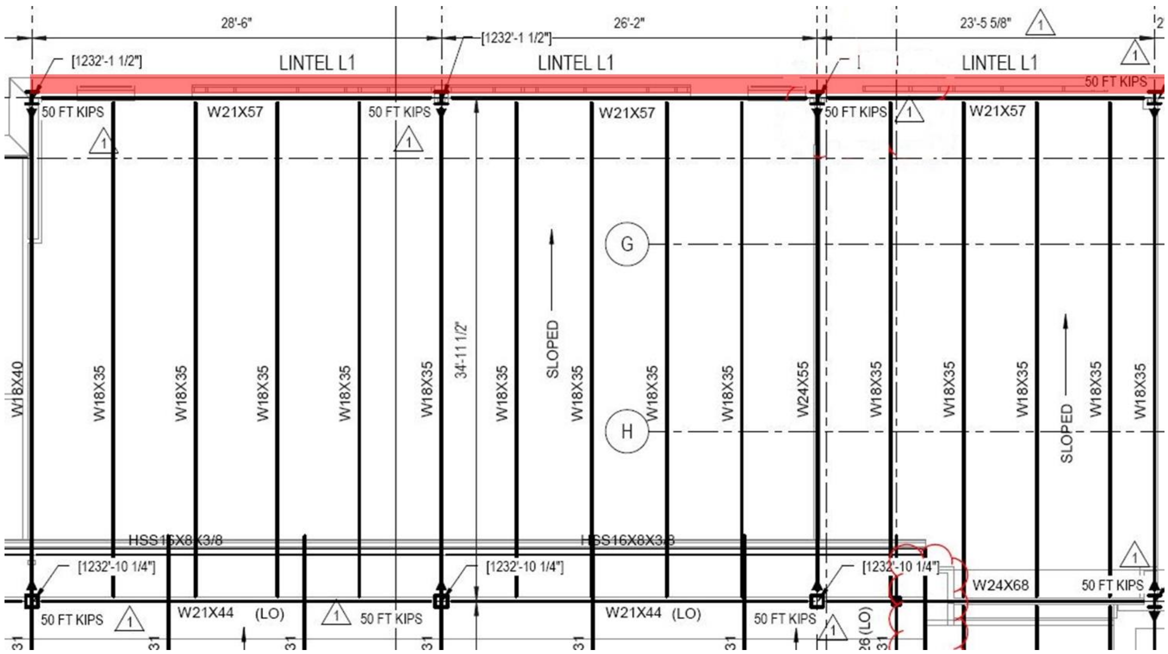


Figure 41: Roof Framing Plan (Astorino Property)

All exterior columns in these bays are **W10x49** wide flange members and the footings in this area are the WF3 design, which is detailed in the image below. These are the structural elements under redesign consideration:

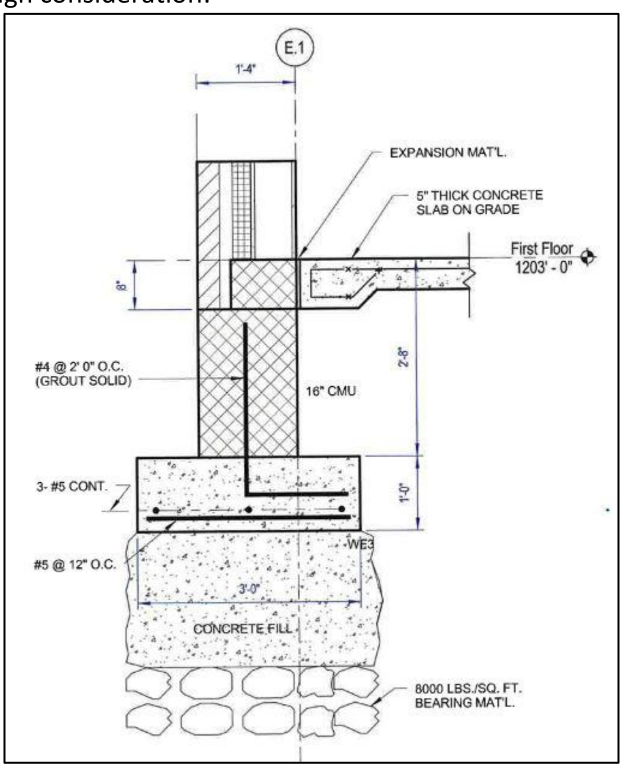


Figure 42: WF3 Footing Detail (Astorino Property)

4.4: Structural Redesign

Column and footing redesign conclusions are shown in the following sub-sections as well as their associated costs. All structural calculations can be found in the appendix of this report.

4.4.1: Column Redesign

By utilizing notes from AE 404 that were gathered during spring 2013, I was able to determine that the W10x49 columns on the north elevation of Area F were not affected by the introduction of the prefabricated masonry panels. The columns were slightly over maximum loading for W10x45 columns, which left a lot of room for additional loading before it was necessary to upgrade to a W10x54 column. While there was not necessarily a typical area to analyze, the north elevation of Area F is the most typical available and one of few areas with a two story height. Also, the 31'-8" of brick surface area in this region is one of the tallest on the building's structure and has the largest corresponding load. All necessary calculations are shown in Appendix G of this report.

4.4.2: Footing Redesign

By utilizing notes from CE 397A that were gathered during fall 2013, I was able to determine that by taking the 50 PSF brick veneer load off of the foundation and adding a much more lightweight panel design to the superstructure of the building, the typical WF3 footing around the perimeter walls of the building can be reduced. The thickness of footing was reduced from 12" to 8". All necessary calculations can be shown in Appendix H of this report.

4.4.3: Redesign Costs

First of all, it was assumed that no additional costs would be incurred after the analysis of the steel superstructure's additional loading due to exterior wall panels. The W10x49 columns that were analyzed were not affected and therefore there is no cost of design change to the steel superstructure. Since the design of the concrete thickness of the footing was reduced from 12" to 8", a 2/3 cost reduction can be associated with the cost of the perimeter WF3 footings. The perimeter of the building is 3,136' and uses the WF3 footing analyzed in this breadth. The total volume of the footing around the perimeter is [(3,136')(3')(1')/ (27 ft^3/CY)] = 349 CY. The estimate associated with the original footing is prepared below:

CSI Division	Item	Unit	Unit Costs					Quantity	Total Costs				
			Material	Labor	Equip.	Total	Total w/ O&P		Material	Labor	Equip.	Total	Total w/ O&P
33053.3950	Footings, strip (3000 psi), 36"x12", reinforced	CY	$127.00	$62.00	$0.54	$189.54	$ 244.00	348	$44,252.44	$21,603.56	$ 188.16	$66,044.16	$ 85,020.44

Figure 43: Structural Redesign Costs

This estimate was prepared using RS Means Open Shop Building Construction Cost Data 2014. The total cost (as seen above) is roughly $85,000. By reducing the footing's concrete thickness by 1/3, a cost savings of that amount can be assumed. The estimated cost of using a 36"x8" strip footing around the perimeter is $56,680.30. This leaves the owner with a foundation cost savings of **$28,340.14**. This is reflected in the estimate in Chapter 2.

4.5: Conclusion and Recommendation

For further visualization purposes, an isometric view of the overall structure and a north-south section cut are shown of the structure. The panels under consideration are highlighted in red:

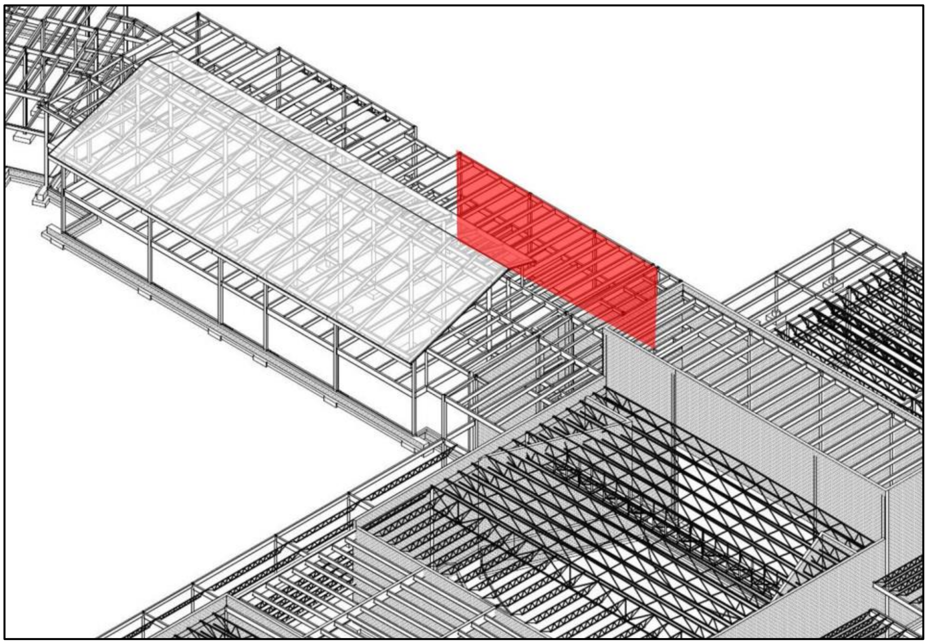


Figure 44: Isometric Structural View (Astorino Property)

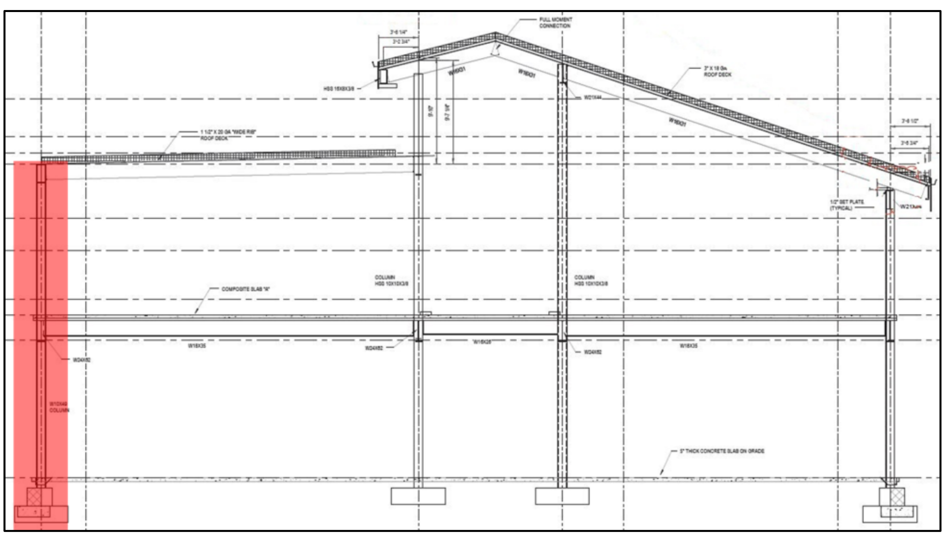


Figure 45: Classroom Wing Section Cut (Astorino Property)

My final recommendations of this structural analysis are that the columns carrying the proposed prefabricated panels will not be altered and that the footings around the perimeter of the building that formerly carried the 50 PSF brick veneer will be reduced in thickness by 4”.

Chapter 5: LIFETIME COSTS OF VE: FINISHES

5.1: Problem Identification

This idea was presented to me during the second session that I attended at the PACE Conference. During the process of Value Engineering, some professionals tend to choose the material with the most immediate cost savings and don't take into consideration the lifecycle maintenance costs. For example, at CWNCHS, the ceramic tile scope was greatly reduced by epoxy paint on the CMU walls of the locker rooms and by semi-gloss in the bathrooms. While this tile needs to be cleaned approximately every year, the costs of cleaning compared to re-painting every 5-6 years throughout the lifecycle of a building may be worth analyzing. Another area of interest would be the installation of polished concrete in place of linoleum tile. Linoleum tile is often stripped and waxed once a year and can be a high cost maintenance item. It is also be worth analyzing these two finishes. A list of finishes, materials and building systems that require maintenance under the current design will be compiled and examined compared to an alternative material and its lifecycle & installation costs.

5.2: Research Goals

The research goals are as follows:

1. Analyze finish materials used on the project and determine their cost/schedule impacts.
2. Research, determine, and suggest alternative materials.
3. Consider alternatives based on aesthetics, ease of installation, replacement, etc.
4. Recommend for or against specific materials recommended.
5. Define and develop an "Owner's Guide" to this process including steps

5.3: Methodology

- Research past or ongoing research/studies on this subject
- Speak with facility managers, custodial stuff, and product manufacturers to determine cleaning, maintenance and replacement details
- Compile program of all finish materials at CWNCHS
- Determine expected lifetime of building
- Develop program of alternatives that were considered as well as other alternatives
- Consider sustainability and aesthetics
- Estimate costs of materials, installation, cleaning, routine maintenance, replacement, etc.
- Develop sample guideline of VE questions for owners, contractors or architects
- Develop recommendations for or against Cost Analysis of VE & Finish Materials
- Develop recommendations for or against proposed alternative materials

5.4: Preliminary Research

The expected lifecycle of Cardinal Wuerl North Catholic High School (without any major renovations) is roughly 50 years. During this time, at least 1,000 students per year will occupy the building daily for 9 months per year, as well as faculty, staff, and visitors. High schools require a lot of routine maintenance due to the difference in behavior/cleanliness/responsibility between children and adults. During the nine months per year that students are present daily, maintenance and janitorial staff is required to maintain the interior aesthetic as much as possible. This same staff usually does as much replacement, refinishing, and yearly routine maintenance work as they can handle during the summer months. So, these ideas should be considered when choosing to value engineer in/out finish materials. On a project where 19.7% of the VE cost savings were reported from Division 9: Finishes, lifecycle cost evaluations should certainly be considered.

A truly complete analysis of a facility's maintenance costs requires performing an analysis of lifecycle costs (LCC). Since facility managers often operate under limited budgets, this means they must make critical decisions on when to stop maintaining finishes and when to start replacing them. Once an FM comes to this decision, an LCC analysis can help in choosing alternatives. ASTM Subcommittee E06.81 on Building Economics developed standards for evaluating lifecycle costs that reduce the risk of misleading or incomplete cost conclusions. According to ASTM, the definition of "life cycle costing" is:

> *"A technique of economic evaluation that sums over a given study period the cost of initial investment less resale value, replacements, operations, energy use, and maintenance and repair of an investment decision. The costs are expressed in either lump sum present value terms or in equivalent uniform annual values."*

To understand an LCC analysis, principles of finance such as compounding, discounting, present value, and equivalent uniform annual value should be known. Compounding is defined as "the process of computing the value of an original principal sum based on interest calculated on the sum of the original principal and accrued interest." All of these will be considered when determining if the best finish materials were chosen throughout the VE process.

5.5: Industry Interviews

According to Billy Charles, the project manager at CWNCHS, he does have experience with lifecycle analyses, but he also informed me that it was not considered on this project. The project team solely analyzed the immediate cost savings during construction. He did inform me that the lifecycle analyses he had done before were beneficial and were typically done by the GC during the planning phases if it was suggested. Overall, if the aesthetics of materials are of highest consideration, the cost cannot matter. If lifecycle costs are dramatically different, or different enough it may persuade the owner to choose cheaper materials or materials that require less maintenance. The most accurate information that he was able to get for lifecycle costs were given to him by product manufacturers.

5.6: VE Finishes & Current Materials

The following table shows a list of the VE program for Division 9: Finishes:

	Cardinal Wuerl North Catholic High School			
	Description	**Cost**	**Analyze**	**Disregard**
1	Delete Level 5 Finish on All Drywall Walls & Ceilings	$140,000.00	x	
2	Reduce Ceramic Wall Tile Scope by 1/2 for Paint	$152,275.00	x	
3	Reduce Material Price of Tile from $17.80/SF to $12.00/SF	$ 52,571.00		x
4	Use Polished Concrete in-lieu of linoleum	$ 16,000.00	x	
5	Use a Standard Rubber Base in-lieu of Custon Rubber Base (take half)	$ 17,000.00		x
6	Use VCT in-lieu of Carpet Under Auditorium Seating rather than carpet	$ 33,000.00	x	
7	Use a different rubber athletic flooring manufacturer	$ 3,000.00		x
8	Use Armstrong School Zone Fine Fissured in-lieu of the Ultima Ceiling Tile	$ 54,000.00	x	
9	Use a curved drywall ceiling in-lieu of the Wood Linear Ceiling in the 2nd Floor Corridors	$ 72,000.00	x	

Figure 46: Reported VE Cost Deductions from Division 9

Other VE items that were proposed and shown as pending or proposed and shown as rejected were disregarded altogether. I have chosen to disregard other items in the proposal above for several reasons. Line Item #3 will not be analyzed since a reduction in the cost of a material cannot be taken very far. This is also the case for Line Item #5. The performance of these items is not affected by a cost reduction whatsoever. Also, I chose to avoid Line Item #7 since it has a very small scope on the project and little cost value.

Line Item #1 describes the skim-coat method of finishing interior GWB joints. This method is much more expensive than a Level 4 GWB finish and has no bearing on lifecycle costs. Level 5 is an extreme measure of finishing ensuring that joints are not visible after finishing, and the project team determined that Level 4 was more than sufficient. A drywall finish map is shown below to the right. For the purposes of this analysis, it was determined that this was a good VE decision and will be disregarded from this point.

Figure 47: Drywall Finish Levels

Line Item #2 provides a lot of potential for analysis since paint needs more regular maintenance than ceramic wall tile. Ceramic tile may require annual cleaning but rarely needs to be replaced. Paint requires a new coat every several years. A big focus of this analysis will focus on that aspect of lifecycle costs. Line Items #4 & #6 both deal with the lifecycle costs of different floor systems and can be analyzed through cleaning, replacement, refinishing, and routine maintenance. Line Items #8 & #9 regard interior ceiling finishes and products that can also be analyzed by a lifecycle cost perspective.

Considering all items that were accepted as Division 9 VE items, the total cost savings are $539,846.00. Since only five of the nine accepted VE items will be further analyzed, the total cost analysis deals with $327,275.00 worth of savings. Also, the total accepted cost reduction of value engineering was $2,738,964, so roughly 12% of the accepted VE savings will be challenged for their lifecycle cost implications. The present value lifecycle costs of all materials will be evaluated against each other, rather than the immediate cost savings alone.

5.7: Alternative Materials Analysis

This analysis utilized the cash flow method for calculating life cycle costs. The process was detailed in RS Means Facilities Maintenance & Repair Cost Data 2014, which heavily referenced the Annual Book of ASTM Standards Vol. 04.07, including:

- ASTM E 833 – Terminology of Building Economics
- ASTM E 917 – Practice for Measuring Life Cycle Costs of Buildings & Building Systems
- ASTM E 1185 – Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems

Five financial analyses choosing between two different finish materials at CWNCHS were compiled and located in the Appendix. They use a 10% compounding interest rate as recommended by ASTM and the equation:

$$P = F\left(\frac{1}{(1+i)^n}\right)$$

Where: *P* = Present Value
F = Future Value
i = compounding interest rate (10%)
n = # of years

Some lifecycle cost values were extracted from RS Means Facilities Maintenance & Repair Cost Data 2014 while as many as I could were attained from product manufacturers. The conclusions of the analyses are as follows:

5.7.1: Ceramic Tile vs. Paint

The lifecycle analysis of ceramic tile vs. paint proved to be slightly disappointing but did verify the fact that it paint/drywall require a lot more maintenance than ceramic tile does over 50 years. The areas that were value engineered had a total wall area of 21,660 square feet and the initial costs of tile were much more expensive at $7.45/SF while paint was only $0.43/SF. Over a 50 year life span, ceramic wall tile only required 2% of wall area to be repaired every ten years at a cost of $8.77/SF and cleaning costs were negligible. On the other hand, paint on interior GWB required a lot more maintenance attention. The details are defined below:

- *Refinish GWB* – every four years. Laborer will place and remove mask and drops, prepare the surface paint the surface with a brush (1 coat). $0.81/SF
- Painting – every five years. Laborer will spread drop cloths, prepare drywall partitions, clean drywall partitions, paint drywall partition (roller & brush) one coat, and remove drop cloths. $2.17/SF

- Repairing GWB – 2% of walls every 20 years. Laborer will remove damage and replace 5/8" drywall, then tape and finish it. $2.06/SF

While it is clear that much more time and effort goes into maintaining and repairing paint on GWB rather than ceramic tile, it is still less expensive over 50 years. Although, the reported savings from VE are much less than the project team stated. The cost of ceramic tile throughout the lifecycle is $163,735.90 while paint is $123,212.59. Even though I would recommend against switching the results of the original VE, the lifecycle cost analysis gives a more representative value of real savings. The lifecycle analysis reported a **$40,523.21** cost savings rather than $152,275.

5.7.2: Polished Concrete vs. Linoleum

Polished concrete was the most heavily used floor finish throughout the building. Linoleum was only used in several bathrooms. The original VE analyzed roughly 60,000 SF of floor area to determine which would be the more cost effective option. Polished concrete is cheaper to install initially than linoleum and its integrity as a floor finish lasts several years longer. RS Means Facilities Cost Data recommends that it only needs to be refinished every 25 years while linoleum needs to be changed every 18 years. I will break down the numbers in the following paragraph why it may be cheaper to use linoleum in the area in question in the next paragraph.

After speaking with the facility manager at CWNCHS, he was able to shed some light on how they clean and maintain polished concrete. They use two iChariot scrubbing machines, shown to the right, that have two diamond pads on the bottom. These pads supposedly will last up to one year and cost $600/pad. So, pads alone cost $2,400/year. He also informed me that they use a Hillyard® product called Super Shine-All in the iChariot to clean the floors. This product costs $36.09/gallon when it's bought in a pack of four. Based on filling up the 25 gallon tank on each iChariot once/day at a dilution rate of 1:128 every week day of the year, this should cost $3,681.18/year in floor cleaning solution. Also, the iChariot needs to be charged every day, and costs roughly $200/year according to CWNCHS' FM. So $400/year for two scrubbers at an 8% interest rate is shown in the estimate for polished concrete. Also, it is recommended that the polished concrete be refinished every 25 years at a cost of $5.60/SF, so this was also factored in (according to RS Means Facilities Maintenance Data). Linoleum uses different pads on the iChariot that cost $30/pad, and last for 3 months, which comes to a cost of $480/year for pads. Super Shine-All is also used at the same dilution but the floors only need to be cleaned every other day according to the FM, so only $1,840.59 is spent per year on it. Also, energy is reduced to $200/year since the iChariots are used half as much as for polished concrete. RS

Figure 48: iChariot Floor Scrubber (Windsor Property)

Means recommends that this type of flooring be replaced every 18 years at $259.65/CY. This cost would come to $1.7 million for the roughly 60,000 ft^2 of floor area being analyzed, which is highly unlikely. As a simpler and more realistic alternative, the initial capital cost was multiplied by a factor of 3 to account for removal of current floor and preparation of the substrate to accept the new linoleum was used every 18 years.

Overall, it has been noted that the linoleum product over 50 years will cost $216,926.62 and the polished concrete will cost $200,958.00. Much to my surprise, the difference of present value lifecycle costs between these two floor finishes was $15,968.62. This is only roughly $30 different from the original VE estimate, so it can be assumed that nothing of the original VE estimate for polished concrete vs. linoleum should change.

5.7.3: VCT vs. Carpet

This lifecycle analysis proved to be very beneficial. I was able to use actual values from the facility manager at CWNCHS since floor finish maintenance is one of their most labor intensive activities during summer months. The project team decided to use VCT flooring rather than carpeting under the auditorium seats and claimed that it saved $33,000 based on immediate costs of installation. Not to mention, stripping and waxing a VCT floor that has a pitched surface, such as the one in this auditorium, is extremely difficult and dangerous due to how slippery the surface is during stripping procedures.

According to the FM, refinishing would occur in a low traffic area such as auditorium seating every 5 years, rather than every year in high traffic areas. He claimed that this costs $1.00/SF which includes all necessary chemicals (wax stripping solution, cleaning chemical, and wax), stripping pads, equipment (wet vacuum and floor scrubber) as well as the cost of labor to refinish and the cost of labor remove and reinstall the auditorium seats. RS Means also stated that replacement should occur every 18 years at a cost of $6.71/SF using in house labor. The FM was not able to provide this figure since the building's he presides over are relatively young in age. The facility manager later informed me that carpeting in a low traffic area like this would only be shampooed every five years. They own a carpet cleaning equipment which can be considered a negligible cost. The big cost comes in replacement. RS Means says it should be replaced every 8 years, but in a low traffic area such as this it is recommended to only do so once every 25 years at a cost of $6.03/SF. Carpet cleaning including labor to clean it/remove auditorium seats, chemicals, and machine rental is roughly $0.13/SF.

I would recommend over a 50 year lifecycle doing the opposite of what was suggested by the VE program for these flooring systems. The carpet costs $94,499.12 over 50 years whereas the VCT costs $114,257.95 due to the Diocese's practices of refinishing VCT very often. So a loss of **$19,758.83** in present value lifecycle costs was reported. All calculations can be seen in the appendix.

5.7.4: Armstrong - School Zone Fine Fissured Ceiling Tile vs. Ultima Ceiling Tile

After speaking with Armstrong, it was quickly realized that there was not much room to analyze life cycle costs here. They do not wear any differently over time and both require several tiles to be repaired every 9-10 years and a complete replacement every 30 years. So over the lifecycle of a building, it is common sense that the cheaper of the two similar products from the same manufacturer with the same warranty will be cheaper. This was analyzed over 73,000 SF and the cost of Ultima was $2.41/SF while the School Zone tile was $1.67/SF. After costs of replacement every ten years and every thirty years, the School Zone Fine Fissured product actually saves **$57,695.50**. So, a lifecycle cost analysis would have shown that $3,695.50 more in present value dollars was saved.

5.7.5: Curved Drywall Ceiling (Paint) vs. Linear Wood Ceiling

The ceiling finish in the second floor classroom wing corridors were of particular importance to the architect and owner, so they asked the GC to determine whether linear wood or a curved ceiling would be more cost effective. The GC determined that the curved ceiling was roughly $72,000 less than the linear wood system. Both systems are not cheap, but paying for the additional labor to bend metal studs and for detailed/difficult GWB work was cheaper than the overall cost of the wood system. After a lifecycle analysis the same result was found, but the cost savings over the lifecycle of the building in present value dollars were only $39,500 (almost half of what was reported). This is because drywall requires much more maintenance including painting and refinishing overtime. Refinishing a high ceiling such as this one costs a lot more to refinish every 5 years (especially from excessive sunlight from the clerestory windows). Repair costs on 2% of the surface area every 20 years also factor into lifecycle costs. The values shown in the estimate (found in Appendix H) for the curved ceiling are from RS Means Facilities Maintenance & Repair Cost Data 2014. Linear Wood Ceiling has a much higher installation cost due to the recycled nature of the wood, but has much lower maintenance costs over time. It is recommended to clean with oil soap every few years, but this cost is very low. Product information for this system can be found in Appendix I. This was also reported to me by the facility manager of CWNCHS. Overall, while maintenance for this curved drywall will be much more difficult and require much more effort, it is still cheaper. The present value lifecycle cost difference is actually **$39,479.61**. The curved ceiling is highlighted in the images below and above:

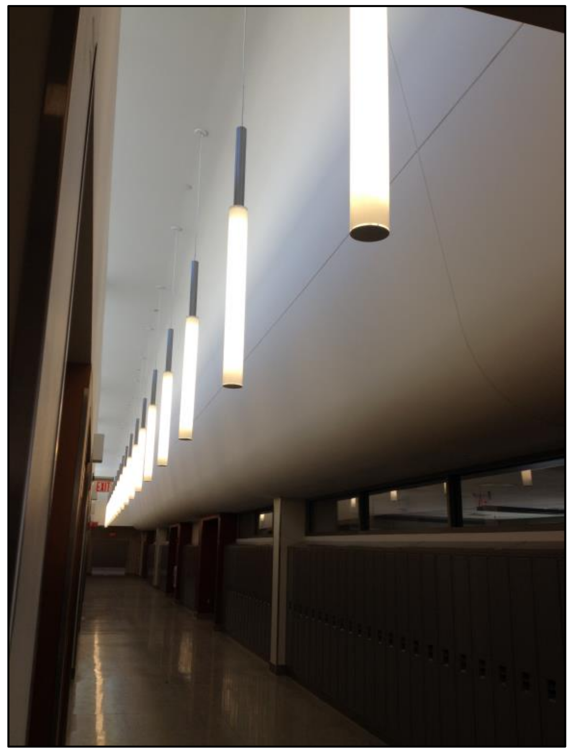


Figure 49: Curved Ceiling at CWNCHS (Mascaro Property)

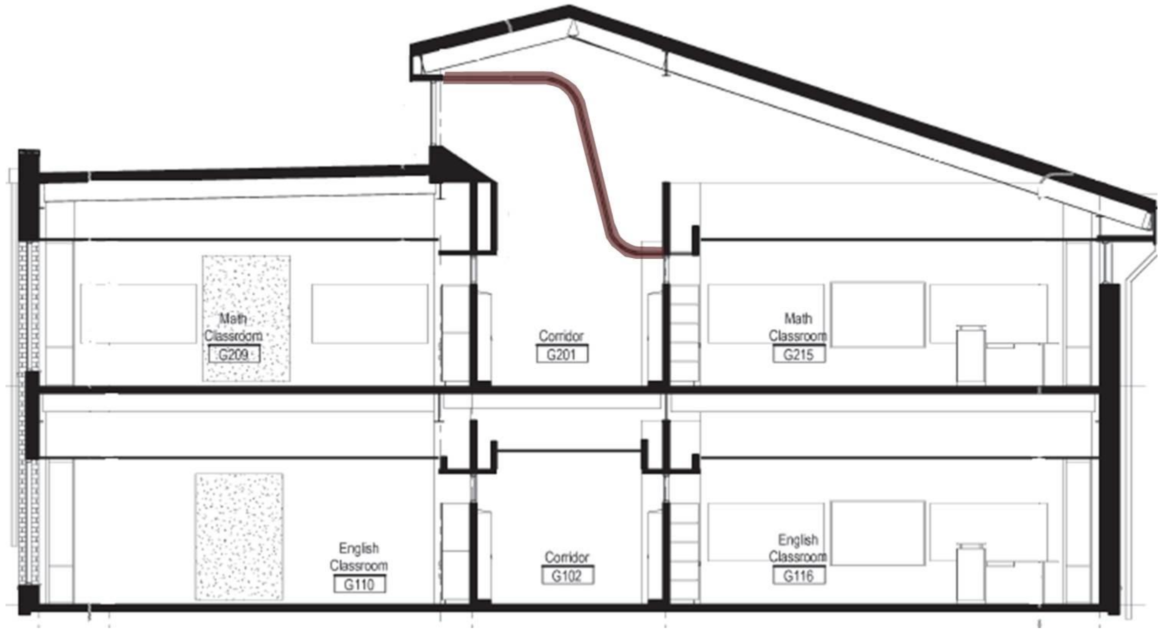


Figure 50: Curved Corridor Ceiling Section (Astorino Property)

5.8: Chosen Finishes

All decisions made in the original VE program for Division 9: Finishes will be kept other than the VCT vs. Carpet decision. If the original decision to use VCT was projected over the lifecycle of the building, it would cost roughly $20,000 more. So, it makes more sense to use carpet under the auditorium seats, especially since VCT in a sloped area is not maintenance friendly at all. The following table shows a more accurate depiction of what the VE Finish materials will cost in present value throughout the lifecycle of CWNCHS:

Materials	Original VE	Present Value LCC
Ceramic Tile vs. Paint	$ 152,275.00	$ 40,523.21
Polished Concrete vs. Linoleum	$ 16,000.00	$ 15,968.62
VCT vs. Carpet	$ 33,000.00	$ (19,758.83)
School Zone vs. Ultima	$ 54,000.00	$ 57,695.50
Curved Drywall vs. Linear Wood Ceiling	$ 72,000.00	$ 39,479.61
TOTAL COST REDUCTION	$ 327,275.00	$ 133,908.11
% Difference		69%

Figure 51: Original VE Reductions vs. Present Value Lifecycle Costs

The LCC analysis shows that the ceramic tile and curved drywall ceiling provide a lesser cost reduction than the original VE reported. It also shows that the polished concrete vs. linoleum reduction is identical to the original value and that the school zone acoustical tile provides almost $4,000 more in cost reductions than originally reported. Ultimately, the analysis gave a more accurate representation of actual savings over time and was 69% less than originally estimated VE cost reductions.

5.9: Owner's Guide to Finish Lifecycle Analysis

There is not necessarily an "owner's guide" that came out of this analysis that is anything outside of common sense. My recommendation to the owner would be to ask for a lifecycle cost analysis as a part of the value engineering cost analysis because value is not only added during construction. It is added throughout the entire lifecycle of your building if you are also paying to maintain it.

5.10: Conclusions & Recommendations

The point of this analysis was not to say that the five VE items that were analyzed were incorrect. It was to show that VE when only considering the present costs of construction can be misleading and lifecycle figures for VE will give real value over the building's lifetime. Obviously the owner wants to know what they're saving in the here and now, but a different perspective may sway the owner in a different direction. In which case, they will be supremely happy with you as a construction manager. I would change the outcome of the original VCT vs. Carpet VE decision and install the carpet under the auditorium seats. All other original VE decisions should remain.

Chapter 6: EFFECTIVE & EFFICIENT DELIVERY OF FM INFORMATION

6.1: Problem Identification

After attending the PACE conference, analyzing the CWNCHS BIM Execution plan, and speaking with the owner about his ambitions with developing a facility management model for the facility manager to utilize effectively, I feel as though it is very beneficial to analyze the process of turnover from construction to occupancy and how to maintain the function and aesthetic of a building. The owner's great ambition to do this should involve an in depth study of how to go about this process in the planning stages, determining who needs to buy in to the process, how it can be managed, cost evaluations, possible schedule impacts, and determining when an appropriate time to hire and begin training a facility manager is. The PACE Roundtable provided a lot of information on this topic. I hope to determine the most efficient method of facility management information transfer for this specific project and tailor it to the owner's needs.

6.2: Methodology

1. Conduct interviews with facility managers, contractors, architects, and owners to determine their experiences and suggestions on this project and elsewhere.
2. Speak directly with owner of this project to determine his goals.
3. Utilize BIM Execution Plan to determine project specific goals.
4. Speak with Mascaro Virtual Construction Engineers to determine specifics on technology being used and other options available.
5. Determine cost/time impact on developing BIM.
6. Utilize information gathered at PACE to gather a current industry consensus.
7. Develop project specific recommendations for best course of action to efficiently and effectively turn over FM information.
8. Develop owner guidelines for any project to help determine their goals in asset management and how to go about achieving those goals.

6.3: Preliminary Research

Construction projects are a fountain of information from day one. Between submittals, contracts, pay applications, drawings, specifications, product data, operations and maintenance guidelines/data, and countless other sources of information, document management on a project is paramount. Ultimately, much of this information will be of importance at the turnover from construction to occupancy. The inhabitants of the building will begin to use its spaces for its intended purposes and the building will need to be properly operated and maintained. This topic is very similar to BIM considerations in that it is not necessary for every project and sometimes should not involve a significant investment, but an early consideration can benefit a project in great ways.

The Partnership for Achieving Construction Excellence (PACE) Conference in November 2013 was very helpful in attaining a preliminary industry consensus with regards to facility management. With the advent of BIM, it is now possible to avoid or increase the efficiency of what is known as the "paper-dump" of closeout documents at the conclusion of a project. All required documents are organized into folders and dropped off to the owner at the end of the project, only to be stored away and rarely referenced. All of the material in these documents can be largely beneficial to a facility manager if presented in an efficient and user-friendly medium. The process of arriving to the point where said information is presented efficiently in a user-friendly method is very tedious and involves long hours of work. In order for an owner to avoid paying for these services or wishing he/she would have paid for them, the owner's goals need to be developed with the end in mind during the planning stages of the project. Once these ideas have been discussed with all stakeholders, the construction management professionals can request a best course of action to pursue. Then, the CM/GC can be contractually bound to perform these activities. In order to improve the turnover process, it is vital to analyze the current procedures that take place and make a critical evaluation. The following questions presented at the PACE Conference can help to analyze FM info turnover:

- What inefficiencies exist now for transferring information between phases effectively?
- What information needs to be turned over for facility management?
- What takes the most time and effort to compile and transfer?
- What relationships or contracts may be hampering the process for efficient transfer of information?
- What workflows would be high value to define more clearly and repeatable?
- What infrastructure or tool support is needed to make these workflows consistent and interoperable?

6.4: Industry Interviews

6.4.1: Owner Interview

The owner wanted to ensure that this project did not end at the conclusion of construction. The Diocese of Pittsburgh owned this building at the conclusion of construction and wanted to do everything in their power to ensure that it would be maintained effectively and efficiently for years to come. Therefore, the owner decided to consider the end product very early on by integrating BIM (very heavily on the information aspect) to produce a record model for the facility manager. He saw no inefficiencies that existed through this process and informed me the following information/materials should be turned over and accounted for at substantial completion:

- BIM Model (NavisWorks Manage 2012)
  - Transfer to Onuma Facility Manager software
- RFIs/Submittals/LEED Submittals
- Attic Stock
- Warranties
- Proof of training demonstrations
- Keys/Keying Cabinets

He also noted that the most time consuming activities in this process were the gradual accumulation of RFIs and Submittals/LEED Submittals that were to be logged in the record model as well as record modeling in NavisWorks (73% of estimated BIM man-hours). This would come at a fee by the subcontractor for BIM services, but the owner believed that it was necessary and worth investing in. His methodology in developing a workflow that yielded high value was to hold a series of meetings where spreadsheets would be presented to track all closeout information and communicated all expectations. At the conclusion of the interview the owner informed me that on this project they would be using Onuma facility management software and would train several of the employees in this, including himself, the business managers, and the facility manager.

6.4.2: Project Manager (GC) Interview

The project manager with Mascaro was able to shed light on a few aspects of closeout and record modeling that I was not able to gather from other sources. An inefficiency that he noticed throughout the process that was difficult to counter was human error. With such a large amount of information to be tracked and published it is easy to misplace information. This opinion led to another conversation pertaining to the contracts and organizational structures that may hamper the process. He was under the impression that the large number of prime contracts makes this process inefficient and can be the source of more human error. The closeout documentation process on other projects that he has worked on where the general contractor was required to compile all information went more smoothly. On this project all primes are responsible to submit their information directly to the owner then back to Mascaro (general contractor) to be logged in the record model. The information to be logged in this model according to the project manager is:

- O&M Manuals for Equipment
- Care & Maintenance for all finishes
- Testing/Balancing Reports
- As-Builts
- Record Submittals
- Keys (casework, lockers, toilet accessories, door hardware, etc.)
- Warranties

Finally, we moved on to speak about what workflows would be of high value to define more clearly and make repeatable. He informed me that in regards to submittals and as-built drawings, the use of web based systems aids tremendously in the turnover process. Record submittals can be pulled from the cloud and the use of Bluebeam Revu software aids in the as-built turnover.

6.4.3: Facility Manager Interview

The facility manager interview was facilitated with a different group of questions than the owners and contractors considering they are the party receiving all of the information required to operate the facility. All questions can be found in Appendix J. The facility manager I interviewed was asked about his experiences with the turnover from construction-to-occupancy, his willingness to be trained with Onuma, and his personal responsibilities and skills as a facility manager. He was in a unique situation, having been involved with the turnover of the K-8 school (St. Kilian Parish) across the street from CWNCHS and he will now be the facility manager of that school as well as CWNCHS. The Catholic Diocese of Pittsburgh delivered St. Kilian as well, but not under the current Chief Facilities Officer who had the vision to utilize BIM for facilities management.

The FM's experience at turnover began about one month prior to substantial completion. He was instructed to help the final clean contractor finish their contract, relocate owner FF&E, and complete floor finishes until substantial completion. At that point, all building system contractors completed their required O&M training by individually walking him through the building. The facility manager mentioned that overall, these sessions were too brief to retain all of the information presented to him and noted that going through the process at CWNCHS 6 years later has been more beneficial with the use of video cameras capturing training for reference rather than quickly scribbling down notes. The facility manager also thought that it was beneficial for him to be involved as early as possible in the process. He thinks that he has more to offer in order to be prepared for all unforeseen circumstances if he is trained properly.

A problem that has been noticed in the construction industry is that facility managers often are not very computer literate or are not able to read construction drawings. An example of this that he mentioned to me was the Building Automation System (BAS) with respect to HVAC controls at St. Kilian. The business manager has taken on a small facility manager role with respect to temperature controls since he is more computer literate than the facility manager rather than training him. This specific facility manager claimed to have a moderate level of computer literacy and is completely willing to accept new technology (federated BIM models) in order to differentiate himself as a professional and make his job easier in the long run.

6.4.3.1: Facility Manager Costs

The facility manager interview helped to develop a cost value on the potential dollar value of hiring a facility manager early on. He was willing to inform the researcher of his current salary as the facility manager at CWNCHS and St. Kilian Parish. The researcher compared the actual salary of the FM on this project to the average for Cranberry Township, PA in the graphic below:

	Lower Quartile (0.25)	Average	Upper Quartile (0.75)	Actual
Yearly Salary	$67,234	$79,709	$91,144	$52,000
Weekly	$1,292.96	$1,532.87	$1,752.77	$1,000.00
Daily	$258.59	$306.57	$350.55	$200.00

Figure 52: Facility Manager Salaries

CWNCHS is at a strategic advantage since their Facility Manager is being compensated on the low end of the average salary for his position in his geographical region, so it is cheaper for the Diocese to bring him in earlier for training. They believed it was appropriate to begin training roughly 4 weeks prior to the conclusion of construction. They are also at a large advantage since they did not have to hire more personnel to manage the building. So, while he is managing CWNCHS prior to its initial occupation in August 2014, he is technically only being compensated for his time at St. Kilian, until raises go into effect on July 1, 2014. By that time, they expect him to be adequately trained. Therefore, the Diocese technically did not accrue any additional costs for training. The only additional cost will be to give the current manager a raise, which is cheaper than hiring a separate facility manager and paying another salary. The researcher expects the yearly salary of the facility manager to increase to approximately that of the average in Cranberry Township, PA to reflect the large increase in gross building area from roughly 70,000 GSF to 250,000 GSF.

6.4.4: Director of Virtual Construction Interview

Bill Derence, Director of Virtual Construction at Mascaro Construction, helped to answer some questions to fill in the holes that were remaining after the other interviews. Bill informed me that the initial software packages being analyzed were Maximo, Evolve FM, FM: Systems, and Onuma. FM: Systems was immediately ruled out due to high costs and the other three systems were evaluated in a weighted matrix based on information available. Categories were weighted based on their importance with the project team. Asset Management, mobile capabilities, and overall cost were the categories that were rated at 100% weight while Space Management, BIM integration, BAS integration, function, flexibility, and technical support help were weighted at 60%. Mascaro's analysis is as follows:

	Onuma	Maximo	Evolve FM
Strengths	AM, SM, Mobile, BIM, BAS, Cost, Funct., Flex., Help	AM, Mobile, BIM, BAS, Function, Flex, Help	AM, SM, Function, Flexibility
Weaknesses	None	SM, Cost	Mobile, BIM, BAS, Cost, Help

Figure 53: FM Software Strengths & Weaknesses

He claimed that the BIM Execution Plan in accordance with Record Modeling was followed stringently. Updates were not always executed perfectly, but this was expected with human error. All time estimates for activities were accurate and within budget. The owner and construction manager were very helpful throughout the entire process to ensure that the necessary support was in place. They were integral in selling the idea of utilizing BIM to allow FM come to fruition at CWNCHS to the Diocese of Pittsburgh.

The conversation with Bill then proceeded to speak about inefficiencies in the process. He informed me that if the Computer Maintenance Management System (CMMS; such as Onuma) software were chosen earlier in the process it would have made things more efficient. For example, he was not sure if it was necessary to aggregate a federated model based on the type of CMMS chosen. So his team took this step in Revit and found out later on that it would not be necessary with Onuma. The conversation was concluded with stating that the most difficult part of the process was the selection of a CMMS system. The Diocese/owner had never done this before so they were not sure how early in the process that it was necessary. Bill offered again that choosing the software earlier on would be the one thing that he would change.

6.5: BIM Execution Plan – Record Modeling Details

The BIM Execution Plan, published by Mascaro Construction, has helped to outline the contractual obligations towards developing a federated model to be used by the facility manager at CWNCHS. Mascaro had the benefit of getting involved at the design document phase (10 months prior to construction), where they were able to communicate facility management goals as quickly as possible. This BIM Plan has clearly outlined that "producing a federated model to aid in the O&M of the facility" is the primary goal of Building Information Modeling. Most preliminary steps in the BIM process are being taken for the final product of a record model to be truly informational for reference purposes. A record model should be populated with the following documents as it relates to architectural/MEP elements as well as equipment and space planning systems:

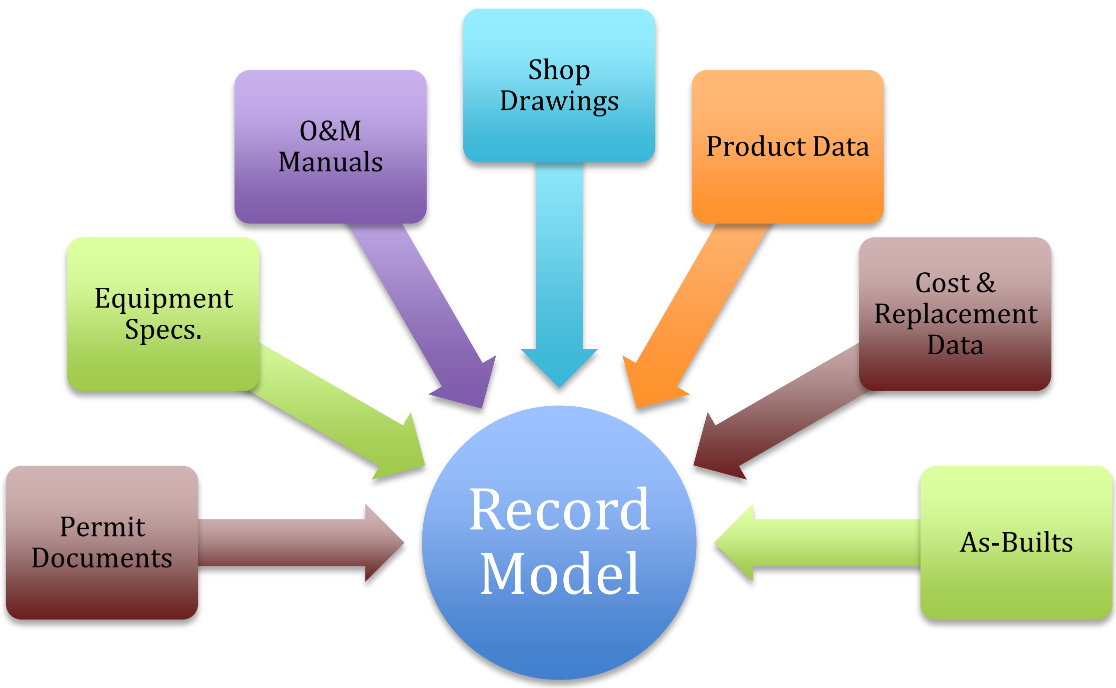


Figure 54: Record Modeling Components

The Director of Virtual Construction with Mascaro Construction was the main point of contact for all BIM questions/concerns on the project and was responsible for the record modeling effort. He was required to aggregate the federated model with the pertinent documentation for the operations and maintenance of CWNCHS. This required all primes and select subcontractors to produce 3D component models of their work. All efforts in 3D modeling will lead to a single, as-built NavisWorks model that will be turned over to the owner. He will utilize this to develop a Computerized Maintenance Management System (CMMS) and train the facility manager to utilize. All hyperlinks to the information shown in the figure above will be available on the CMMS for reference by the facility manager. To develop a perspective on cost of BIM services for record modeling, the rough estimate below was prepared:

Record Modeling Estimate	
Record Modeling Hours	800
Total Mascaro BIM Hours	1096
RM/Total	0.73
Total Cost of BIM	$50,000
Cost of Record Modeling	**$36,496**

Figure 55: Estimate of Record Modeling Costs

6.6: Facility Management Technology/Software

6.6.1: Onuma

Onuma is a cloud-based program that runs in your web browser. It has multi-user capability and is deep enough for a BIM expert to operate efficiently and simple enough for someone with average computer skills to operate efficiently with proper training. This cloud-based platform allows the user to connect to other systems on the web in real time such as GIS systems (Google Earth and Esri). Onuma is available on all major platforms such as iPad, Mac, PC, iPhone, and Android. Some other advantages include real time design updates, reduced email due to connection through cloud based software, and the capability to import/export many different design formats like Revit, ArchiCAD, Bentley, SketchUp, Ecotect, IES, ArcGIS, Excel and Google Earth. Onuma can be used in all phases of planning, construction, and facility management including:

- Rapid early planning
- Project Program Development
- Schematic Design
- Connection to other BIM Applications
- Cost Estimating
- Energy Analysis
- Lifecycle Costs
- Facility Management
- Portfolio & Program Management

Onuma was used as the program of choice at CWNCHS only for Facility Management. The owner rep, business manager, and facility manager will be trained in Onuma in order to have the capability of efficient and effective operation throughout the lifecycle of the building. The image below shows several examples of the graphical Onuma interface:

Figure 56: Onuma Interface (Onuma Property)

6.6.2: IBM Maximo Asset Management

Maximo is one of the most industry proven technologies for facilities management that exists. For all intended purposes at CWNCHS, it is top notch with two of their three biggest considerations for choosing a software program (Asset management and mobile capabilities), but the cost was much, much higher than the Diocese was willing to pay. While Onuma and Maximo were very similar in their capabilities, Onuma was about ½ of the price. Purchasing several different software packages would not be as cost effective as other options. Regardless, IBM stresses that the main advantages of Maximo are space planning and execution, facility utilization increases, and cost controls. A comparison of the advantages of Maximo compared with other systems can be seen in Chapter 6.4.4.

6.6.3: Evolve FM

This Computer Aided Facility Management (CAFM), browser-based software helps facility professionals achieve costs savings related to facility management as well as real time insight into available/in-use space. EvolveFM boasts its many features, such as multiple properties, interactive floor plans, space utilization & occupancy, occupant move in/move out tracking, asset management, on-demand work orders, scheduled preventative maintenance routines, interactive campus maps, and graphically managed roof areas/other “outside the building” assets. This software is more applicable to the demands of CWNCHS because it offers an “Operations & Maintenance Management” module specifically. The following images are examples of the user interface:

Figure 57: EvolveFM Space Management Interface (EvolveFM Property)

Figure 58: Campus Management Feature (EvolveFM Property)

As is evident in these images, it stresses occupancy of spaces in a 2D setting more than any other usage of the program. While this may be important in some buildings, it is not of grave importance at CWNCHS. The owner wants to invest in developing a 3D model for reference in order to help preserve the building for as long as possible by stressing operations and maintenance. While financial costs are reasonable, this software simply was not equipped with what the owner was looking for at CWNCHS.

6.6.4: FM:Systems

FM:Systems is a browser-based information sharing software that stresses map driven navigation as well as space management and the business aspect of facility management. The core modules that are typically purchased are either Space Management or Asset Management. These modules have additional module packages that can be purchased such as:

- Space Management
- FM:Mobile

- Strategic Planning
- Facility Maintenance
- Move Management
- Project Management
- Real Estate & Portfolio Management
- Sustainability/Energy Auditing

All of these additional modules come at an additional cost and do not touch on the integration of a 3D, federated BIM model very much. FM:Systems claims that integrating BIM within their software has the benefits of improved space management, streamlined maintenance, efficient use of energy, economical retrofits & renovations, and enhanced lifecycle management. While the use of BIM in FM:Systems can streamline maintenance, this program is more beneficial with 2D drawings and space planning (much like the other model software options). The image below shows the user interface:

Figure 59: FM:Systems Space Management Interface (FM:Systems Property)

6.7: Owner Guide to Facility Management

The efficient and effective turnover of facility management information should be considered by all owners as early on in the building planning process as possible. While the researcher has focused primarily on BIM applications in this analysis, the paper dump (non-electronic turnover of FM information) at the end of the construction process can be organized and explained for training purposes in an effective manner that allows efficiency of operations. The non-electronic method has been the method of choice for decades and has served its purpose very well in many applications. In this circumstance the owner should work to develop a procedure that allows for a proper explanation of all materials, literature, and training by all required parties. As buildings become more technologically advanced and aggregated by more and more complicated systems, it is not effective to turnover a plethora of documents that are vital to a buildings survival in a banker's box only to be stored away in a musty basement never to be seen again. The following bullet points show a recommended thought progression for owners to follow in the planning phases when considering facility management information delivery:

1. *Early Training*?
   a. Yes:
      i. If the owner decides to invest in early training for a facility manager, all "trainer" parties must be properly informed of when training will take place. The owner must also consider incurred costs from hiring a facility manager prior to the beginning of building occupation. (Much like the situation at CWNCHS, it may help costs to promote from within or to add additional responsibility to an existing facility manager).
   b. No:
      i. The owner must understand that the "baptism by fire" approach to hiring a facility manager and letting him or her learn about the building systems "as they go" may lead to inefficiencies and possibly even a reduction in the building's predicted lifecycle. A system is only as good as its weakest link and an ineffective facility manager who does not follow a good operations maintenance schedule can be a cause of equipment malfunction/failure.

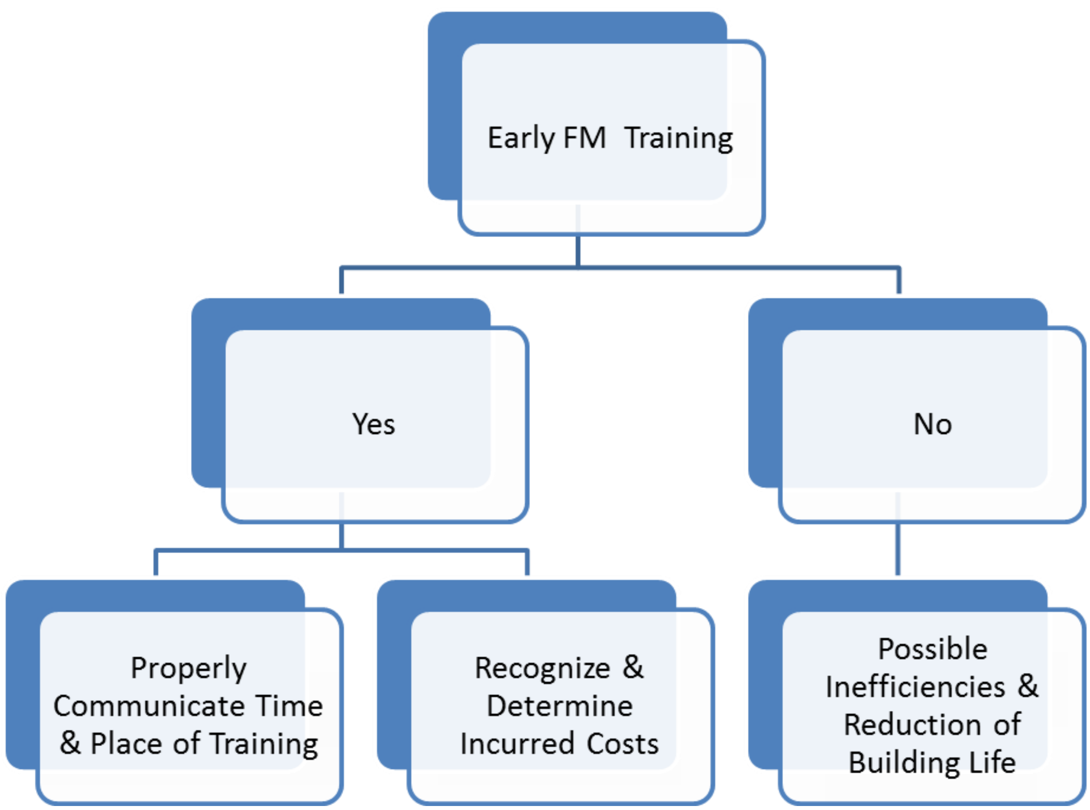


Figure 60: Owner Guide to FM Training

2. *Software?* → Involves asking questions of whether the capital and time investment makes sense based on:
    a. Pre-decision considerations:
        i. Available funds
        ii. If it makes sense for the lifecycle of the building
        iii. Computer literacy and experience of facility manager
        iv. GC/CM's skill and expertise in record modeling
        v. How early the facility manager can be trained
        vi. Begin with end product in mind
    b. <u>Yes:</u>
        i. Have all subs/primes buy into 3D modeling; anything with close-out information attached to it should be modeled and placed into one comprehensive model in order to have all files hyperlinked to it.
        ii. CM should hold meetings/check-ups on record modeling progress periodically in order to ensure a timely completion (especially if occupation begins in close proximity to the conclusion of construction). Record modeling is a tedious process that often requires more man-hours for the virtual construction engineer than any other BIM activity.
        iii. Choose software that allows all documents to be hyperlinked to appropriate systems in the 3D model. Make sure the software is user friendly enough for individuals with lower-to-average computer literacy
            1. Consider training and capital investment in this model.
        iv. Weigh pros/cons of different FM software. Which makes the most sense for the owner's FM goals? Software can be beneficial from planning through occupancy, so the owner should choose what stages the software should be implemented:
            1. Rapid early planning
            2. Project Program Development
            3. Schematic Design
            4. Connection to other BIM Applications
            5. Cost Estimating
            6. Energy Analysis
            7. Lifecycle Costs
            8. Facility Management
            9. Portfolio & Program Management
    c. <u>No:</u>
        i. If using BIM, leave "RECORD MODELING" out of Execution Plan and follow procedure below.
        ii. If not using BIM, disregard and follow the procedure below:
            1. Develop spreadsheets of what documents are needed for closeout at the beginning of the project and distribute to all subcontractors, prime contractors, etc. with agreed upon deadlines. Track periodically and deliver hard copies in an organized fashion. Explain any documents or organization of said documents to facility manager in most effective fashion.

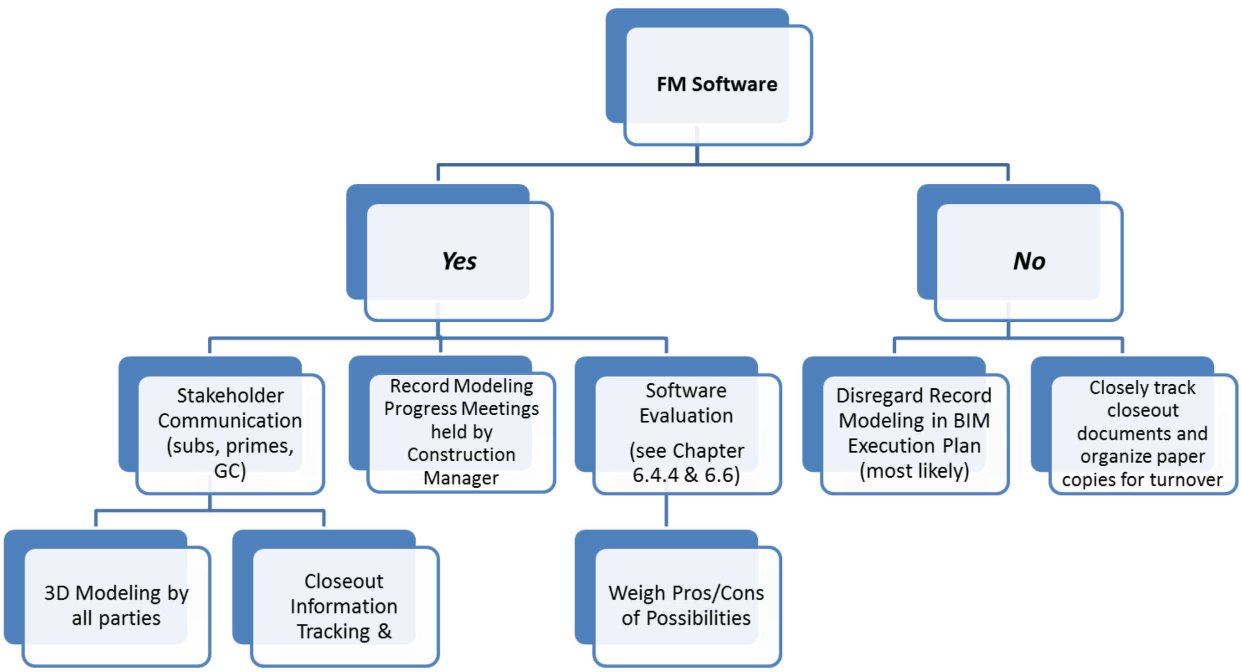


Figure 61: Owner Guide to FM Software Choices

6.8: Software Recommendations and Conclusions

Considering that it was decided from the get-go of this project that BIM's usage would focus on record modeling more than any other aspect in conjunction with Onuma's BIM prowess, it is clear that Onuma should be the software of choice compared to the other three programs that were analyzed. The other web-based programs focus much more on business management and space management. The owner desired FM software for lifecycle analyses, operations and maintenance procedures, and BIM integration. The primary purpose was to ensure that the "I" in Building Information Modeling was utilized to its full capability while the school is in operation. Also, Onuma's approach to FM is very simple and user friendly, which allows a facility manager with minimal computer literacy to be trained. At the same time, it is deep enough to be utilized effectively by a BIM expert. Onuma is also cost effective to purchases and operate. Single users are charged $45/month and up to 5 users can operate Onuma for $210/month. According to the owner, costs with other software programs were competitive and worth the cost, whether they choose 1 user or 5 users. In accordance with these values, an overall cost estimate has been developed to describe the efforts in Facilities Management turnover. The table below shows this:

Facilities Management Information Turnover Costs		
Record Modeling Costs		
Total BIM Costs	$	50,000.00
% of Man-Hours for Record Modeling		0.73
Record Modeling Costs	$	36,500.00
Onuma Software Costs		
Onuma Studio Software (5 users/100 viewers; first year)	$	2,311.00
Work Order Module	$	850.00
Implementation & Training Services	$	20,000.00
Space & Assemt Management Module (per year)	$	2,520.00
Operation - Years 2-5	$	10,080.00
Purchase, Implementation, and 5-Year Subscription	$	33,241.00
Facility Manager Early Training Costs		
FM Actual Salary ($/yr)	$	52,000.00
FM Actual Weekly Pay	$	1,000.00
FM Average Salary (Cranberry, PA)	$	79,709.00
FM Average Weekly Pay (Cranberry, PA)	$	1,532.87
Weeks of Early Training		4
Actual Cost	$	4,000.00
Average Cost	$	6,131.48
TOTAL FM INVESTMENT	**$73,741 - $75,873**	
**EvolveFM Cost = $51,000. Maximo Cost = $70,000 (5 years of service)*		

Figure 62: Cost of FM Training, BIM and Software

Something that is immediately evident from this estimate is that if you are going to go about with record modeling and choosing the appropriate software to most effectively utilize it, training is a very small percentage of your total costs that can provide the most pay-off in the long run. The software and BIM usage are great, but if your personnel can not effectively operate it then it is useless. Your personnel, communication, planning, and training are the most important part of this process. While most of this analysis focused on the BIM aspect of FM, it is important to note this again (most of the information available on this topic dealt with BIM and FM software). According to the industry consensus at PACE, training was the biggest issue with implementing FM Information turnover effectively and efficiently. So, if cost is not the impacting factor, it is clearly obvious that the owner's team needs to take the initiative to coordinate and plan better training processes. BIM can make this process more efficient by utilizing FM software and making the paper dump obsolete and a thing of the past. Overall, Onuma is a very effective and efficient program for facility management and should be highly considered when an owner is deciding on a program to integrate with BIM for facility management.

Chapter 7: ALTERNATIVE ROOFING SYSTEMS ANALYSIS

7.1: Problem Identification

Cardinal Wuerl North Catholic High School has a very expansive roof system that was a vital part of the critical path schedule. Several days prior to the beginning of TPO roofing installation, it was realized that it could not be installed due to cold weather temperature threshold issues. It was slotted to be installed during the winter months when the temperature was too low (according to spec). This caused issues with trades that succeeded the completion of roofing logically. The roughly one month delay caused by TPO required a large overtime labor effort, and was the reason for unexpected costs against the GMP. With a better knowledge of temperature ranges for roofing installation, this problem could have been avoided by re-sequencing or evaluating the possibility of using a different roofing system that can be installed at colder temperatures.

7.2: Research Goals

- Recommend implementing a different roofing system (built-up, EPDM, or PVC) if it can be installed in cold weather with the most minimal impact on the critical path
- Recommend against the implementation of a different roofing system due to cost, schedule, aesthetic, specification implications, or overall quality of the system
- Determine if re-sequencing or simply following the course of action that was initially taken would be better

7.3: Application Methodology

- Conduct extensive research of what went wrong with TPO system including costs and schedule impacts
- Research other flat roofing systems and determine compatibility with current roof deck
- Determine if alternative flat roofs can be installed in cold weather
- Perform basic structural checks (PSF)
- Determine site logistics for installation of roofing
- Determine schedule implications and communicate with industry professionals to attain accurate installation durations
- Perform estimate to determine cost effectiveness of alternative systems compared to TPO
- Determine safety implications
- Evaluate potential risks and create a risk prevention plan
- Develop a recommendation for or against an alternative system

7.4: Preliminary Analysis

At the Pre-Installation Conference (PIC) with Phoenix Roofing (TPO Installers) and Mascaro Construction, Phoenix informed Mascaro that they would encounter issues with TPO installation over the next few weeks/months due to cold weather instructions in the specifications.

Specification 07 54 23 – Thermoplastic Polyolefin (TPO) Roofing – Article 3.6.F.3 – Insulation Installation, clearly states "Set each subsequent layer of insulation in a solid mopping of hot roofing asphalt, applied within plus or minus 25°F of equiviscous temperature." C-RFI-0406-00 at CWNCHS stated that, "insulation is not to be adhered in asphalt or adhesive, but simultaneously fastened with top layer of insulation as stated, will modify spec as required." This example of an area where the spec was incorrect and needed to be amended led to a discussion about cold weather installation of the TPO membrane. Ultimately, the adhesive used to fully adhere the membrane to the insulation required a 25°F threshold temperature for installation. Considering that the PIC occurred on December 20th, 2012 with Phoenix Roofing, this would be problematic since TPO activities on the gymnasium roof as well as both classroom wings would be beginning during the winter months when <25°F temperatures would be very likely. This caused lot of re-sequencing, critical path problems, and delays throughout the winter and the early part of spring. In order to gain the time back that was missed, the project team increased manpower and a lot of activities were condensed in the beginning of the schedule. While all of these ideas are difficult to quantify in a cost perspective, overtime labor alone cost Mascaro $15,000. This scheduled TPO installation on the gym and classroom wings during winter weather conditions. If this was recognized early enough a possible roof system redesign could have occurred to accommodate the cold weather. My preliminary analysis is that a different system could prove to be cost effective compared to the costs of increased manpower and overtime labor. Also, other systems have less cold weather installation risk and are of better quality overall.

7.5: Current TPO Roof Assembly Analysis

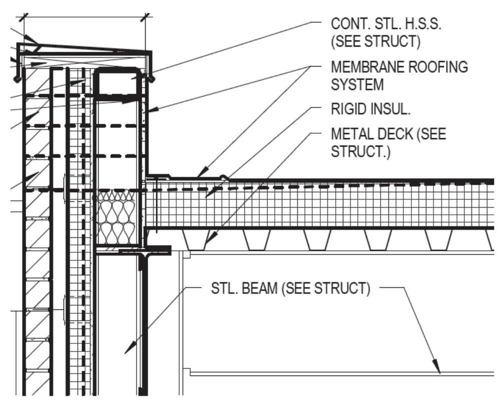


Figure 63: CWNCHS TPO Detail (Astorino Property)

The project team decided to go with the original plan of installing the TPO roofing system on 20 gauge metal deck. A section of this assembly is shown on the right. The bottom of the assembly was the Firestone V-Force vapor barrier. Prior to installation of the VB, the deck need to be blown clean with a gas blower, a threshold temperature of 25°F and rising was required, and all ice/frost needed to be heated, mopped, and blown dry. This product was adhered straight to the deck using a low VOC primer (LEED requirement) everywhere other than the gymnasium and auditorium roofs. These areas required fluting insulation for acoustical purposes underneath the vapor barrier (this detail was atypical for the majority of the roof surface). After installing the V-Force, all lap seams need to be inspected to ensure that they are sealed tight. The pictures below show deck cleaning, flute insulation and vapor barrier insulation, and seam lap inspection/sealing respectively:

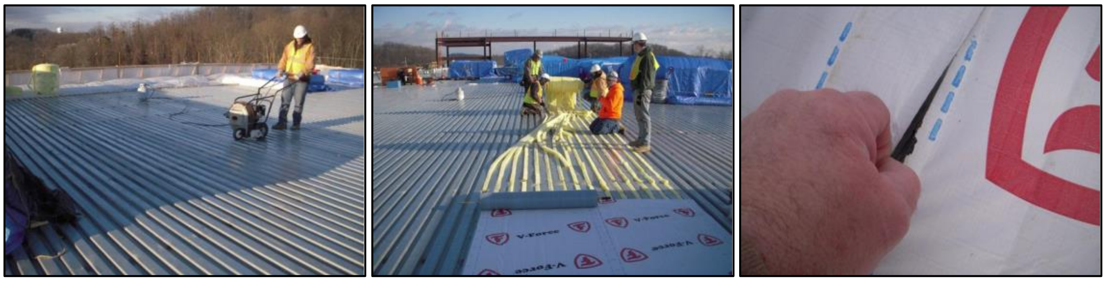


Figure 64: CWNCHS TPO Installation (Florida Consulting Property)

Following vapor barrier installation, a 5/8” Dens Deck fireguard roof board is installed for fire protection as well as to mechanically attach the rigid insulation to. Said rigid insulation is designed to be 6” thick (R-value = 37). Since Firestone does not make insulation that thick, 2 layers of 3” thick Firestone Resista™ insulation were mechanically attached to the roof board using plates and screws. All MEP penetrations should be prepared and detailed correctly during this step. For example, roof drains required a 4’x4’ square around them to have only one layer of 3” insulation. A sump with cant strips was installed surrounding it for slope/drainage purposes. To finish this process prior to TPO installation, water cut offs should be installed at the circumference of the drains. The following pictures show the roof board and two layers of 3” insulation installed as well as the roof drain assembly, respectively:

Figure 65: CWNCHS TPO Installation (Florida Consulting Property)

Finally, the single-ply, 60-mil TPO membrane is installed (Firestone UltraPly TPO). The Firestone low-VOC adhesive that fully-adheres the TPO membrane to the insulation should be stored in a climate controlled room and stirred to ensure consistency prior to being rolled onto the deck. Also, the TPO should be rolled out in place prior to rolling the adhesive on the insulation so it can relax. Next the TPO should be folded to the side so the adhesive can be applied and the bottom of the TPO can be mopped clean and dried. The heat-weld of the lap seam between TPO rolls is the final step in the process. A test-weld should be done first to that ensure conditions are good for installation. If any voids are present in the test weld, the TPO should not be heat-welded and the installers should wait for better conditions. Also, prior to the weld the seam lap should be cleaned with a splice wash (low-VOC) Firestone product. The pictures below show the application of the TPO adhesive, cleaning of the seam lap with splice wash, and the heat-welder closing the seam between two rolls of TPO, respectively:

Figure 66: CWNCHS TPO Installation (Florida Consulting Property)

In summation:

- Clean deck of debris, frost, ice
- Install V-Force vapor barrier (flute insulation if acoustic roof)
- Install 5/8” Dens Deck fireguard roof board
- Install (2) layers of 3” thick Firestone Resista™ with necessary detailing for MEP
- Roll out TPO, clean bottom, apply adhesive to insulation, broom surface of TPO, clean seam lap with splice wash, heat-weld seam
- Clear TPO surface of all debris, materials, and sharp objects

Figure 67: TPO Failure at CWNCHS (Florida Consulting Property)

All of the above steps should be taken very cautiously when around the threshold temperature of 25°F. Installing TPO systems at this temperature is very risky because TPO has a reputation of shrinking and pulling away from seams, curbs, and parapet walls. Some systems have a lot of issues with rapid deterioration, but the industry consensus is that Firestone products have the right chemical formula to counteract this issue (Firestone used at CWNCHS). The rigidity of this system is often accredited to the laminated white material that is exposed to the elements, called the “wearing surface.” The wearing surface is a different material than what is on the bottom, or the “filler material.” Another disadvantage to TPO systems is that it comes in relatively small rolls, which means there are more seams, which ultimately sacrifices the waterproofing integrity. A seamless roof is ideally the best circumstance. An example of where the heat-weld failed and caused a void at one of the seams at CWNCHS is shown to the upper-right. This shows why it is risky to heat-weld in cold weather.

7.6: Alternative Systems Analysis

Three systems were analyzed against the current TPO systems. Their analyses are outlined below:

7.6.1: Built-Up Roof (TOUGHROOF Product)

Built-up roofing systems are one of the oldest and most reliable in the industry. They have been in use for approximately 160 years due to their excellent waterproofing and drainage performance. The key to their strength and durability is that all plies of the roof are fused together to compose a monolithic barrier. This eliminates problems such as the need for fasteners (cause leakage risks), need for ballasts (gravel blows away), and less expansion/contraction. This product also has a very high tensile strength, which helps to preserves the system’s elasticity for longer, providing necessary durability.

My analysis will focus on the ToughRoof™ built-up roofing product. Throughout my research, this seemed to be the best option for a BUR manufacturer/installer and it has the additional advantage of the ToughCoat™ Finish Coat. This finish coat differentiates ToughRoof from the competition in that it provides a surface of UV ray reflectivity. The flood coat of BUR systems that is applied as the finish coat absorbs a lot of heat and contributes greatly to the Heat Island Effect that programs such as LEED are trying to reduce. So, ToughRoof provides the proven strength, durability, and water protection expertise of built-up systems as well as the additional benefit of solar reflectivity and the LEED Credit for Heat Island Effect – Roof. An image of ToughRoof’s assembly is shown to the below.

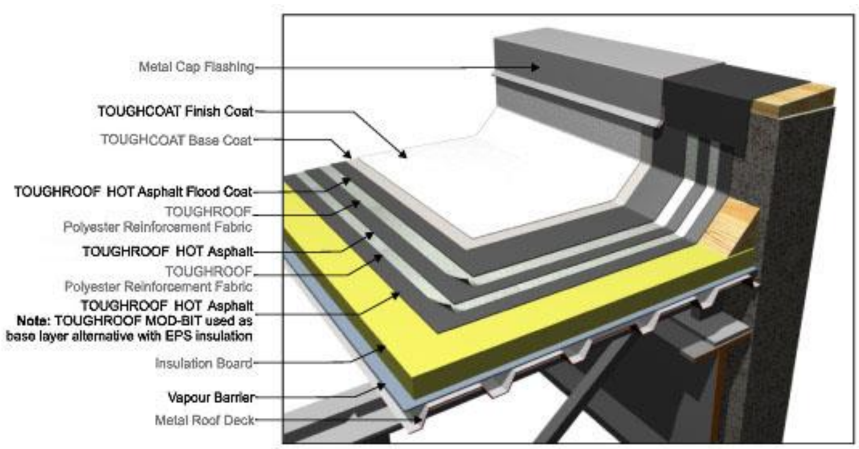
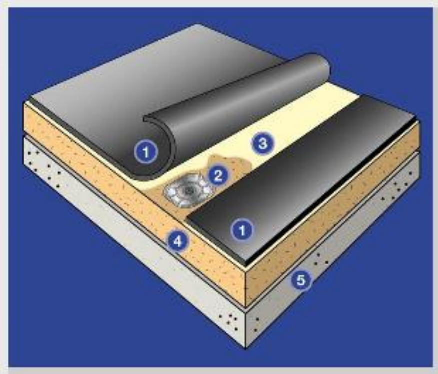


Figure 68: Built-Up Roofing System Assembly (ToughRoof Property)

Another deciding factor in the analysis of this roofing system’s benefits is that it can be installed in cold weather. It is perhaps the most effective roofing system to install in cold weather. The hot asphalt is pumped to the roof at 400°F. This high temperature contributes greatly to workability and aids in creeping into every crack and crevice of the roof area to create a uniform, monolithic watertight seal. Between layers of hot asphalt, a polyester reinforcement fabric is laid out for additional strength. The ToughRoof product uses its own insulation that is not affected by the first coat of hot asphalt, but when using this system in general it should be evaluated if the rigid insulation specification allows hot asphalt to be applied directly to it. If not, the warranty may be sacrificed. The schedule/cost analyses in the following chapter serve to differentiate PVC and BUR systems from TPO since both can be installed in cold weather. I will not be using this exact system in my cost analysis since I have chosen against it for its inability to be prefabricated. Consequently, the potential cost savings are most likely tangible compared to that of PVC. This product was used as a best possible alternative for the BUR systems in general, so RS Means will be utilized for cost purposes to gain perspective on relative costs with TPO.

7.6.2: EPDM Roof



Fully Adhered (EPDM)
1. EPDM membrane, 2. Contact Adhesive, 3. Fasteners and plates, 4. Acceptable Insulation, 5. Approved Roof Deck.

Figure 69: EPDM Assembly (Courtesy of Google Images)

Ethylene-Propylene-Diene-Monomer (EPDM) roofing systems are made of a rubber material that is dried out and cured (vulcanized) in sheets. These sheets are put in place atop roof insulation. All detailing work, such as flashing, parapets, and seam lap sealing, is done using a semi-solid EPDM material (non-vulcanized). Roughly 95% of EPDM systems use the black surface, although white-on-black (WB) EPDM products are available. WB EPDM systems are often discouraged because they are more expensive, they are unstable due to the chemical composition (titanium oxide added to make white color chalks and deteriorates quickly), and white roofing systems that are more proven are cheaper in general. A black EPDM system can be seen in the image above:

Black EPDM systems have the benefits of great rain, snow, ozone, and UV ray resistance as well as abrasion performance and low temperature flexibility. They also come in larger sheet sizes compared to TPO systems, which means fewer seams and higher strength/durability. Unfortunately, EPDM roofs pull apart and shrink at the seams. For this reason they are often coated with a reflective surface. High temperature issues can be alleviated with extensive repairs and rigorous preventative maintenance. A properly maintained system can achieve longevity if it is cared for correctly, but it is very expensive to keep up with. Another drawback of EPDM systems is their high cost. The method of installation requires that the system be fully adhered to the substrate through the use of expensive adhesives. Also, when using EPDM, the insulation below requires more fasteners than with other systems.

Finally, it was realized that this system would not be ideal to install in cold weather. Of the three alternative systems evaluated, this system has the highest risk of failure when installed during the winter season. There is some confusion in the industry on whether it can be done or not. Contractors will install it, claiming that adhesives can be pre-warmed but this is very risky. Sales representatives of EPDM manufacturers will also say it can be done, often because they will make a commission if their product is sold. Overall, it should not be installed below 40°F and that is the most important criteria of this analysis.

7.6.3: PVC Roof (Duro-Last Product)

Polyvinyl chloride (PVC) roofing systems are relatively new systems and are one of the most promising options for the future. They are very easily bent and flexible systems, which helps greatly for workability during installation. Most PVC roofs are mechanically attached, although fully adhered and ballasted systems can be utilized. PVC systems are always heat-welded at their seams, which creates a monolithic structure that is able to withstand frequent expansion and contraction. This feature can be very beneficial in a climate like western Pennsylvania where winter temperatures can be sub-zero and summer temperatures can reach 100°F. Some additional advantages of PVC are:

- Excellent puncture & heat resistance
- Relatively light material
- Primary color is white (LEED compatible with Heat Island Credit)
    - Other colors available
- Great resistance to bacterial grown and vegetable/animal oils
- Prefabrication can eliminate 85% fields seams (Duro-Last system; explained below)
- Larger sheet sizes than TPO
- Often are manufactured as reinforced systems

The only negative aspect of PVC systems that I was able to uncover is that they are apparently very high in cost, but competitive with EPDM systems. This seemed to be logical since it is a very high quality system, therefore having a higher cost. After speaking with Jay Monteverde, a sales representative at Duro-Last, this high cost speculation was reduced. He was able to provide me with a cost of $1.04/SF, which includes the PVC membrane material and labor (a cost analysis of this value is in the following chapters of this analysis). He also directed me to a section of the Duro-Last website that allows you to build your own spec and 3D rendered image of the desired roof assembly. It has the same substrate as the TPO used it CWNCHS, only with a PVC membrane instead of TPO. This image is displayed to the below.

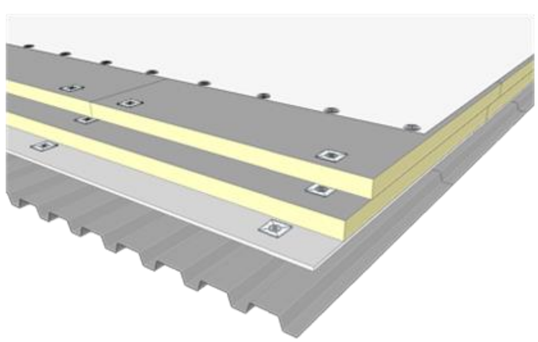


Figure 70: PVC Assembly (Duro-Last Property)

Jay Monteverde stated that while the 60-mil PVC product is rated at $1.17/SF, this has a warranty that is 25 years, while the 60-mil TPO used at CWNCHS only has a 20-year warranty. So, he stated that using a $1.04/SF, 50-mil PVC would be equal to using 60-mil TPO. Jay also informed me the following about the advantages of PVC prefabrication:

1. Roughly 85% of the system can be prefabricated. Most failures occur at seams and various changes of "plane" (curbs, drains, parapet wall, etc.) and prefabrication reduces the chance of errors and leakage.
2. The small amount of seaming that is done on-site is heat-welded, which is unaffected by cold or damp weather.
3. Pre-measuring the roof's dimensions prior to prefabrication reduces material waste so that costs can be more closely controlled.
4. The unpredictable environment that is a construction site is closely controlled. This yields the reward of higher worker productivity and quality of installation.

With the available benefits of prefabrication using the Duro-Last system, as well as its durability and competitive cost, it appears that PVC is the front-runner for the best alternative roofing system. All prefabrication is performed in Duro-Last's warehouse outside of Pittsburgh, Pennsylvania. The Duro-Last PVC system will be further analyzed in the next section in order to come to a final decision on what roofing system to use at Cardinal Wuerl North Catholic High School.

7.7: Investigation of Chosen Alternative

Since, it was evaluated that PVC and BUR systems can be installed in cold weather, it is necessary to differentiate them to determine the best possible option when going up against the calamity that occurred with TPO roofing installation the occurred during the winter of 2013.

7.7.1: Schedule Analysis

As it was explained in several earlier parts of this report, this project was delayed from day one. The building pad turnover didn't occur until September 26th, 2012, when it was supposed to occur on September 1st, 2012. The general contractor and project team as a whole decided to stick with the original substantial completion date of January 31st, 2014. To reach this date, the project team decided to try to gain back as much of the time lost during September of 2012 as possible. This required some re-sequencing and increasing of manpower by subcontractors and prime contractors. While it is difficult to quantify any direct costs from this effort, there are a few areas of the schedule that can be quantified to determine financial loss. For example, the original baseline schedule did not have TPO activities beginning until the end of March and early April. The condensation of the schedule pushed these activities to the beginning of February. The issue that was presented was that the adhesive used to fully adhere the TPO to the substrate could not be installed in excessively cold weather. If the original baseline schedule were followed it would not have been an issue, but the condensation of the early parts of the schedule placed it during a high-risk installation period. So, in a period where the project team was attempting to regain the schedule, it was further delayed. Phoenix Roofing attempted to increase manpower at the project and basically followed a path that they would have material ready if they got a day where weather was cooperating with installation specifications. This is shown in the pictures presented in Chapter 7.5. Phoenix Roofing doubled their manpower and worked whenever Mother Nature gave them an acceptable day. Following this trend through the late part of the winter and early spring pulled the projected substantial completion date back to January 31st, 2014 from where it was projected to be at its worst point, March 7th, 2014. The following table shows the different roofing areas that were scheduled to be completed. The first update shows the baseline schedule prior to the initial turnover delay. The next update is when the general contractor was able to begin working. The following three updates show the progress directly before TPO activities began up until May 14th when the schedule's substantial completion date was regained. The final update shows when all TPO roofing activities were completed.

DATE UPDATED	Cafeteria			Locker Rooms			Gym			A100 Corridor		
	Start	*Finish*	*Float*	*Start*	*Finish*	*Float*	*Start*	*Finish*	*Float*	*Start*	*Finish*	*Float*
8/14/12	3/29/13	4/18/13	106	6/21/13	7/12/13	47	3/29/13	4/18/13	57	6/7/13	6/20/13	35
9/26/12	5/2/13	5/15/13	-13	7/24/13	8/6/13	3	5/2/13	5/15/13	-13	7/10/13	7/23/13	13
2/5/13	3/15/13	3/28/13	-24	3/29/13	4/11/13	-24	2/5/13	3/14/13	-24	4/25/13	5/8/13	-7
3/5/13	3/8/13	3/22/13	-20	3/22/13	4/5/13	-45	2/11/13	2/25/13	x	5/13/13	5/24/13	-19
5/14/13	4/22/13	5/3/13	x	4/2/13	4/12/13	x	2/11/13	2/25/13	x	5/28/13	6/10/13	58
8/6/13	4/22/13	5/3/13	x	4/2/13	4/12/13	x	2/11/13	2/25/13	x	6/5/13	8/6/13	x

DATE UPDATED	Area B			Auditorium			Stage			D East		
	Start	*Finish*	*Float*	*Start*	*Finish*	*Float*	*Start*	*Finish*	*Float*	*Start*	*Finish*	*Float*
8/14/12	6/7/13	7/5/13	65	5/2/13	5/22/13	73	4/12/13	4/25/13	87	5/23/13	6/20/13	72
9/26/12	7/10/13	7/23/13	-22	6/4/13	6/17/13	-20	5/16/13	5/22/13	-13	6/25/13	7/9/13	10
2/5/13	4/12/13	4/25/13	-22	3/5/13	3/21/13	3	3/22/13	3/28/13	18	4/26/13	5/9/13	-22
3/5/13	4/5/13	4/19/13	-18	3/11/13	3/22/13	2	3/25/13	3/29/13	17	4/22/13	5/3/13	-18
5/14/13	4/10/13	5/14/13	1	3/9/13	4/5/13	x	6/12/13	6/18/13	49	5/8/13	5/17/13	12
8/6/13	4/10/13	5/14/13	x	3/9/13	4/5/13	x	8/6/13	8/12/13	x	5/8/13	5/22/13	x

DATE UPDATED	Area E			Area F			Area G		
	Start	*Finish*	*Float*	*Start*	*Finish*	*Float*	*Start*	*Finish*	*Float*
8/14/12	5/2/13	5/8/13	9	2/18/13	2/22/13	22	2/18/13	2/22/13	18
9/26/12	6/4/13	6/10/13	-13	3/7/13	3/13/13	9	3/7/13	3/13/13	5
2/5/13	4/1/13	4/5/13	-8	3/15/13	3/21/13	-7	3/25/13	3/29/13	-8
3/5/13	4/12/13	4/18/13	-17	3/8/13	3/15/13	-3	4/5/13	4/11/13	-17
5/14/13	3/5/13	5/21/13	0	4/15/13	5/9/13	x	5/29/13	6/11/13	49
8/6/13	3/5/13	5/22/13	x	4/15/13	5/9/13	x	5/13/13	6/21/13	x

**8/14/12 - This schedule was utilized because it is the original baseline schedule. It is used to show what was planned before the building pad turnover delay.*

**9/26/12 - Schedule reflects the schedule after the building pad turnover delay concluded.*

**2/5/13 - Schedule shows directly prior to when TPO activities began. Also, schedule was showing conclusion of March 7th, 2014.*

**5/14/13 - Schedule update shows that the original substantial completion date was gained. Activities in the prior three months must have been pushed.*

**8/6/13 - All roofing activities are complete or are within one week of completion.*

Figure 71: TPO Roofing Float Analysis

The graphic below shows the representative areas of the roof described in the image above. The colors in the titles of the table above correspond with the areas on the graph where TPO work was installed. The black areas of the roof were the standing seam metal roofing areas that did not have any direct issue with cold weather installation or the critical path:

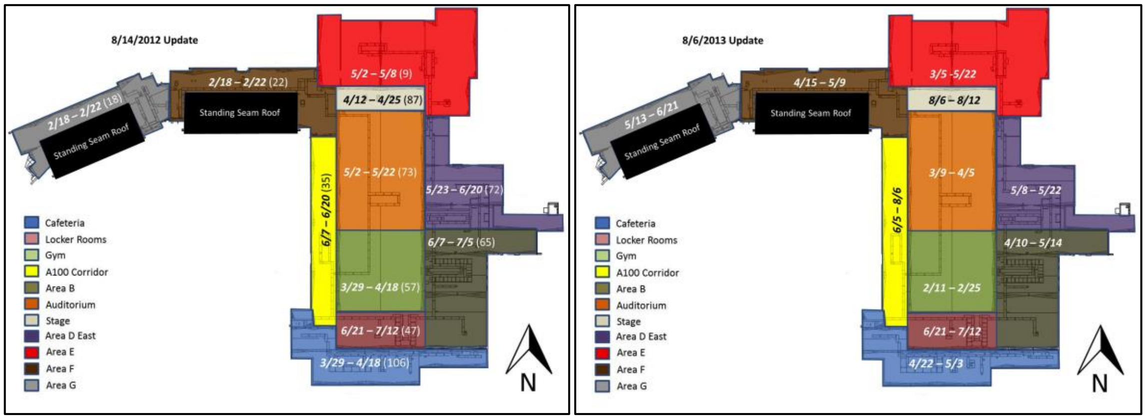


Figure 72: Roof Planning vs. Completion Schedule Graphics

Of the following areas that were evaluated, only A100 Corridor's period of installation was not representative of accurate installation dates. This area was in a period of redesign and work around it stopped due to the delayed design/construction of the chapel. This image shows that it would be difficult to quantify any losses during this period. Although, the project manager from Mascaro Construction informed me that they paid $15,000 in overtime labor during this time. Also, when evaluating the PVC roofing system against TPO, costs can be saved in general conditions. Since 85% of the Duro-Last PVC product can be prefabricated (according to their sales representative); this figure can be applied to the number of days that the TPO activities occurred along the critical path. I will use 75% prefabrication for conservative purposes, since the roof at CWNCHS is riddled with many different areas, levels, and sections. This will reduce critical path activities for the roof to 25%. The project team will save roughly $6,835/day in general conditions costs from the overall substantial completion date being reduced due to roof prefabrication efforts. This is quantified below:

General Conditions Savings from Critical Path Reduction	
Days TPO on Critical Path	
Gymnasium	11 days
Cafeteria	10 days
Area F	13 days
Total TPO Critical Path Time	40 days
Prefabrication of PVC Reduction	(40 days)*(0.75) = 30 days
On-Site PVC Install Duration	10 days
GC Cost Savings	
Total GC Costs	$2,871,341
Daily GC Costs (21 months)	$6,835/day
Total Savings	**$205,050**

Figure 73: Maximum General Conditions Savings from PVC Prefabrication

Several assumptions were made about this estimate. First of all, it was assumed that the duration of PVC activities is the same as TPO activities. This was made because all methods of installation are almost exactly the same. In fact, this estimate is somewhat conservative because the mechanical connections used for the edges of the PVC where it is not heat-welded take less time than the adhesive for TPO and there is less risk since the mechanical fasteners can be installed in cold weather. Another assumption was that other activities will not adversely affect the critical path. This would require a float analysis or the use of a scheduling program such as Primavera. This will not be done for the scope of this analysis.

As another general note, it should be considered how the figure of 75% prefabrication is assumed. The methods of construction are almost identical for both membranes since they are both heat-welded at the seams. The only difference is in how they are adhered to the substrate of the membranes. The PVC system will be mechanically fastened at the perimeter and TPO is fully adhered through the use of adhesives. Mechanically fastened systems have a quicker installation time than fully adhered systems so this can be assumed to be negligible.

7.7.2: Cost Analysis

A cost analysis was performed on each system that was analyzed. Even though at a certain point I realized that PVC would be the most viable option, all systems were analyzed for cost to ensure that EPDM and BUR were not dramatically cheaper, and therefore a better possibility. This cost analysis further reinforced that those systems would not be used as the best option. Also, TPO was estimated using RS Means in order to have the same source of estimation as all of the other roofing systems. The values determined by RS Means were speculated by an equalizing factor that was developed by dividing the actual value of TPO at CWNCHS by the estimated value (TPO). The full RS Means estimate can be found in the appendix. The equalizing factor was re-distributed with the other systems' estimated values as shown below:

ADJUSTED COST ANALYSIS		
Actual TPO Cost (Mat + Lab + Eq)	**$**	**1,035,000.00**
Estimated TPO Cost (RS Means)	$	720,099.00
Real Cost Multiplier		(\$1,035,000)/(\$720,099) = 1.4373
EPDM Estimate (RS Means)	$	761,070.15
EPDM Estimate*Multiplier	**$**	**1,093,886.13**
BUR Estimate (RS Means)	$	819,423.00
BUR Estimate*Multiplier	**$**	**1,177,756.68**
PVC Estimate (RS Means)	$	802,041.30
PVC Estimate*Multiplier	**$**	**1,152,773.96**

Figure 74: RS Means Alternative Roofing Systems Analysis w/ Real Cost Adjustment

This shows that RS Means estimates that EPDM would be the cheapest option to TPO. This is negligible since it cannot be installed during low temperatures. The next best option is PVC, which is $25,000 less than built-up roofing. This RS Means was used solely to affirm that PVC would be used. In actuality, the actual costs are a bit different. That actual TPO cost will be inflated by the overtime labor costs that were necessary to regain the substantial completion date of January 31st, 2014. Also, the PVC material value will be used as $1.04/SF, as given to me by the Duro-Last sales representative, Jay Monteverde. General conditions savings will also be factored into the best alternative for cost purposes:

FINAL RECOMMENDATION ESTIMATE		
Actual TPO Subtotal	$	1,035,000.00
Overtime Labor for TPO	$	15,000.00
Total TPO Costs (Actual)	$	1,050,000.00
PVC Estimate (RS Means)	$	712,649.70
PVC Estimate (Real Cost Adjustment)	$	1,024,291.41
PVC Estimate (Duro-Last)	$	703,344.28
PVC Estimate (Real Cost Adjustment)	$	1,010,916.74
General Conditions Savings		(30 days)*($6,835/day) = $205,050.00
Actual Cost of PVC (RS Means)	$	819,241.41
Actual Cost of PVC (Duro-Last)	$	805,866.74
Cost Savings of Prefabricated PVC (Duro-Last)	**$**	**244,133.26**

Figure 75: Final Roofing Estimate

This table clearly shows that by factoring in actual costs of TPO at CWNCHS with overtime and reducing the Duro-Last estimate by the potential cost savings from general conditions, there is a potential overall cost savings of **$244,133.26** from switching to the prefabricated Duro-Last system. The previous figure is estimated as the prefabricated 50-mil Duro-Last product with a warranty of 20 years. Utilizing the RS Means PVC estimate for 60-mil PVC roofing, a savings of $230,758.59 was forecasted. Also, with such a large savings for the owner, there is an opportunity to add value to the project. Duro-Last offers a 60-mil product that is warrantied for 25-years (5 years longer than 50-mil Duro-Last PVC and 60-mil Firestone UltraPly TPO). The 60-mil Duro-Last PVC has a material cost of $1.17/SF and after running the same cost analysis displayed above, it was forecasted that by using the increased millage and therefore longer warrantied product, the savings for the owner would be **$199,555.51**. So depending on the estimate taken and the decision of the owner to use a 20-year or 25-year warranty, the estimated savings for the owner are between:

$199,555.51 - $229,133.26

7.7.3: Logistics/Constructability

Duro-Last's prefabricated PVC roofing system actually greatly improves the constructability of the roof at Cardinal Wuerl North Catholic High School. While costs were incurred by the delay of the roof, other than $15,000 worth of overtime labor, most of said costs were not quantifiable. The huge advantage of this system is that it can be installed during cold weather. Also, prefabrication greatly reduces a lot of the risk involved in unstable weather conditions and the general calamity that is a construction project. Prefabrication would occur in a Duro-Last warehouse in Pittsburgh, PA, so shipping costs are basically negligible. One constructability issue that may be of concern to the owner is that the edges of the membrane are mechanically fastened. This decreases the risk of installation delays since adhesives are not involved but it increases the risk of leakage. Jay from Duro-Last ensured me that he has never seen an issue with this method of installation and that 6" of insulation, 5/8" of roof board, as well as a strong vapor barrier should be sufficient protection against this risk. When comparing the issue of mechanically fastening the edges of PVC to the substrate against the ability of the TPO membrane to accept a quality heat-weld in cold weather, I believe that the TPO constructability issue is worse. This is clearly demonstrated by the failure seen on-site and in Chapter 7.5 of this analysis. Florida Consulting, LLC provided this photograph and was able to show several other areas of the TPO membrane where it failed and needed to be reworked. Other constructability issues such as the integrity of the alternative systems as well as cold weather installation of said systems were outlined and discussed in previous chapters of this analysis.

Another advantage to the TPO system at CWNCHS was that since it was white and highly reflective, it provided a LEED Credit for Heat Island Effect. After doing some brief research with the Environmental Protection Agency, it is clear that the white PVC roofing system being analyzed also provides that same credit.

Finally, when attempting to choose between two different roofing systems, weight should be factored in to determine if the roof structure would change. The weights of the systems being considered are as follows:

60-mil Firestone UltraPly TPO = 0.40 PSF
50-mil Duro-Last PVC = 0.29 PSF
60-mil Duro-Last PVC = 0.40 PSF

The two 60-mil products have exactly equal weights and the 50-mil PVC alternative is actually lighter than the current system by 0.11 PSF. If the 50-mil PVC was used it can be assumed that the roof structure would not be changed since this weight difference is so minor. If the 60-mil PVC were used it would have no direct influence on the roof structure since it is the same exact weight.

7.8: Conclusions and Recommendations

My conclusion for this analysis is that based on the competitive cost, constructability, prefabrication, overall quality of the system, general conditions savings, and schedule reduction of using PVC roofing as an alternative to TPO, it should definitely be used. The following graphic shows the pros/cons of both systems:

TPO Analysis		PVC Analysis	
Pros	**Cons**	**Pros**	**Cons**
• Cheap • White Surface • Fully-Adhered • LEED Credit	• Can't install in cold weather • Not very durable • No prefabrication • Poor workmanship & quality of installation during winter weather	• Strength • Durability • Weather Resistance • Prefabrication • LEED Credit • Cost Competitive • Workmanship	• Mechanically fastened • Somewhat higher initial investment • Risk – GC payback may not be as high as estimated

Figure 76: TPO vs. PVC - Pros & Cons

So, with the benefit of hindsight, it is clear that the prefabricated Duro-Last PVC roofing system would have been the better option. The pros/cons of both systems above clearly illustrated this. Also, roughly $213,000 could have been saved by the owner due to a potential reduction of approximately 30 days in the schedule and $15,000 could have been saved by the general contractor by not having to pay for overtime labor. Duro-Last claimed that prefabrication could have reduced it even further but for the sake of being conservative as well as the fact that CWNCHS has a very expansive and non-uniform roofing layout, I estimated a rate of 75% prefabrication as opposed to their claim of 85%. It is ultimately the efforts in prefabrication that make this analysis worthy of recommending a different product than that installed. The cost savings reported from the reduction of the overall project schedule differentiated this system from the other alternatives.

Chapter 8: OVERALL CONCLUSIONS & RECOMMENDATIONS

8.1: Prefabricated Exterior Masonry Panels

It is of the belief of the researcher that the owner and project team would not benefit from the implementation of prefabricated exterior masonry panels. While they would reduce structural costs and possibly reduce the overall duration of the project several weeks, those benefits do not outweigh the extremely high cost of prefabrication. There are buildings where Sto Panel Brick Insulated systems would be a great option due to their lightweight/energy-efficient properties, but they would be better suited for more geometrically simple, taller buildings. A schedule reduction was not of great importance to the owner, so despite the great performance of this system, it should not be used due to the high costs.

8.2: Lifetime Costs of VE: Finishes

It is of the belief that, while most VE decisions for Division 9: Finishes were not overturned; this lifecycle analysis regarding maintenance, repair, refinishing, energy costs, and other routine concerns over the lifecycle of a building was very beneficial. It showed that the VCT decision could prove to be more expensive rather than less expensive over time and that only 69% of the reported cost reductions would be accurate throughout CWNCHS' lifecycle. As a construction professional, you want to give the most accurate depiction of the building you are assembling for the owner as possible. In my opinion, this involves reporting present value costs for the expected lifecycle of their building because reporting only initial costs may be misleading.

8.3: Efficient & Effective Turnover of Facility Management Information

This critical industry research topic proved to line up very well with the practices that were occurring at CWNCHS. The Diocese wanted to ensure that their large investment of $72.5 million in this building was well-maintained for as long as possible. They believed that this required the implementation of BIM technologies for facilities management. The Onuma system has not been integrated, but the process of developing a federated model with all necessary close-out information is fully underway and going smoothly. It is of the belief of the researcher and the project team that they chose the best program for FM based on the criteria of cost, BIM integration, space management, and O&M procedures of the software. It is also of the belief that, based on the availability and willingness of the FM that manages the Dioceses' K-8 school across the road from CWNCHS to take on the management of this building, that the Diocese fell into a good situation with respect to training of the FM. Early training is the most important aspect of efficiently turning over FM information for operations. When all of the project tools are in place for the training to occur and a facility manager is not present, inefficiencies occur and beneficial information goes under the radar.

8.4: Alternative Roofing Systems Analysis

It is of the belief of the researcher that the proposed Duro-Last PVC roofing system is the better option compared to the Firestone TPO product that was installed at CWNCHS. PVC offers better performance and can maintain similar sustainability properties of TPO. The general contractor would have saved $15,000 without having to pay for overtime labor and the owner could have saved upwards of $213,000 from schedule reductions and cost effectiveness of the PVC system over TPO. Value was also added by increasing the warranty by 5 years while still retaining a great cost savings for the owner. Constructability was also improved since this system can be installed during cold weather due to the lack of adhesives.

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APPENDIX A: PROJECT COSTS

Actual Building Costs for Cardinal Wuerl North Catholic High School		
	Construction Cost	Cost/SF
Actual Building Construction Costs (CC)	$43,027,573.00	$242.92
Total Project Cost (TC)	$72,525,969.00	$13.91
MEP/FP Systems Total Cost	$8,860,010.00	$49.99
Structural Systems Cost	$6,017,485.00	$33.97

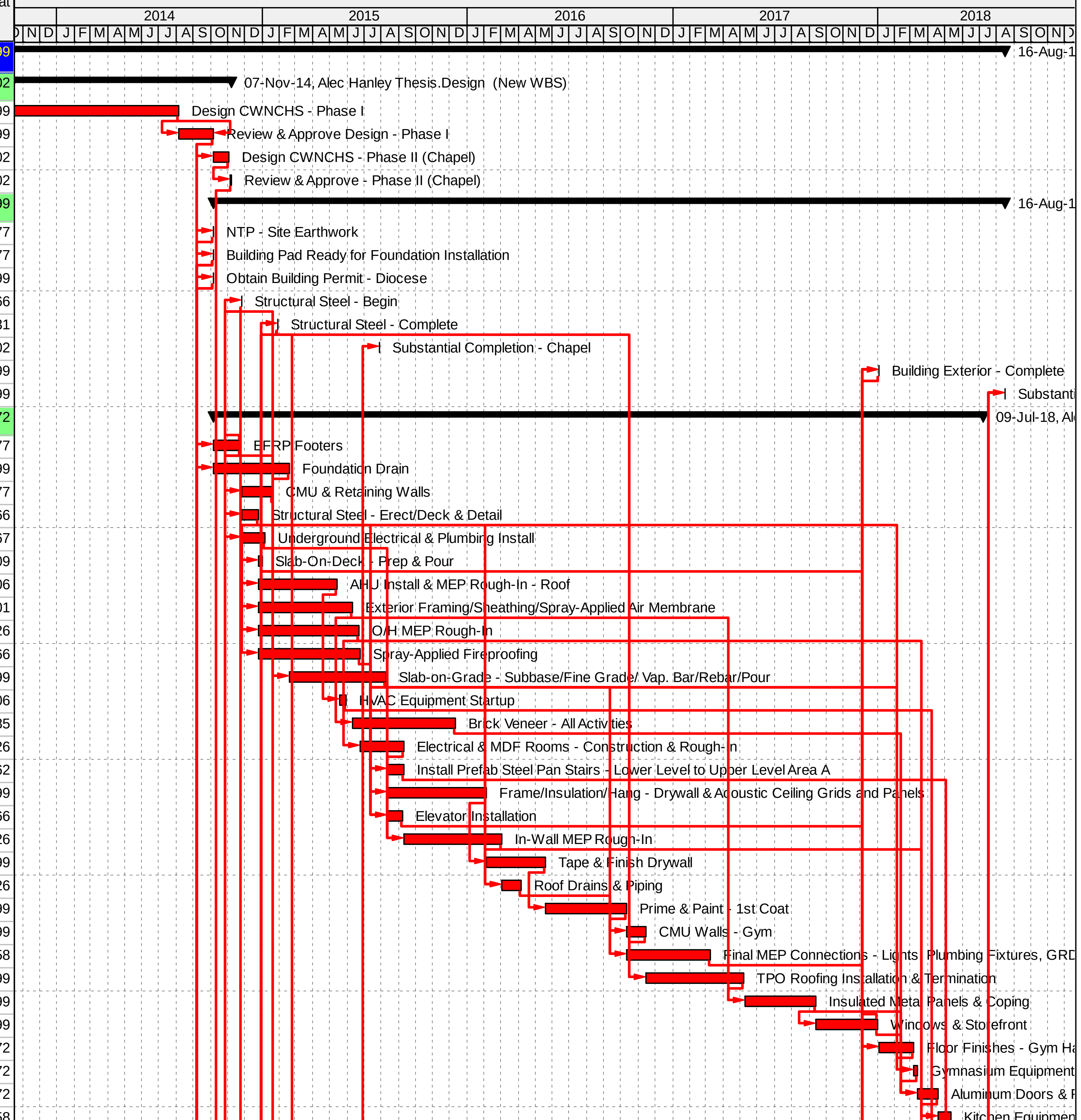
Figure 77: CWNCHS Actual Building Costs

Square Foot Estimate for Cardinal Wuerl North Catholic High School	
Gross Floor Area	177,129
Average Floor Height	20'1"
Perimeter	3,136'
Interpolated Construction Cost	$162.92/SF
Perimeter Adjustment Cost	$3.86/SF
Story Height Adjustment Cost	$14.80/SF
Final CC/SF	$181.58/SF
Additives	$1,481,640
Final Total Cost	**$33,644,723.82**

Figure 78: Square Foot Estimate of CWNCHS

APPENDIX B: SCHEDULE

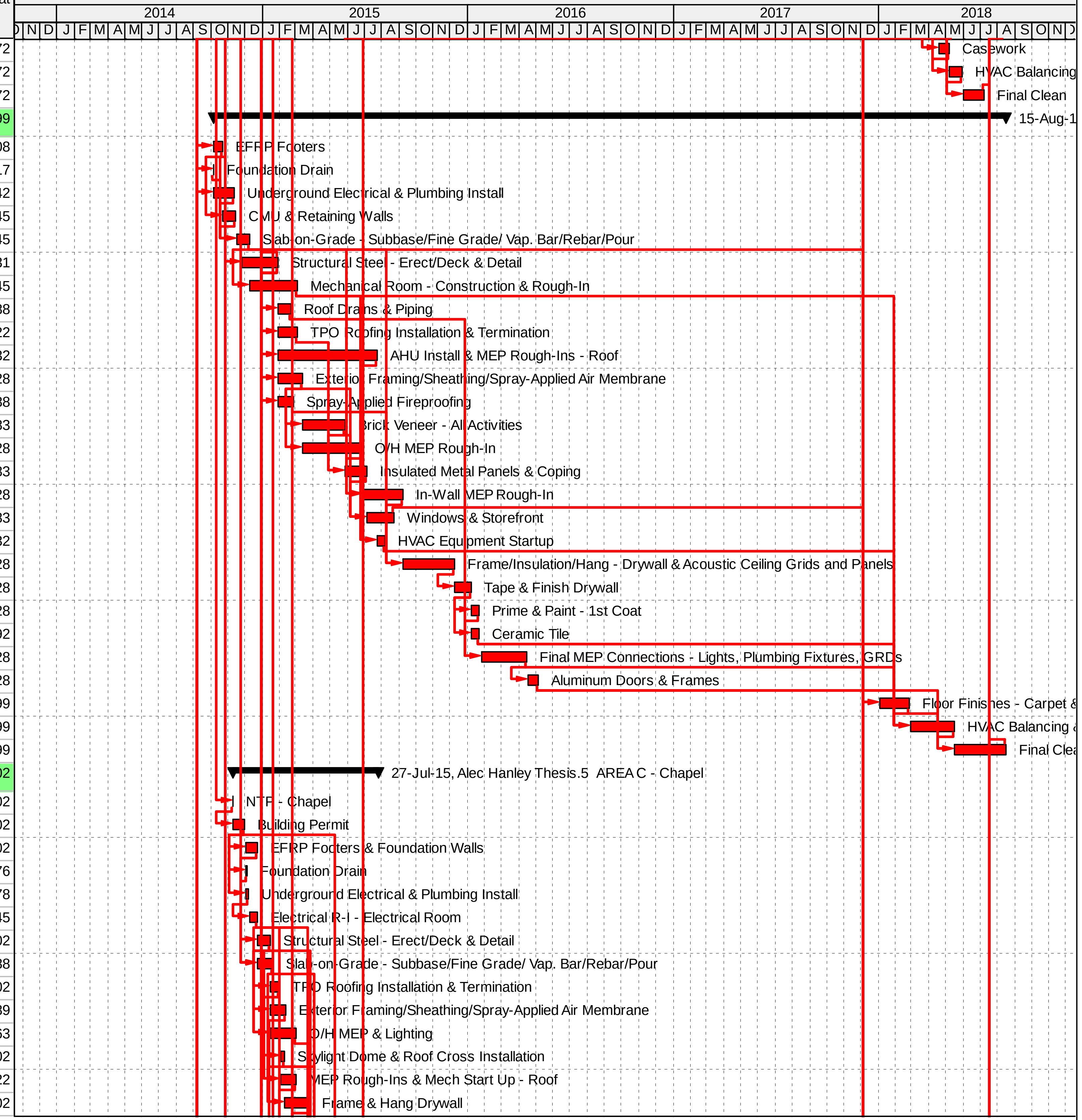
Activity Name	Original Duration	Start	Finish	Total Float
Alec Hanley Thesis CWNCHS	1261	14-Oct-13	16-Aug-18	-1099
Alec Hanley Thesis.Design (New WBS)	278	14-Oct-13	07-Nov-14	-302
Design CWNCHS - Phase I	210	14-Oct-13	05-Aug-14	-1099
Review & Approve Design - Phase I	44	06-Aug-14	06-Oct-14	-1099
Design CWNCHS - Phase II (Chapel)	20	07-Oct-14	03-Nov-14	-302
Review & Approve - Phase II (Chapel)	4	04-Nov-14	07-Nov-14	-302
Alec Hanley Thesis.8 Key Milestones	1007	07-Oct-14	16-Aug-18	-1099
NTP - Site Earthwork	0	07-Oct-14	07-Oct-14	-1077
Building Pad Ready for Foundation Installation	0	07-Oct-14	07-Oct-14	-1077
Obtain Building Permit - Diocese	0	07-Oct-14	07-Oct-14	-1099
Structural Steel - Begin	0	25-Nov-14	25-Nov-14	-1066
Structural Steel - Complete	0	29-Jan-15	29-Jan-15	-631
Substantial Completion - Chapel	0	28-Jul-15	28-Jul-15	-302
Building Exterior - Complete	0	03-Jan-18	03-Jan-18	-1099
Substantial Completion - Main Building	0	16-Aug-18	16-Aug-18	-1099
Alec Hanley Thesis.7 AREA A - 1st & 2nd Floor	980	07-Oct-14	09-Jul-18	-1072
EFRP Footers	35	07-Oct-14	24-Nov-14	-1077
Foundation Drain	97	07-Oct-14	18-Feb-15	-1099
CMU & Retaining Walls	40	25-Nov-14	19-Jan-15	-1077
Structural Steel - Erect/Deck & Detail	23	25-Nov-14	25-Dec-14	-1066
Underground Electrical & Plumbing Install	30	25-Nov-14	05-Jan-15	-1067
Slab-On-Deck - Prep & Pour	5	26-Dec-14	01-Jan-15	-309
AHU Install & MEP Rough-In - Roof	101	26-Dec-14	15-May-15	-306
Exterior Framing/Sheathing/Spray-Applied Air Membrane	119	26-Dec-14	10-Jun-15	-601
O/H MEP Rough-In	128	26-Dec-14	23-Jun-15	-726
Spray-Applied Fireproofing	129	26-Dec-14	24-Jun-15	-1066
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	123	19-Feb-15	10-Aug-15	-1099
HVAC Equipment Startup	10	18-May-15	29-May-15	-306
Brick Veneer - All Activities	131	11-Jun-15	10-Dec-15	-485
Electrical & MDF Rooms - Construction & Rough-In	57	24-Jun-15	10-Sep-15	-726
Install Prefab Steel Pan Stairs - Lower Level to Upper Level Area A	23	11-Aug-15	10-Sep-15	-362
Frame/Insulation/Hang - Drywall & Acoustic Ceiling Grids and Pan	127	11-Aug-15	03-Feb-16	-1099
Elevator Installation	20	11-Aug-15	07-Sep-15	-466
In-Wall MEP Rough-In	124	11-Sep-15	02-Mar-16	-726
Tape & Finish Drywall	76	04-Feb-16	19-May-16	-1099
Roof Drains & Piping	26	03-Mar-16	07-Apr-16	-726
Prime & Paint - 1st Coat	102	20-May-16	10-Oct-16	-1099
CMU Walls - Gym	25	11-Oct-16	14-Nov-16	-1099
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	107	11-Oct-16	08-Mar-17	-858
TPO Roofing Installation & Termination	125	15-Nov-16	08-May-17	-1099
Insulated Metal Panels & Coping	91	09-May-17	12-Sep-17	-1099
Windows & Storefront	80	13-Sep-17	02-Jan-18	-1099
Floor Finishes - Gym Hardwood & Sealed/Polished Concrete	45	03-Jan-18	06-Mar-18	-1072
Gymnasium Equipment Installation	4	07-Mar-18	12-Mar-18	-1072
Aluminum Doors & Frames	27	13-Mar-18	18-Apr-18	-1072
Kitchen Equipment Installation	17	19-Apr-18	11-May-18	-1058



Actual Level of Effort | Remaining Work | ◆ Milestone
Actual Work | Critical Remaining Work | summary

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish	Total Float
Casework	13	19-Apr-18	07-May-18	-1072
HVAC Balancing & Commissioning	18	08-May-18	31-May-18	-1072
Final Clean	27	01-Jun-18	09-Jul-18	-1072
Alec Hanley Thesis.6 AREA B - Mechanical/Ele	1007	07-Oct-14	15-Aug-18	-1099
EFRP Footers	12	07-Oct-14	22-Oct-14	-608
Foundation Drain	1	07-Oct-14	07-Oct-14	-517
Underground Electrical & Plumbing Install	26	07-Oct-14	11-Nov-14	-542
CMU & Retaining Walls	17	23-Oct-14	14-Nov-14	-545
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	17	17-Nov-14	09-Dec-14	-545
Structural Steel - Erect/Deck & Detail	47	25-Nov-14	28-Jan-15	-631
Mechanical Room - Construction & Rough-In	60	10-Dec-14	03-Mar-15	-545
Roof Drains & Piping	17	29-Jan-15	20-Feb-15	-388
TPO Roofing Installation & Termination	25	29-Jan-15	04-Mar-15	-422
AHU Install & MEP Rough-Ins - Roof	126	29-Jan-15	23-Jul-15	-432
Exterior Framing/Sheathing/Spray-Applied Air Membrane	31	29-Jan-15	12-Mar-15	-628
Spray-Applied Fireproofing	19	29-Jan-15	24-Feb-15	-488
Brick Veneer - All Activities	55	13-Mar-15	28-May-15	-483
O/H MEP Rough-In	76	13-Mar-15	26-Jun-15	-628
Insulated Metal Panels & Coping	27	29-May-15	06-Jul-15	-483
In-Wall MEP Rough-In	52	29-Jun-15	08-Sep-15	-628
Windows & Storefront	35	07-Jul-15	24-Aug-15	-483
HVAC Equipment Startup	10	24-Jul-15	06-Aug-15	-432
Frame/Insulation/Hang - Drywall & Acoustic Ceiling Grids and Pan	66	09-Sep-15	09-Dec-15	-628
Tape & Finish Drywall	21	10-Dec-15	07-Jan-16	-628
Prime & Paint - 1st Coat	11	08-Jan-16	22-Jan-16	-628
Ceramic Tile	11	08-Jan-16	22-Jan-16	-592
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	60	25-Jan-16	15-Apr-16	-628
Aluminum Doors & Frames	15	18-Apr-16	06-May-16	-628
Floor Finishes - Carpet & Sealed/Polished Concrete	39	03-Jan-18	26-Feb-18	-1099
HVAC Balancing & Commissioning	57	27-Feb-18	16-May-18	-1099
Final Clean	65	17-May-18	15-Aug-18	-1099
Alec Hanley Thesis.5 AREA C - Chapel	186	10-Nov-14	27-Jul-15	-302
NTP - Chapel	0	10-Nov-14	10-Nov-14	-302
Building Permit	16	10-Nov-14	01-Dec-14	-302
EFRP Footers & Foundation Walls	15	02-Dec-14	22-Dec-14	-302
Foundation Drain	3	02-Dec-14	04-Dec-14	-276
Underground Electrical & Plumbing Install	5	02-Dec-14	08-Dec-14	-278
Electrical R-I - Electrical Room	10	09-Dec-14	22-Dec-14	-245
Structural Steel - Erect/Deck & Detail	18	23-Dec-14	15-Jan-15	-302
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	21	23-Dec-14	20-Jan-15	-288
TPO Roofing Installation & Termination	11	16-Jan-15	30-Jan-15	-302
Exterior Framing/Sheathing/Spray-Applied Air Membrane	19	16-Jan-15	11-Feb-15	-289
O/H MEP & Lighting	32	16-Jan-15	02-Mar-15	-263
Skylight Dome & Roof Cross Installation	6	02-Feb-15	09-Feb-15	-302
MEP Rough-Ins & Mech Start Up - Roof	21	02-Feb-15	02-Mar-15	-222
Frame & Hang Drywall	31	10-Feb-15	24-Mar-15	-302



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

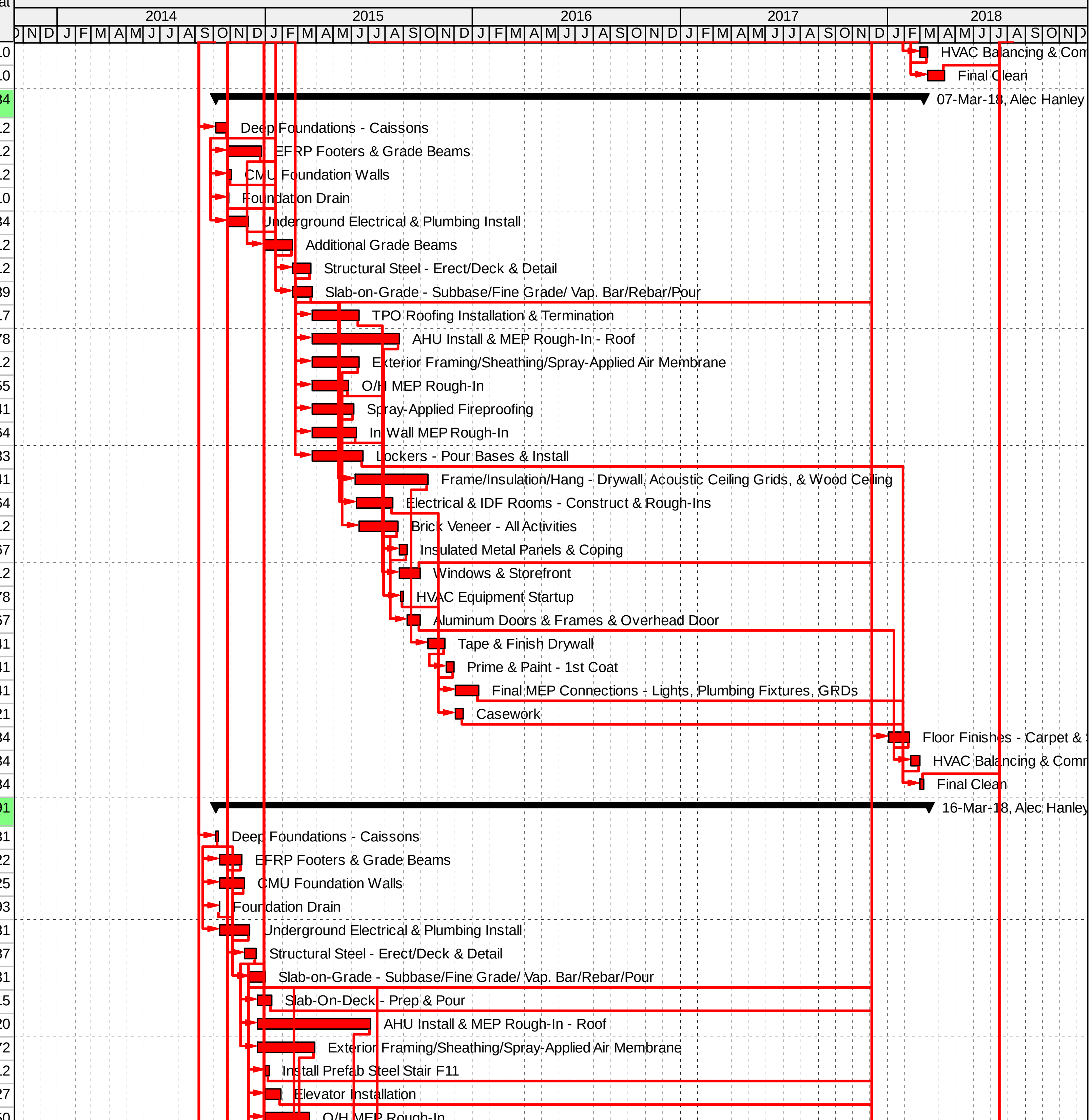
TASK filter: All Activities

Activity Name	Original Duration	Start	Finish	Total Float
Ext. CMU & Brick	33	12-Feb-15	30-Mar-15	-289
HVAC Equipment Startup	5	03-Mar-15	09-Mar-15	-222
Install Light Fixtures	10	25-Mar-15	07-Apr-15	-229
Tape & Finish	15	25-Mar-15	14-Apr-15	-302
Soffit/Fascia/Metal Panels	28	31-Mar-15	07-May-15	-289
Prime & Paint 1st Coat	5	15-Apr-15	21-Apr-15	-302
Electrical Trim Out	1	22-Apr-15	22-Apr-15	-239
Decorative Rose Petal - Ceiling	5	22-Apr-15	28-Apr-15	-259
Final Plumbing Fixtures & Connections	3	22-Apr-15	24-Apr-15	-302
Roof Plumbing & Accessory Installation	5	27-Apr-15	01-May-15	-302
Install Floor Finishes	25	04-May-15	05-Jun-15	-302
Windows & Storefront	24	08-May-15	10-Jun-15	-289
Pews & Casework - S/A/FD & Installation	15	08-Jun-15	26-Jun-15	-302
Aluminum Doors & Frames	1	29-Jun-15	29-Jun-15	-302
HVAC Balancing & Commissioning	15	30-Jun-15	20-Jul-15	-302
Final Clean	5	21-Jul-15	27-Jul-15	-302
Alec Hanley Thesis.4 AREA D - Auditorium, Sta	**918**	**07-Oct-14**	**12-Apr-18**	**-1010**
EFRP Footers	12	07-Oct-14	22-Oct-14	-582
Foundation Drain	1	07-Oct-14	07-Oct-14	-554
Underground Electrical & Plumbing Install	26	07-Oct-14	11-Nov-14	-579
CMU Foundation Walls	17	23-Oct-14	14-Nov-14	-582
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	87	17-Nov-14	17-Mar-15	-582
Structural Steel - Erect/Deck & Detail	31	25-Nov-14	06-Jan-15	-584
Roof Drains & Piping	35	07-Jan-15	24-Feb-15	-294
MEP Rough-Ins & Mech Start Up - Roof	144	07-Jan-15	27-Jul-15	-403
Exterior Framing/Sheathing/Spray-Applied Air Membrane	50	07-Jan-15	17-Mar-15	-424
O/H MEP Rough-In	82	07-Jan-15	30-Apr-15	-417
Spray-Applied Fireproofing	52	07-Jan-15	19-Mar-15	-584
TPO Roofing Installation & Termination	114	29-Jan-15	07-Jul-15	-406
CMU Walls - Auditorium	89	18-Mar-15	20-Jul-15	-454
Brick Veneer - All Activities	55	18-Mar-15	02-Jun-15	-424
Auditorium Seating - Installation, Field Measure, Fab & Deliver	80	18-Mar-15	07-Jul-15	-311
Frame/Insulate/Hang - Drywall, Acoustic Wall/Celing Panels, & Wc	129	20-Mar-15	16-Sep-15	-584
Insulated Metal Panels/Soffit & Fascia/Coping	68	03-Jun-15	04-Sep-15	-424
Smoke Vents - Stage Roof	10	08-Jul-15	21-Jul-15	-406
Deck & Pour Spot Platforms - Auditorium	2	21-Jul-15	22-Jul-15	-407
Install Prefab Spiral Stairs & Caged Ladders - Auditorium	2	21-Jul-15	22-Jul-15	-371
A/V Stage Equipment & Rigging	36	23-Jul-15	10-Sep-15	-407
Windows & Storefront	45	07-Sep-15	06-Nov-15	-424
In-Wall MEP Rough-In	68	17-Sep-15	21-Dec-15	-584
Aluminum & Overhead Doors & Frames	15	09-Nov-15	27-Nov-15	-424
Tape & Finish Drywall	20	22-Dec-15	18-Jan-16	-584
Prime, Paint & Block Filler - 1st Coat	56	19-Jan-16	05-Apr-16	-584
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	68	06-Apr-16	08-Jul-16	-584
Casework & Architectural Woodwork	9	06-Apr-16	18-Apr-16	-564
Floor Finishes - Stage Hardwood, Carpet & Sealed/Polished Conc	39	03-Jan-18	26-Feb-18	-1010

Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish	Total Float
HVAC Balancing & Commissioning	10	27-Feb-18	12-Mar-18	-1010
Final Clean	23	13-Mar-18	12-Apr-18	-1010
Alec Hanley Thesis.3 AREA E - Library & Arts E	892	07-Oct-14	07-Mar-18	-984
Deep Foundations - Caissons	15	07-Oct-14	27-Oct-14	-512
EFRP Footers & Grade Beams	44	28-Oct-14	26-Dec-14	-512
CMU Foundation Walls	5	28-Oct-14	03-Nov-14	-312
Foundation Drain	3	28-Oct-14	30-Oct-14	-310
Underground Electrical & Plumbing Install	27	28-Oct-14	03-Dec-14	-334
Additional Grade Beams	38	29-Dec-14	18-Feb-15	-512
Structural Steel - Erect/Deck & Detail	23	19-Feb-15	23-Mar-15	-512
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	25	19-Feb-15	25-Mar-15	-389
TPO Roofing Installation & Termination	60	24-Mar-15	15-Jun-15	-317
AHU Install & MEP Rough-In - Roof	112	24-Mar-15	26-Aug-15	-378
Exterior Framing/Sheathing/Spray-Applied Air Membrane	60	24-Mar-15	15-Jun-15	-512
O/H MEP Rough-In	48	24-Mar-15	28-May-15	-355
Spray-Applied Fireproofing	54	24-Mar-15	05-Jun-15	-441
In-Wall MEP Rough-In	55	26-Mar-15	10-Jun-15	-364
Lockers - Pour Bases & Install	63	26-Mar-15	22-Jun-15	-283
Frame/Insulation/Hang - Drywall, Acoustic Ceiling Grids, & Wood C	94	08-Jun-15	15-Oct-15	-441
Electrical & IDF Rooms - Construct & Rough-Ins	46	11-Jun-15	13-Aug-15	-364
Brick Veneer - All Activities	50	16-Jun-15	24-Aug-15	-512
Insulated Metal Panels & Coping	11	25-Aug-15	08-Sep-15	-367
Windows & Storefront	29	25-Aug-15	02-Oct-15	-512
HVAC Equipment Startup	5	27-Aug-15	02-Sep-15	-378
Aluminum Doors & Frames & Overhead Door	16	09-Sep-15	30-Sep-15	-367
Tape & Finish Drywall	21	16-Oct-15	13-Nov-15	-441
Prime & Paint - 1st Coat	11	16-Nov-15	30-Nov-15	-441
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	31	01-Dec-15	12-Jan-16	-441
Casework	11	01-Dec-15	15-Dec-15	-421
Floor Finishes - Carpet & Sealed/Polished Concrete	28	03-Jan-18	09-Feb-18	-984
HVAC Balancing & Commissioning	12	12-Feb-18	27-Feb-18	-984
Final Clean	6	28-Feb-18	07-Mar-18	-984
Alec Hanley Thesis.2 AREA F - 1st & 2nd Floor	899	07-Oct-14	16-Mar-18	-991
Deep Foundations - Caissons	4	07-Oct-14	10-Oct-14	-431
EFRP Footers & Grade Beams	30	13-Oct-14	21-Nov-14	-422
CMU Foundation Walls	33	13-Oct-14	26-Nov-14	-425
Foundation Drain	1	13-Oct-14	13-Oct-14	-393
Underground Electrical & Plumbing Install	39	13-Oct-14	04-Dec-14	-431
Structural Steel - Erect/Deck & Detail	17	25-Nov-14	17-Dec-14	-387
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	19	05-Dec-14	31-Dec-14	-431
Slab-On-Deck - Prep & Pour	18	18-Dec-14	12-Jan-15	-215
AHU Install & MEP Rough-In - Roof	143	18-Dec-14	06-Jul-15	-320
Exterior Framing/Sheathing/Spray-Applied Air Membrane	73	18-Dec-14	30-Mar-15	-372
Install Prefab Steel Stair F11	5	01-Jan-15	07-Jan-15	-212
Elevator Installation	20	01-Jan-15	28-Jan-15	-227
O/H MEP Rough-In	57	01-Jan-15	20-Mar-15	-350



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

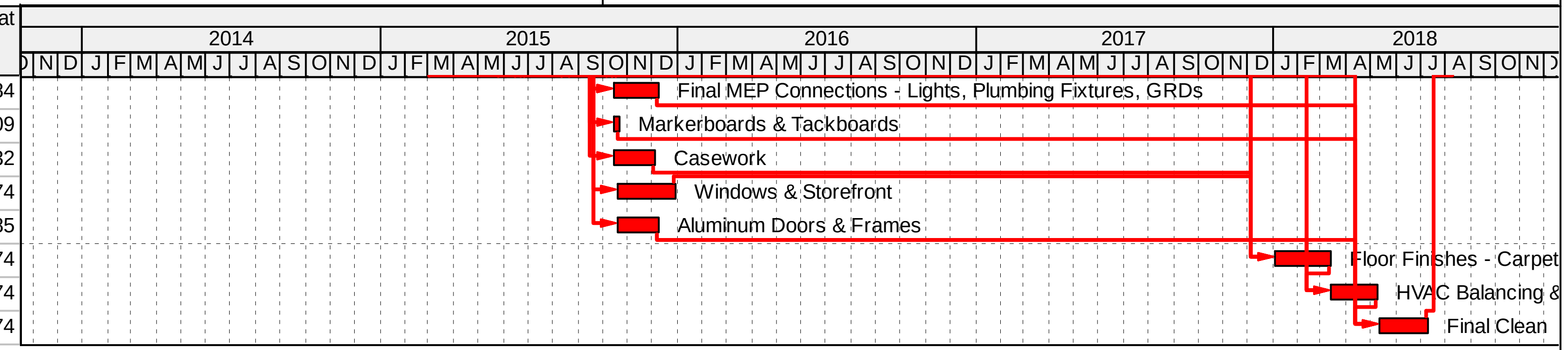
TASK filter: All Activities

Activity Name	Original Duration	Start	Finish	Total Float
In-Wall MEP Rough-In	46	01-Jan-15	05-Mar-15	-339
Lockers - Pour Bases & Install	91	01-Jan-15	07-May-15	-256
Frame/Insulation/Hang - Drywall, Acoustic Ceiling Grids, 2nd Floor	156	01-Jan-15	06-Aug-15	-431
TPO Roofing Installation & Termination	80	29-Jan-15	20-May-15	-369
Standing Seam Metal Roofing Installation	82	29-Jan-15	22-May-15	-417
Electrical & IDF Rooms - Construct & Rough-Ins	76	23-Mar-15	06-Jul-15	-350
Brick Veneer - All Activities	40	31-Mar-15	25-May-15	-372
Insulated Metal Panels/Soffit & Fascia/Coping	59	26-May-15	14-Aug-15	-372
Windows & Storefront	47	26-May-15	29-Jul-15	-360
HVAC Equipment Startup	5	07-Jul-15	13-Jul-15	-320
Tape & Finish Drywall	39	07-Aug-15	30-Sep-15	-431
Construct Mockup Classroom F126	45	17-Aug-15	16-Oct-15	-372
Aluminum Doors & Frames	21	17-Aug-15	14-Sep-15	-365
Prime & Paint - 1st Coat	15	01-Oct-15	21-Oct-15	-431
Ceramic Tile	5	01-Oct-15	07-Oct-15	-417
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	35	08-Oct-15	25-Nov-15	-417
Markerboards & Tackboards	11	22-Oct-15	05-Nov-15	-386
Casework - Lab & Classroom	14	22-Oct-15	10-Nov-15	-431
Floor Finishes - Carpet & Sealed/Polished Concrete	25	03-Jan-18	06-Feb-18	-991
HVAC Balancing & Commissioning	17	07-Feb-18	01-Mar-18	-991
Final Clean	11	02-Mar-18	16-Mar-18	-991
Alec Hanley Thesis.1 AREA G - 1st & 2nd Floor	982	07-Oct-14	11-Jul-18	-1074
Deep Foundations - Caissons	3	07-Oct-14	09-Oct-14	-555
EFRP Footers	13	10-Oct-14	28-Oct-14	-555
Foundation Drain	1	10-Oct-14	10-Oct-14	-460
Underground Electrical & Plumbing Install	38	10-Oct-14	02-Dec-14	-497
CMU Foundation Walls	14	29-Oct-14	17-Nov-14	-486
Structural Steel - Erect/Deck & Detail	25	25-Nov-14	29-Dec-14	-574
Slab-on-Grade - Subbase/Fine Grade/ Vap. Bar/Rebar/Pour	14	03-Dec-14	22-Dec-14	-497
Slab-On-Deck - Prep & Pour	30	30-Dec-14	09-Feb-15	-532
AHU Install & MEP Rough-In - Roof	121	30-Dec-14	16-Jun-15	-361
Exterior Framing/Sheathing/Spray-Applied Air Membrane	111	30-Dec-14	02-Jun-15	-574
TPO Roofing Installation & Termination	29	29-Jan-15	10-Mar-15	-461
Standing Seam Metal Roofing Installation	63	29-Jan-15	27-Apr-15	-398
Install Prefab Steel Stair G11 & G12	16	10-Feb-15	03-Mar-15	-334
O/H MEP Rough-In	100	10-Feb-15	29-Jun-15	-447
In-Wall MEP Rough-In	78	10-Feb-15	28-May-15	-425
Lockers - Pour Bases & Install	97	10-Feb-15	24-Jun-15	-323
Frame/Insulation/Hang - Drywall & Acoustic Ceiling Grids	145	10-Feb-15	31-Aug-15	-532
Brick Veneer - All Activities	53	03-Jun-15	14-Aug-15	-574
HVAC Equipment Startup	2	17-Jun-15	18-Jun-15	-361
Electrical & IDF Rooms - Construct & Rough-Ins	40	30-Jun-15	24-Aug-15	-447
Insulated Metal Panels/Soffit & Fascia/Coping	46	17-Aug-15	19-Oct-15	-574
Tape & Finish Drywall	16	01-Sep-15	22-Sep-15	-532
Prime & Paint - 1st Coat	16	23-Sep-15	14-Oct-15	-532
Ceramic Tile	11	23-Sep-15	07-Oct-15	-479

Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish	Total Float
Final MEP Connections - Lights, Plumbing Fixtures, GRDs	39	15-Oct-15	08-Dec-15	-484
Markerboards & Tackboards	6	15-Oct-15	22-Oct-15	-409
Casework	37	15-Oct-15	04-Dec-15	-532
Windows & Storefront	51	20-Oct-15	29-Dec-15	-574
Aluminum Doors & Frames	37	20-Oct-15	09-Dec-15	-485
Floor Finishes - Carpet & Sealed/Polished Concrete	50	03-Jan-18	13-Mar-18	-1074
HVAC Balancing & Commissioning	42	14-Mar-18	10-May-18	-1074
Final Clean	44	11-May-18	11-Jul-18	-1074



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

TASK filter: All Activities

APPENDIX C: STRUCTURAL & MEP/FP TAKEOFFS & ESTIMATES

BEAMS & JOISTS														
Category	CSI Division	Item	Unit	Unit Costs					Quantity	Total Costs				
				Material	Labor	Equipment	Total	Total Including O&P		Material	Labor	Equipment	Total	Total Including O&P
Beams	512230300	W8x10	LF	$ 14.60	$ 4.68	$ 2.55	$ 21.83	$ 27.00	21.32	$ 311.27	$ 99.78	$ 54.37	$ 465.42	$ 575.64
	512230320	W8x15	LF	$ 22.00	$ 4.68	$ 2.55	$ 29.23	$ 35.00	187.25	$ 4,119.50	$ 876.33	$ 477.49	$ 5,473.32	$ 6,553.75
	512231100	W12x16	LF	$ 23.50	$ 3.19	$ 1.74	$ 28.43	$ 33.00	92.88	$ 2,182.75	$ 296.30	$ 161.62	$ 2,640.66	$ 3,065.14
	512231300	W12x22	LF	$ 32.00	$ 3.19	$ 1.74	$ 36.93	$ 43.00	1093.60	$ 34,995.20	$ 3,488.58	$ 1,902.86	$ 40,386.65	$ 47,024.80
	512231500	W12x26	LF	$ 38.00	$ 3.19	$ 1.74	$ 42.93	$ 49.00	1352.40	$ 51,391.20	$ 4,314.16	$ 2,353.18	$ 58,058.53	$ 66,267.60
	512231510	W12x30 (W12x26/W12x35 interpolation)	LF	$ 44.50	$ 3.33	$ 1.82	$ 49.65	$ 56.50	277.22	$ 12,336.29	$ 923.14	$ 504.54	$ 13,763.97	$ 15,662.93
	512231900	W14x22	LF	$ 38.00	$ 2.84	$ 1.54	$ 42.38	$ 48.00	52.00	$ 1,976.00	$ 147.68	$ 80.08	$ 2,203.76	$ 2,496.00
	512231900	W14x26	LF	$ 38.00	$ 2.84	$ 1.54	$ 42.38	$ 48.00	1274.49	$ 48,430.62	$ 3,619.55	$ 1,962.71	$ 54,012.89	$ 61,175.52
	512232100	W14x30	LF	$ 43.50	$ 3.12	$ 1.70	$ 48.32	$ 55.00	170.67	$ 7,424.15	$ 532.49	$ 290.14	$ 8,246.77	$ 9,386.85
	512232700	W16x26	LF	$ 38.00	$ 2.81	$ 1.53	$ 42.34	$ 48.00	2596.94	$ 98,683.72	$ 7,297.40	$ 3,973.32	$ 109,954.44	$ 124,653.12
	512232900	W16x31	LF	$ 45.00	$ 3.12	$ 1.70	$ 49.82	$ 56.50	2314.27	$ 104,142.36	$ 7,220.54	$ 3,934.27	$ 115,297.17	$ 130,756.52
	512233000	W16x36	LF	$ 51.75	$ 3.32	$ 1.80	$ 56.87	$ 64.25	55.50	$ 2,872.13	$ 184.26	$ 99.90	$ 3,156.29	$ 3,565.88
	512233300	W18x35	LF	$ 51.00	$ 4.22	$ 1.74	$ 56.96	$ 65.00	4952.64	$ 252,584.81	$ 20,900.15	$ 8,617.60	$ 282,102.56	$ 321,921.81
	512233500	W18x40	LF	$ 58.50	$ 4.22	$ 1.74	$ 64.46	$ 73.00	1450.86	$ 84,875.31	$ 6,122.63	$ 2,524.50	$ 93,522.44	$ 105,912.78
	512234100	W21x44	LF	$ 64.00	$ 3.81	$ 1.57	$ 69.38	$ 79.00	3750.00	$ 240,000.00	$ 14,287.50	$ 5,887.50	$ 260,175.00	$ 296,250.00
	512234900	W24x55	LF	$ 80.00	$ 3.65	$ 1.51	$ 85.16	$ 96.00	2637.32	$ 210,985.60	$ 9,626.22	$ 3,982.35	$ 224,594.17	$ 253,182.72
	512235100	W24x62	LF	$ 90.50	$ 3.65	$ 1.51	$ 95.66	$ 107.00	938.37	$ 84,922.49	$ 3,425.05	$ 1,416.94	$ 89,764.47	$ 100,405.59
	512235300	W24x68	LF	$ 99.00	$ 3.65	$ 1.51	$ 104.16	$ 117.00	1228.08	$ 121,579.92	$ 4,482.49	$ 1,854.40	$ 127,916.81	$ 143,685.36
	512235500	W24x76	LF	$ 111.00	$ 3.65	$ 1.51	$ 116.16	$ 130.00	31.35	$ 3,479.85	$ 114.43	$ 47.34	$ 3,641.62	$ 4,075.50
	512235700	W24x84	LF	$ 122.00	$ 3.75	$ 1.55	$ 127.30	$ 143.00	284.56	$ 34,716.32	$ 1,067.10	$ 441.07	$ 36,224.49	$ 40,692.08
	512235800	W27x84	LF	$ 122.00	$ 3.41	$ 1.40	$ 126.81	$ 142.00	73.38	$ 8,952.36	$ 250.23	$ 102.73	$ 9,305.32	$ 10,419.96
	512236100	W30x99	LF	$ 144.00	$ 3.38	$ 1.39	$ 148.77	$ 166.00	111.35	$ 16,034.40	$ 376.36	$ 154.78	$ 16,565.54	$ 18,484.10
	512237300	W36x135	LF	$ 197.00	$ 3.46	$ 1.43	$ 201.89	$ 224.00	24.00	$ 4,728.00	$ 83.04	$ 34.32	$ 4,845.36	$ 5,376.00
	512230476	L3x3x1/4	LF	$ 5.70	$ 22.00	$ 2.49	$ 30.19	$ 47.50	143.00	$ 815.10	$ 3,146.00	$ 356.07	$ 4,317.17	$ 6,792.50
	512230400	L4x4x3/8	LB	$ 0.77	$ 2.82	$ 0.32	$ 3.91	$ 6.20	530.52	$ 408.50	$ 1,496.07	$ 169.77	$ 2,074.33	$ 3,289.22
	512230672	C12x20.7	LF	$ 9.15	$ 34.50	$ 3.95	$ 47.60	$ 75.50	85.35	$ 780.95	$ 2,944.58	$ 337.13	$ 4,062.66	$ 6,443.93
Joists	521190160	12K3	LF	$ 4.72	$ 2.70	$ 1.21	$ 8.63	$ 11.15	347.04	$ 1,638.03	$ 937.01	$ 419.92	$ 2,994.96	$ 3,869.50
	521190180	14K3	LF	$ 4.97	$ 2.70	$ 1.21	$ 8.88	$ 11.40	563.00	$ 2,798.11	$ 1,520.10	$ 681.23	$ 4,999.44	$ 6,418.20
	521190200	16K3	LF	$ 5.20	$ 2.03	$ 1.01	$ 8.46	$ 10.75	89.33	$ 464.52	$ 180.89	$ 90.22	$ 755.73	$ 960.30
	521190210	16K4 (16K4/16K6 interpolation)	LF	$ 5.70	$ 2.25	$ 1.01	$ 8.96	$ 11.30	949.08	$ 5,409.76	$ 2,135.43	$ 958.57	$ 8,503.76	$ 10,724.60
	521191180	16KCS4	LF	$ 12.35	$ 2.25	$ 1.01	$ 15.61	$ 18.55	196.00	$ 2,420.60	$ 441.00	$ 197.96	$ 3,059.56	$ 3,635.80
	521190240	18K4	LF	$ 6.40	$ 2.03	$ 0.91	$ 9.34	$ 11.50	627.00	$ 4,012.80	$ 1,272.81	$ 570.57	$ 5,856.18	$ 7,210.50
	521191220	18KCS4	LF	$ 12.75	$ 2.03	$ 0.91	$ 15.69	$ 18.55	201.25	$ 2,565.94	$ 408.54	$ 183.14	$ 3,157.61	$ 3,733.19
	521190240	18K5	LF	$ 6.40	$ 2.03	$ 0.91	$ 9.34	$ 11.50	2074.71	$ 13,278.12	$ 4,211.65	$ 1,887.98	$ 19,377.76	$ 23,859.13
	521190245	18KCS5	LF	$ 6.40	$ 2.03	$ 0.91	$ 9.34	$ 11.50	562.67	$ 3,601.06	$ 1,142.21	$ 512.03	$ 5,255.29	$ 6,470.65
	521190500	20K4	LF	$ 6.65	$ 2.03	$ 0.91	$ 9.59	$ 11.85	178.50	$ 1,187.03	$ 362.36	$ 162.44	$ 1,711.82	$ 2,115.23
	521190500	20K5	LF	$ 6.65	$ 2.03	$ 0.91	$ 9.59	$ 11.85	2118.04	$ 14,084.94	$ 4,299.61	$ 1,927.41	$ 20,311.97	$ 25,098.73
	521191260	20KCS5	LF	$ 14.05	$ 2.03	$ 0.91	$ 16.99	$ 19.95	278.30	$ 3,910.12	$ 564.95	$ 253.25	$ 4,728.32	$ 5,552.09
	521190505	20K6 (20K5/20K9 interpolation)	LF	$ 7.19	$ 2.03	$ 0.91	$ 10.13	$ 12.43	557.00	$ 4,004.83	$ 1,130.71	$ 506.87	$ 5,642.41	$ 6,923.51
	521190540	22K5	LF	$ 7.15	$ 2.03	$ 0.91	$ 10.09	$ 12.35	404.67	$ 2,893.37	$ 821.47	$ 368.25	$ 4,083.09	$ 4,997.63
	521190545	22K6 (22K5/22K9 interpolation)	LF	$ 7.67	$ 2.03	$ 0.91	$ 10.61	$ 12.92	235.69	$ 1,807.74	$ 478.45	$ 214.48	$ 2,500.67	$ 3,045.11
	521190590	24K8 (24K6/24K10 interpolation)	LF	$ 9.28	$ 1.84	$ 0.82	$ 11.94	$ 14.28	399.66	$ 3,708.84	$ 735.37	$ 327.72	$ 4,771.94	$ 5,707.14
	521190600	24K9	LF	$ 10.65	$ 1.84	$ 0.82	$ 13.31	$ 15.80	270.55	$ 2,881.36	$ 497.81	$ 221.85	$ 3,601.02	$ 4,274.69
	521190620	26K5	LF	$ 8.60	$ 1.84	$ 0.82	$ 11.26	$ 13.55	396.84	$ 3,412.82	$ 730.19	$ 325.41	$ 4,468.42	$ 5,377.18
	521191380	26KCS5	LF	$ 14.05	$ 1.84	$ 0.82	$ 16.71	$ 19.55	264.56	$ 3,717.07	$ 486.79	$ 216.94	$ 4,420.80	$ 5,172.15
	521190625	26K7 (26K6/26K10 interpolation)	LF	$ 9.25	$ 1.84	$ 0.82	$ 11.91	$ 14.28	342.00	$ 3,163.50	$ 629.28	$ 280.44	$ 4,073.22	$ 4,883.76
	521190630	26K8 (26K6/26K10 interpolation)	LF	$ 9.90	$ 1.84	$ 0.82	$ 12.56	$ 15.00	219.45	$ 2,172.56	$ 403.79	$ 179.95	$ 2,756.29	$ 3,291.75
	521190660	28K6	LF	$ 10.30	$ 1.69	$ 0.76	$ 12.75	$ 15.10	563.66	$ 5,805.70	$ 952.59	$ 428.38	$ 7,186.67	$ 8,511.27
	521190710	30K10 (30K8;/30K12 interpolation)	LF	$ 15.53	$ 1.69	$ 0.76	$ 17.98	$ 17.53	441.00	$ 6,848.73	$ 745.29	$ 335.16	$ 7,929.18	$ 7,730.73
	521162355	32LH06	LF	$ 12.70	$ 2.25	$ 1.01	$ 15.96	$ 18.00	818.72	$ 10,397.74	$ 1,842.12	$ 826.91	$ 13,066.77	$ 14,736.96
	521162360	32LH08	LF	$ 15.60	$ 2.25	$ 1.01	$ 18.86	$ 22.00	904.00	$ 14,102.40	$ 2,034.00	$ 913.04	$ 17,049.44	$ 19,888.00
	521133290	60DLH14 (60DLH12/60DLH17 interpolat.)	LF	$ 36.80	$ 2.03	$ 0.91	$ 39.74	$ 45.00	3729.00	$ 137,227.20	$ 7,569.87	$ 3,393.39	$ 148,190.46	$ 167,805.00
BEAMS & JOISTS TOTAL										$ 1,691,243.65	$133,856.34	$ 58,104.46	$ 1,883,224.56	**$ 2,150,108.08**

Figure 79: Beams & Joists Structural Estimate

Slab-On-Deck														
Category	CSI Division	Item	Unit	Unit Costs					Quantity	Total Costs				
				Material	Labor	Equipment	Total	Total Including O&P		Material	Labor	Equipment	Total	Total Including O&P
Slab On Deck	531135400	2" x 18 GA. Composite Steel Deck	SF	$ 2.62	$ 0.49	$ 0.04	$ 3.15	$ 3.79	38,478.26	$100,813.04	$18,854.35	$ 1,539.13	$121,206.52	$ 145,832.61
	331051400	Elevated Slab, less than 6" pumped	CY	$ 91.50	$ 17.25	$ 5.50	$ 122.75	$ 134.00	415.00	$ 37,972.50	$ 7,158.75	$ 2,282.50	$ 50,941.25	$ 55,610.00
	322110200	WWF 6x6 - W2.1 x W2.1	CSF	$ 17.20	$ 26.00	-	$ 43.20	$ 60.00	384.78	$ 6,618.26	$10,004.35	-	$ 16,622.61	$ 23,086.96
TOTAL SLAB ON DECK										$145,403.80	$36,017.45	$ 3,821.63	$188,770.38	**$ 224,529.56**

Figure 80: Slab-On-Deck Structural Estimate

MISC														
Category	CSI Division	Item	Unit	Unit Costs					Quantity	Total Costs				
				Material	Labor	Equipment	Total	Total Including O&P		Material	Labor	Equipment	Total	Total Including O&P
Metal Deck - Roofing	531232650	1-1/2" deep, 20 GA	SF	$ 1.84	$ 0.40	$ 0.03	$ 2.27	$ 2.77	137760	$ 253,478.40	$ 55,104.00	$ 4,132.80	$ 312,715.20	$ 381,595.20
Shear Studs	505230300	3/4" Diameter, 4-3/16" long	EA	$ 0.63	$ 0.89	$ 0.51	$ 2.03	$ 2.82	7470	$ 4,706.10	$ 6,648.30	$ 3,809.70	$ 15,164.10	$ 21,065.40
CMU Walls	422101150	8"x16" units, Reinf., alt. courses, 12" thick	SF	$ 3.92	$ 6.60	-	$ 10.52	$ 14.35	33092.85	$ 129,723.97	$ 218,412.81	-	$ 348,136.78	$ 474,882.40
MISC. TOTAL										$ 387,908.47	$ 280,165.11	$ 7,942.50	$ 676,016.08	**$ 877,543.00**

Figure 81: Misc. Structural Elements Estimate

GRAND TOTAL														
Category	CSI Division	Item	Unit	Unit Costs					Quantity	Total Costs				
				Material	Labor	Equipment	Total	Total w/ O&P		Material	Labor	Equipment	Total	Total w/ O&P
SUBGRADE										$ 499,564.14	$325,748.65	$ 24.09	$ 825,336.88	**$ 1,056,919.50**
COLUMNS										$ 445,866.63	$ 24,478.97	$13,343.72	$ 483,689.32	**$ 545,869.84**
BEAMS & JOISTS										$ 1,691,243.65	$133,856.34	$58,104.46	$1,883,204.45	**$ 2,150,108.08**
SLAB-ON-DECK										$ 387,908.47	$280,165.11	$ 7,942.50	$ 676,016.08	**$ 877,453.00**
MISC.										$ 145,403.80	$ 36,017.45	$ 3,821.63	$ 185,242.88	**$ 224,529.56**
Sub-Total										$ 3,169,986.69	$800,266.52	$83,236.40	$4,053,489.61	**$ 4,854,879.98**
Location Factor (1.02)										$ 3,233,386.42	$816,271.85	$84,901.13	$4,134,559.40	**$ 4,951,977.58**
Grand Total														**$4,951,977.58**

Figure 82: Complete Structural Systems Estimate

PLUMBING ESTIMATE				
DESCRIPTION	QUANTITY	UNIT	TOTAL $/UNIT	COST
WATER CLOSET (vitreous china, bowl only with flush valve, wall hung)	88	EA	$ 2,760.00	$ 242,880.00
URINAL (vitreous china, wall hung)	18	EA	$ 765.00	$ 13,770.00
LAVRATORY (Wall hung, PE on CI, 18" x 15")	81	EA	$ 1,615.00	$ 130,815.00
KITCHEN SINK (w/ trim, countertop PE on CI, 24" x 21", single bowl)	10	EA	$ 1,615.00	$ 16,150.00
KITCHEN SINK (w/ trim, countertop PE on CI, 32" x 21", double bowl)	1	EA	$ 1,785.00	$ 1,785.00
LAB SINK (w/ trim, stainless steel, single bowl, single drainboard)	41	EA	$ 2,575.00	$ 105,575.00
SERVICE SINK (w/ trim, PE on CI, corner floor, 28" x 28", w/ rim guard)	5	EA	$ 3,775.00	$ 18,875.00
SHOWER (group w/ five heads, thermostatic mix valves & balancing valve)	6.6	EA	$ 5,375.00	$ 35,475.00
CUP SINK (polypropylene, oval, 10" x 4-1/2")	1	EA	$ 1,225.00	$ 1,225.00
ELECTRIC WATER COOLER (wall hung, dual height, 14.3 GPH)	19	EA	$ 2,120.00	$ 40,280.00
ELECTRIC WATER HEATER (commercial, 100F rise, 120 gal, 36 kW, 147 GPH)	1	EA	$ 12,050.00	$ 12,050.00
ELECTRIC WATER HEATER (commercial, 100F rise, 500 gal, 30 kW, 123 GPH)	2	EA	$ 40,400.00	$ 80,800.00
FIXTURE & EQUIPMENT SUBTOTAL	**$**			**699,680.00**
75% Multiplier for distribution piping, Drains, Waste, & Vents	$			524,760.00
Kitchen Equipment Addition Services & Accessories (RS Means SF Cost 2013)	$			189,605.00
Location Modifier (Pittsburgh)				1.02
TOTAL PLUMBING SYSTEM COST	**$**			**1,442,325.90**

Figure 83: Plumbing Assemblies Estimate

MECHANICAL ESTIMATE				
DESCRIPTION	QUANTITY	UNIT	TOTAL $/UNIT	COST
SPLIT SYSTEM AIR CONDITIONER (school, 3.83 ton)	27,000	SF	$ 9.66	$ 260,820.00
ROOFTOP MULTIZONE UNIT (schools, 15,000 SF, 575.5 ton)	153,000	SF	$ 21.10	$ 3,228,300.00
SUBTOTAL	**$**			**3,489,120.00**
ADDITIONAL EQUIPMENT				
UNIT HEATER (400 CFM, wall mounted, 34.1 Mbh)	5	EA	$ 950.00	$ 4,750.00
FAN COIL UNITS (15,000 BTUH cooling, 13,900 BTUH heating)	2	EA	$ 1,550.00	$ 3,100.00
Location Modifier (Pittsburgh)				1.02
TOTAL MECHANICAL SYSTEM COST	**$**			**3,566,909.40**
*Assumptions: chilled water circulation system & natural gas supply included with rooftop multizone units.				
*Electric baseboard heaters not listed in RS Means Assemblies Cost Data 2013, but assumed negligable since only 51 LF in CWNCHS.				

Figure 84: Mechanical Assemblies Estimate

ELECTRICAL ESTIMATE				
DESCRIPTION	**QUANTITY**	**UNIT**	**TOTAL $/UNIT**	**COST**
UNDERGROUND ELECTRIC SERVICE (3000A, including excavation, backfill & compaction)	1	EA	$ 90,800.00	$ 90,800.00
MAIN SWITCHBOARD (installation, breakers, panels, 277/480V, 3 phase, 3000A)	1	EA	$ 95,375.00	$ 95,375.00
RECEPTACLE (10 per 1,000 SF w/ transformer)	180	1000 SF	$ 3.48	$ 626.40
RECEPTACLE BRANCH WIRING (3/4" EMT conduit & wire, 120V grounded, 20A)	1800	EA	$ 263.00	$ 473,400.00
LIGHT SWITCHES (5 per 1000 SF)	180	1000 SF	$ 2.47	$ 444.60
LIGHT SWITCH BRANCH WIRING (3/4" EMT conduit & wire, 3 way switch, 20A)	900	EA	$ 275.00	$ 247,500.00
FLUORESCENT FIXTURES (23 fixtures per 1000 SF, avg. of strip, surface, recessed & pendant)	180,000	SF	$ 11.68	$ 2,102,400.00
LED (6" pendant downlights)	58	EA	$ 228.00	$ 13,224.00
FLUORESCENT HIGH BAY (1.5 watt/SF, 103 FC, 7 fixtures per 1000 SF)	12,765	SF	$ 5.97	$ 76,207.05
PANELBOARD (NQOD, 4 wire, 120/208V w/ conductor & conduit, 100A, avg. length)	29	EA	$ 4,900.00	$ 142,100.00
PANELBOARD (NEHB, 4 wire, 277/480V w/ conductor & conduit & safety switch, 100A, avg. length)	11	EA	$ 7,137.50	$ 78,512.50
PANELBOARD (NQOD, 4 wire, 120/208V w/ conductor & conduit, 225A, avg. length)	5	EA	$ 9,418.75	$ 47,093.75
PANELBOARD (NEHB, 4 wire, 277/480V w/ conductor & conduit & safety switch, 225A, avg. length)	9	EA	$ 12,006.25	$ 108,056.25
PANELBOARD (NQOD, 4 wire, 120/208V w/ conductor & conduit, 400A, avg. length)	8	EA	$ 10,650.00	$ 85,200.00
PANELBOARD (NEHB, 4 wire, 277/480V w/ conductor & conduit & safety switch, 400A, avg. length)	7	EA	$ 15,350.00	$ 107,450.00
PANELBOARD (NEHB, 4 wire, 277/480V w/ conductor & conduit & safety switch, 600A, avg. length)	2	EA	$ 21,700.00	$ 43,400.00
PANELBOARD (NQOD, 4 wire, 120/208V w/ conductor & conduit, 800A, avg. length)	1	EA	$ 65,000.00	$ 65,000.00
SUBTOTAL	**$**			**3,776,789.55**
Location Modifier (Pittsburgh)				1.02
TOTAL ELECTRICAL SYSTEM COST	**$**			**3,852,325.34**

Figure 85: Electrical Assemblies Estimate

FIRE PROTECTION ESTIMATE				
DESCRIPTION	**QUANTITY**	**UNIT**	**TOTAL $/UNIT**	**COST**
WET PIPE SPRINKLER SYSTEM (steel, black, sch. 40 pipe, light hazard, one floor, 50,000 SF)	177,129	SF	$ 2.10	$ 371,970.90
SUBTOTAL	**$**			**371,970.90**
Cost Reduction (~97,500 SF/floor avg.) (see calculations below)	177,129	SF	$ 0.64	$ 113,362.56
10,000 SF --> 50,000 SF = $2.64 - $2.10 = $0.54/40,000SF difference = $1.35 x 10^(-5) ((sq. ft.)^2) x (97,500 SF - 50,000 SF) = $0.64125/SF				
Cost Difference				$371,970.90 - $113,362.56
Location Modifier (Pittsburgh)				1.02
TOTAL FIRE PROTECTION SYSTEM COST	**$**			**263,780.51**

Figure 86: Fire Protection Systems Assemblies Estimate

APPENDIX D: GC ESTIMATE

GC Estimate	QTY.	UNIT	MAT. $/UNIT	MAT. TOTAL	LABOR $/UNIT	LABOR TOTAL	GRAND TOTAL
UTILITIES							$ 1,051,859.20
TEMP. HEAT (FUEL, OPERATION, 12 HR/DAY)	886 GSF*40 WK	CSF FLR/WK	$ 29.68	$ 1,051,859.20			$ 1,051,859.20
TEMPORARY STRUCTURES							$ 312,950.00
JOB OFFICE/TRAILER (50'x12')	2	EA	$ 31,600.00	$ 63,200.00			$ 63,200.00
TRAILER MOB/DEMOB	4	EA	$ 2,000.00	$ 8,000.00			$ 8,000.00
TRAILER SET-UP	2	EA	$ 10,000.00	$ 20,000.00			$ 20,000.00
TRAILER TEAR-DOWN	2	EA	$ 10,000.00	$ 20,000.00			$ 20,000.00
TEMPORARY PARKING & STAGING	1	LS	$ 50,000.00	$ 50,000.00			$ 50,000.00
TEMP. BUILDING ENCLOSURE (FRAMES + TARP)	25,000	SF	$ 2.63	$ 65,750.00			$ 65,750.00
TEMPORARY ACCESS ROADS	10,000	SY	$ 8.60	$ 86,000.00			$ 86,000.00
TEMPORARY SERVICES							$ 191,446.00
TOILETS/SANITARY SPACE	21	MO	$ 1,000.00	$ 21,000.00			$ 21,000.00
DRINKING WATER	21	MO	$ 100.00	$ 2,100.00			$ 2,100.00
CAMERAS, SITE PHOTOGRAPHY & OX BLUE	21	MO	$ 1,575.00	$ 33,075.00			$ 33,075.00
DUMPSTERS/TRASH REMOVAL	21	MO	$ 950.00	$ 19,950.00			$ 19,950.00
SNOW REMOVAL	12	MO	$ 500.00	$ 6,000.00			$ 500.00
DAILY CLEAN UP	455	DAY	$ 39.50	$ 17,972.50			$ 17,972.50
TRAILER CLEANING	455	MO	$ 39.50	$ 17,972.50			$ 17,972.50
TELE/DATA/LIGHTS	21	MO	$ 256.00	$ 5,376.00			$ 5,376.00
SECURITY	21	MO	$ 3,000.00	$ 63,000.00			$ 63,000.00
RADIOS/PHONES	21	MO	$ 500.00	$ 10,500.00			$ 10,500.00
PROJECT RELATED TRAVEL							$ 60,000.00
UTILITY VEHICLE PURCHASE & FUEL	1	LS	$ 50,000.00	$ 50,000.00			$ 50,000.00
AUTO ALLOWANCES	1	LS	$ 10,000.00	$ 10,000.00			$ 10,000.00
ADMINISTRATIVE SUPPLIES							$ 109,195.00
OFFICE SUPPLIES	21	MO	$ 75.00	$ 1,575.00			$ 1,575.00
OFFICE EQUIPMENT	21	MO	$ 220.00	$ 4,620.00			$ 4,620.00
OFFICE FURNITURE	1	LS	$ 8,000.00	$ 8,000.00			$ 8,000.00
COMPUTER SOFTWARE/EQUIPMENT	1	LS	$ 80,000.00	$ 80,000.00			$ 80,000.00
PRINTING - DRAWING & SPECS	1	LS	$ 15,000.00	$ 15,000.00			$ 15,000.00
STAFFING MONITOR & EBE							$ 1,151,900.00
SR. PROJECT MANAGER	23	WK			$ 4,000.00		$ 92,000.00
PROJECT MANAGER	91	WK			$ 3,200.00		$ 291,200.00
SUPERINTENDENT	91	WK			$ 2,950.00		$ 268,450.00
PROJECT ENGINEER	91	WK			$ 1,950.00		$ 177,450.00
PROJECT ENGINEER	91	WK			$ 1,950.00		$ 177,450.00
HOME OFFICE ADMINISTRATOR	23	WK			$ 1,100.00		$ 25,300.00
PROJECT ADMINISTRATOR	91	WK			$ 550.00		$ 50,050.00
BIM & MEP COORD	1	LS			$ 50,000.00		$ 50,000.00
PRECONSTRUCTION	1	LS			$ 20,000.00		$ 20,000.00
MISCELLANEOUS							$ 113,630.00
FIRE EXTINGUISHERS (20 LB)	10	EA	$ 163.00				$ 1,630.00
SURVEYING	180,000	SF	$ 0.50				$ 90,000.00
ELECTRICAL/DATA HOOK-UP	1	LS	$ 1,000.00				$ 1,000.00
MISC SAFETY EQUIPMENT	1	LS	$ 10,000.00				$ 10,000.00
SMALL TOOLS	1	LS	$ 2,000.00				$ 2,000.00
PROJECT CLOSEOUT DOCS	1	LS	$ 5,000.00				$ 5,000.00
FIRST AID	1	LS	$ 2,000.00				$ 2,000.00
						SUBTOTAL	$ 2,990,980.20
						LOCATION FACTOR (Butler, PA)	0.96
						TOTAL	**$ 2,871,340.99**

Figure 87: CWNCHS General Conditions Estimate

APPENDIX E: SITE PLANS

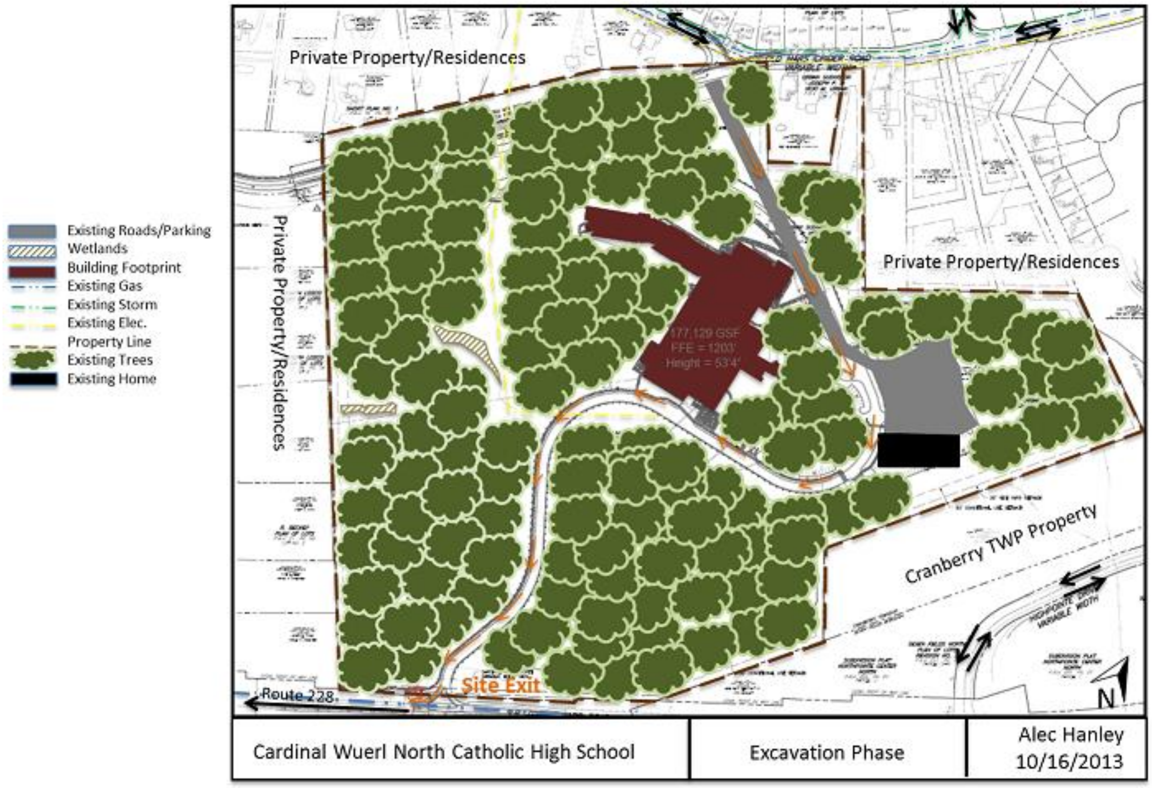


Figure 88: Excavation Phase Site Plan

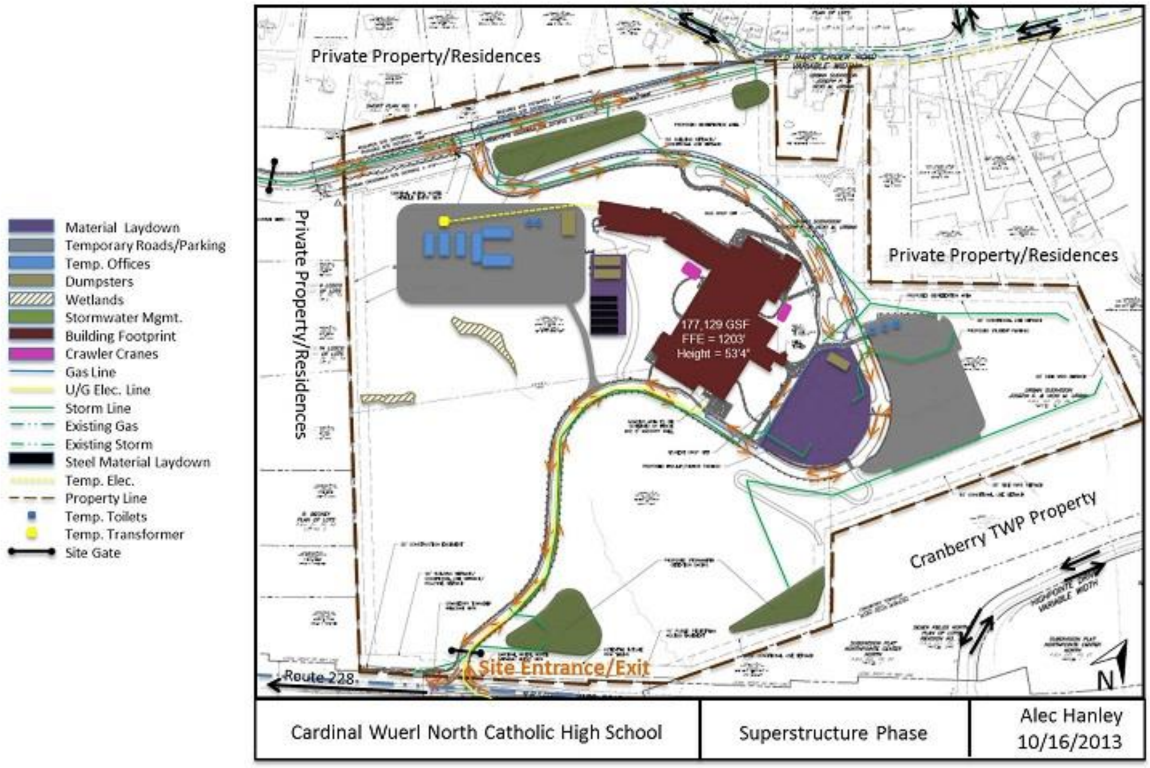


Figure 89: Superstructure Phase Site Plan

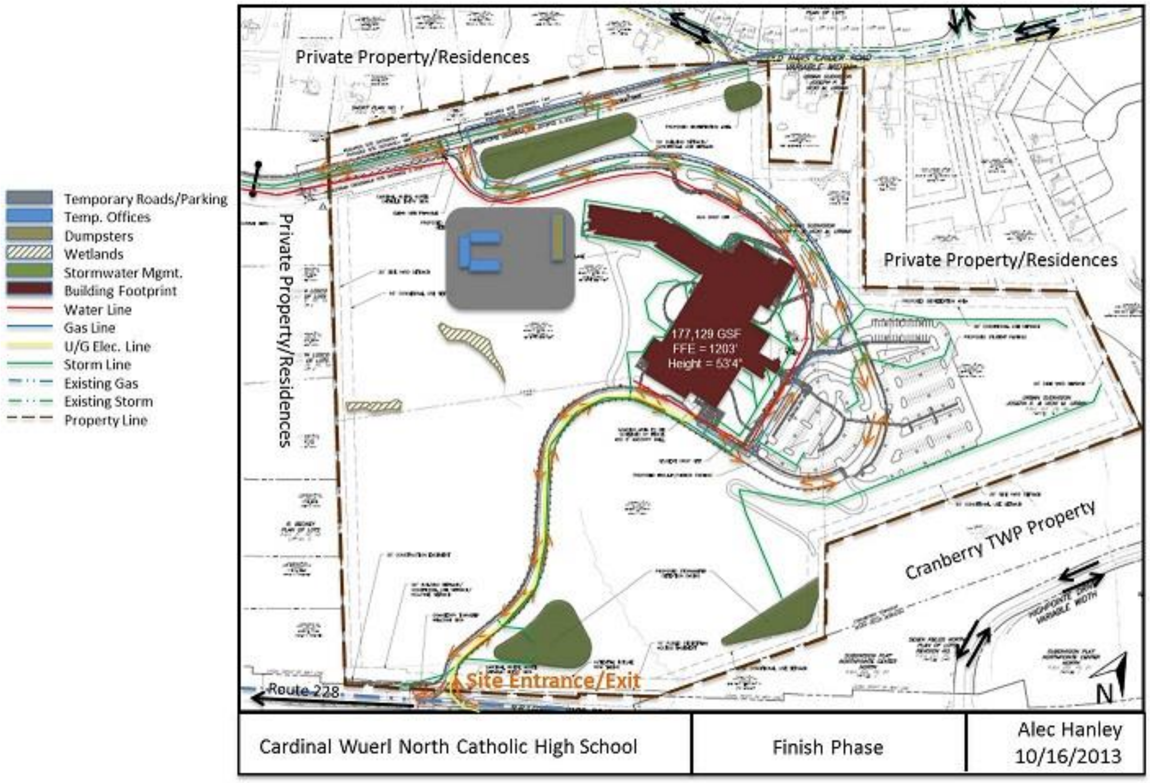


Figure 90: Finish Phase Site Plan

APPENDIX F: LEED EVALUATION TABLES

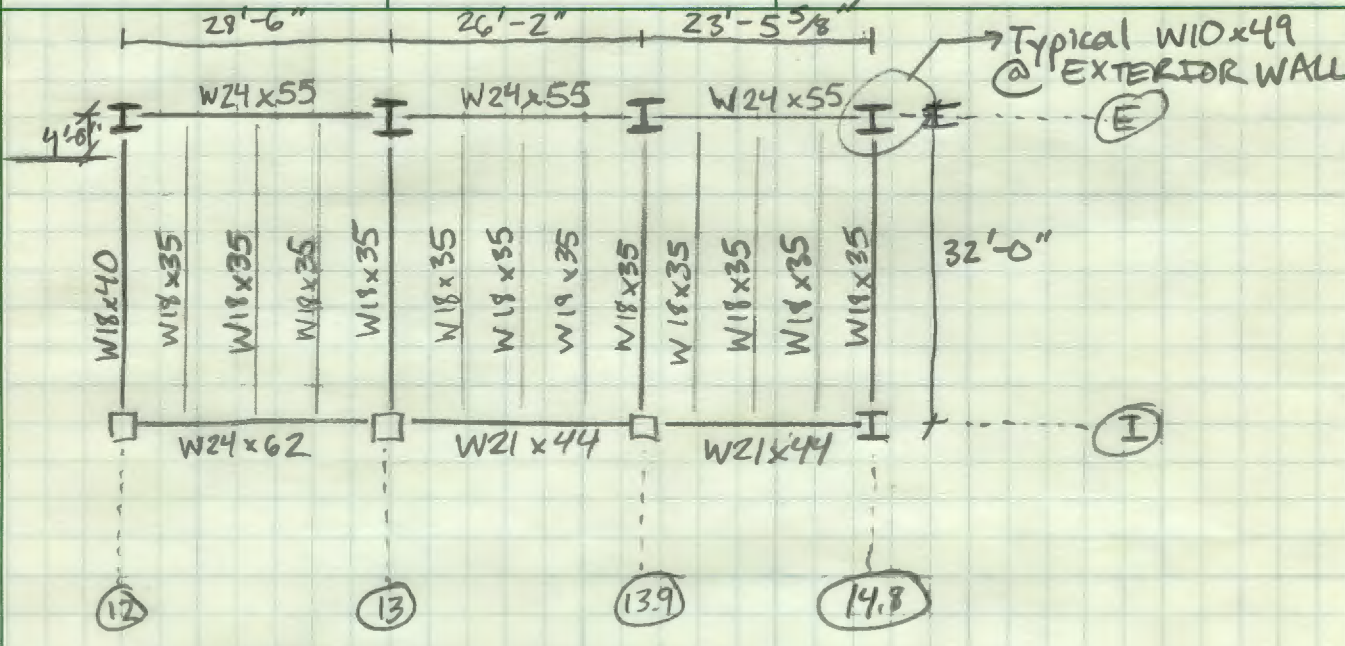
SUSTAINABLE SITES (*24 available points*)	Points	Description
Alternative Transportation/Fuel Efficient Vehicles	2	5% of parking is reserved for fuel efficient vehicles (19/375)
Alternative Transportation/Parking Capacity	2	Minimum parking requirements not exceeded.
Site Development - Maximize Open Space	1	LEED requires 20% - CWNCHS has 34.9%
Stormwater Design - Quantity Control	1	Susbstantial vegetation as well as wet detention basins.
Stormwater Design - Quality Control	1	90% of site can be infilfrated by vegetated portion of site.
Heat Island Effect - Roof	1	White TPO Roof meets requirements.
Light Pollution Reduction	1	Excessive lighting standards met. (<2% initial site lumens)
Joint Use of Facilities	1	Certain portions of the school are made available for sharing.
TOTAL	**10**	
WATER EFFICIENCY (11 available points)	**Points**	**Description**
Water Efficient Landscaping	4	Stormwater management basin water to be used for irrigation; no potable used.
Water Use Reduction	4	Rediced by 40%.
Process Water Use Reduction	1	Extensive list of water using appliances using water reduction.
TOTAL	**9**	
ENERGY & ATMOSPHERE (33 available points)	**Points**	**Desciption**
Optimize Energy Peformance	2	15.54% improvement from ASHRAE model.
Enhanced Commissioning	2	No Comment provided.
Enhanced Refrigerant Management	1	Architect MEP & food service consultant coordinated to choose approp. Equipment.
Measurement & Verification	2	Energy & Water Use Release form for USGBC provided & meters installed.
Green Power	2	Using Renewable Choice Energy for at least 2 years.
TOTAL	**7**	
MATERIALS & RESOURCES (13 available points)	**Points**	**Desciption**
Construction Waste Management	2	Utilizing 75% waste reduction plan. Mascaro reporting 0% waste to date.
Recycled Content	2	20% threshold. Should be achieved b/c of struct. Steel. Mascaro at 12.95% to date.
Regional Materials	2	20% threshold. Achievable b/c of concrete. Mascaro tracking 17.65% to date.
Certified Wood	1	FSC-certified products have been specified. Mascaro showing 60.59% thus far.
TOTAL	**7**	
INDOOR ENVIRONMENTAL QUALITY (19 available)	**Points**	**Description**
Outdoor Air Delivery Monitoring	1	Associated points in control board, CO2 monitoring, airflow monitoring in design.
Construction IAQ Management Plan (During Const.)	1	Included in Construction Documents
Construction IAQ Management Plan (Before occup.)	1	Client requested baseline IAQ test option. Ample time included in schedule.
Low-Emitting Materials - Adhesives & Sealants	1	VOC limits tracked by contractor throughout construction.
Low-Emitting Materials - Paints & Coatings	1	VOC limits tracked by contractor throughout construction.
Low-Emitting Materials - Composite Wood/Agrifiber	1	Compliant woods tracked by contractor.
Low-Emitting Materials - Ceiling & Wall Systems	1	VOC limits tracked by contractor throughout construction.
Indoor Chemical & Pollutant Source Control	1	Self-closing doors, deck-to-deck partitions, exhaust systems, MERV-13 filters.
Controllability of Systems - Lighting	1	Task lights in offices, minimum of one switch with two mode functions in classrooms
Controllability of Systems - Thermal Comfort	1	Thermostats in every office and all shared multi-occupant spaces.
Thermal Comfort - Design	1	Design meets credit requirements.
TOTAL	**11**	
INNOVATION & DESIGN PROCESS (6 available points)	**Points**	**Description**
Innovation in Design	1	Water reduced by 40%
Innovation in Design	1	Wetland mitigation integrated into Bio courses for Green Education credit.
Innovation in Design	1	Additional cost estimated by Renewable Choice Energy.
LEED Accredited Professional	1	Design Team included LEED APs.
TOTAL	**4**	
REGIONAL PRIORITY (5 available points)	**Points**	**Description**
Regional Priority: SS Credit 6.1	1	Achieved.
Regional Priority: SS Credit 6.2	1	Achieved.
Regional Priority: SS Credit 7.2	1	Achieved.
TOTAL	**3**	

Figure 92: LEED Evaluation

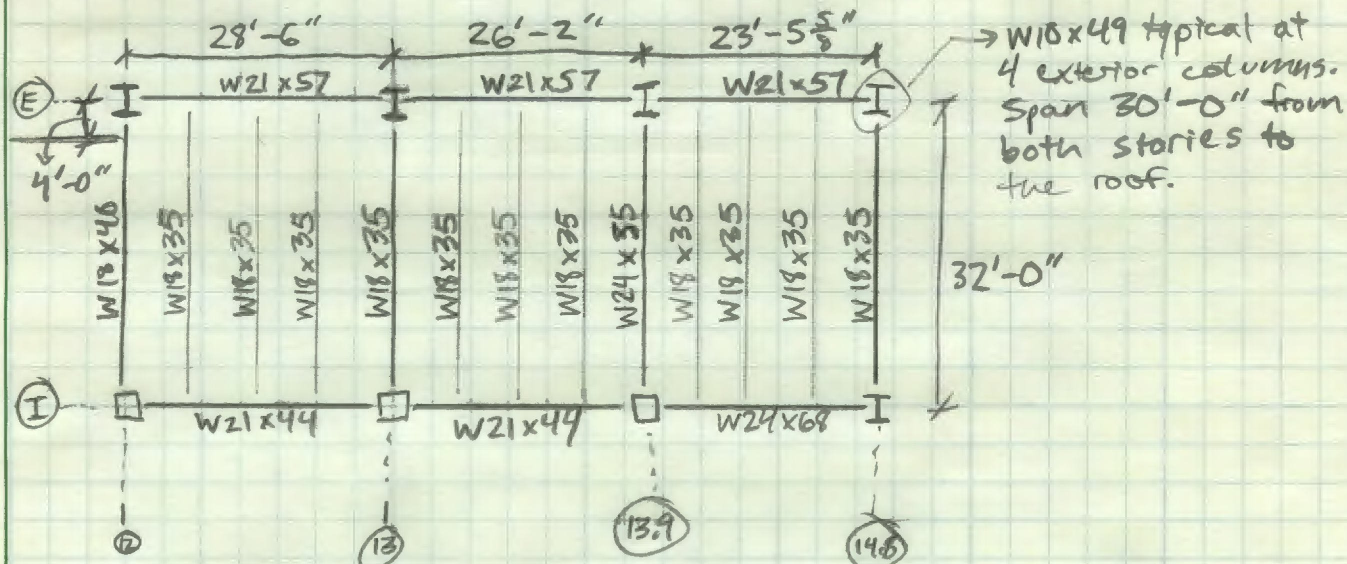
	Very Likely	Somewhat Likely	Not Likely	Not Attempting
Sustainable Sites	10	0	1	13
Water Efficiency	9	0	0	2
Energy & Atmosphere	9	0	0	24
Materials & Resources	7	0	0	6
Indoor Environmental Quality	11	0	1	7
Innovation & Design Process	4	2	0	0
Regional Priority	3	0	0	1
TOTALS	53	2	2	53

Figure 91: LEED Summary

APPENDIX G: STRUCTURAL CALCULATIONS



FIRST FLOOR PLAN



ROOF PLAN

-calculate additional weight on columns. Assume 20 PSF uniform exterior wall load over the entire surface area

COLUMN E12 → $\left(\frac{28'-6''}{2}+4'-0''\right)(31'-8'')(20\text{ PSF}) = 11{,}559\text{ lbs} = 11.56\text{ K}$

width wall height prefab panel weight

COLUMN E13 → $\left(\frac{28'-6''}{2}+\frac{26'-2''}{2}\right)(31'-8'')(20\text{ PSF}) = 17{,}312\text{ lbs} = 17.31\text{ k}$

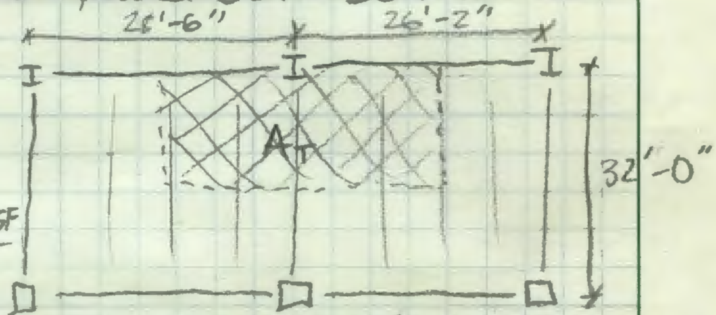
COLUMN E13.9 → $\left(\frac{26'-2''}{2}+\frac{23'-5\frac{5}{8}''}{2}\right)(31'-8'')(20\text{ PSF}) = 15{,}718\text{ lbs} = 15.72\text{ k}$

COLUMN E14.8 → $\left(\frac{23'-5\frac{5}{8}''}{2}\right)(31'-8'')(20\text{ PSF}) = 7{,}432\text{ lbs} = 7.43\text{ K}$

REVISED ON NEXT PAGE

- I will focus on $\boxed{\text{Column E13}}$ since it has the largest influence area and exterior wall load.

- Continuing to use W10 sections
- 1 floor, 1 roof using 1 column
- Total Exterior Panel Height = 31'-8" ; Panel Load = 20 PSF



LIVE LOAD REDUCTION

$$L = 80 \times \left|\begin{matrix} 0.9 \\ 0.25 + \dfrac{15}{\sqrt{1837\,ft^2}} \end{matrix}\right. = 0.6(80\,PSF) = \underline{48\,PSF}$$

(1st FLOOR)

Influence Width $= (28.5' + 26.16' + 1') = 55'-8"$

Influence Length $= (32' + 1') = 33'-0"$

$K_{LL}A_T = (55.67')(33') = 1837\,ft^2$

$L_o = 80$ PSF (school w/ corridors)

$LL_{ROOF} = 20$ PSF
$SL_{ROOF} = \underline{25\ PSF}$ } SNOW CONTROLS
(Cranberry, PA)

WALL LOAD (previous page)

$(20\,PSF)(31'-8") = (633.33\,PLF$ / ~~floor)(1 flr)~~

ASSUMING ONE FLOOR SINCE COLUMN IS CONTINUOUS FROM PIER → ROOF.

$P_u = 1.2\,(633.33\,PLF)(14.25' + 13.083' + 1' + 1')$
$= 1.2(633.33)(29.33') = 22{,}293$ lbs
$= \underline{22.3\text{ kips}}$

$A_T = (14.25' + 1' + 13.0833' + 1)(16' + 1')$
$A_T = 499\,ft^2$ (roof & first floor)

ROOF $= \left[1.2\,(\underset{(TPO\ DL)}{12\,PSF} + \underset{(SDL)}{8\,PSF} + \underset{(BEAMS\ GIRDERS\ COLUMNS)}{8\,PSF}) + 0.5\,(\underset{(SNOW\ LOAD)}{25})\right] \times (499\,ft^2) = 23{,}004$ lbs $= \underline{23\ K}$

FLOOR $= \left[1.2\,(\underset{(slab)}{57\,PSF} + \underset{(SDL)}{10\,PSF} + \underset{allowances}{8\,PSF}) + 1.6\,(48\,PSF)\right] \times (499\,ft^2) = 83{,}233.2$ lbs $= \underline{83.24\,k}$

$P_u = \underset{(FLR)}{83.24\,k} + \underset{(ROOF)}{23\,k} + \underset{(wall)}{22.3\,K} = 128.54\,K$; $KL = 30'-0"$
↳ USE W10x49 STILL

P_u (before wall) $= 106.24\,K$ @ $30'-0"$ ⟶ USE W10x49 still

W10x49 @ KL = 30' ⟹ $\phi_c P_n = 162\,K$

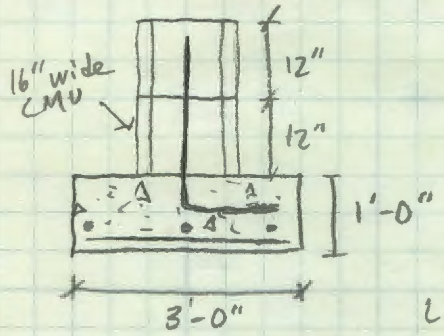
*BASED ON THIS CALCULATION, IT CAN BE ASSUMED THAT THE STRUCTURAL SYSTEM WAS DESIGNED WITH ENOUGH CONTINGENCIES THAT IT CAN HANDLE AN ADDITIONAL 20 PSF EXT. WALL LOAD

- Assumptions in structural checks for steel superstructure adjustment due to prefabricated exterior masonry panels:
  - 20 PSF UNIFORM LOAD OVER ENTIRE SURFACE AREA REGARDLESS OF WINDOWS & OTHER FINISHES
  - SINCE COLUMN EXTENDS FROM FOUNDATION TO ROOF, SPLICING DOESN'T MATTER AND FLR-FLR HEIGHT IS THE HEIGHT FROM BOTTOM OF BRICK TO TOP OF PANEL.
  - ALL LATERAL BRACING AND WIND LOADING ACCOUNTED FOR BY PANEL DESIGN ENGINEER / STRUCTURAL ENGINEER
  - WHILE LINTELS SUPPORTED SOME OF THE MASONRY LOAD, IT IS ASSUMED THAT THE MAJORITY BEARED DIRECTLY ON THE FOUNDATION.

- LOAD ASSUMPTIONS:
  - ROOF:
    - TPO = 0.4 PSF
    - RIGID INSUL = (1.5 PSF/inch)(6") = 9 PSF
    - 1.5B20 ROOF DECK = 2.14 PSF (VULCRAFT MANUAL)
    - VAPOR BARRIER NEGLIGIBLE
    - TOTAL ASSEMBLY = 12 PSF
    - ROOF LIVE LOAD = 20 PSF
    - SNOW LOAD = 25 PSF (IBC 2009 Map)
    - Framing Allowances = 8 PSF
      - ↳ Beams, Girders, Columns = ASTM A992 Grade 50
    - SDL = 8 PSF
  - FLOOR
    - School Occupancy → Use 80 PSF LL for corridor allowance
    - Exterior Wall Load = 20 PSF (Sto Panel Allowance)
      - ↳ Reduced to 48 PSF
    - Framing Same as roof allowances = 8 PSF
      - ↳ ASTM A992 Grade 50 Structural Steel
    - SDL = 10 PSF
    - SLAB = 5.5" thick w/ 2" 18GA composite steel deck; $3\frac{1}{2}$" NWT Concrete
      - ↳ = 57 PSF

- AISC Steel Manual Notes used from AE 404 to size column and perform accompanying calculations.
- IBC 2009 used for snow load, live load
- Vulcraft Manual used for Roof Deck & Composite Slab Weights
- Firestone Cutsheets used for TPO and rigid insulation weights.

FOOTING REDESIGN



$q_e = 2000\,PSF$
(CONCRETE FILL)

$f'_c = 3{,}000\,PSI$

$$q_a = \frac{P}{B} \Rightarrow 2\,KSF = \frac{P}{3'}$$

$$P = 6\,KLF$$

BRICK VENEER LOAD = 50 PSF
TOTAL UNIFORM BRICK HEIGHT = 31'-8"

LINEAR BRICK VENEER LOAD = (50 PSF)(31'-8") / (1000 lb/kip)
= 1.5833 KLF

ADJUSTED FOOTING LOAD (P) = 6 − 1.5833

$$P = 4.42\,KLF$$

Since a lot of the dead load has been reduced, assume live when using IBC load combos.

(× 1') (USES UNIT STRIP METHOD)

$$P_U = 1.6\,(4.42\,KLF) = 7.07\,KLF$$

$$q = \frac{7.07\,KLF}{3'} = 2.36\,KSF$$

$$M_U = \frac{(2.36\,KSF)(1.16)^2}{2} \leftarrow l = \frac{3 - 8"}{2} = 1.16'$$

$$M_U = 1.61\ ft\cdot kips$$

- Determine footing depth:

$$M_U \le \phi M_n \qquad \phi(5)(\sqrt{f'_c})(12h^2/6)$$

$$(1.61\ ft\cdot k)\left(\frac{1000\ lbs}{1k}\right)\left(\frac{12\,in}{1\,ft}\right) \le 0.55\,(5)\sqrt{3000}\left(\frac{12h^2}{6}\right)$$

$$19{,}273.33 = 301.25h^2$$

$$\boxed{h = 8"}$$

- Check Shear:

$$\phi V_n = \phi(4/3)\sqrt{f'_c}\,bh$$

$$q \le 0.55\left(\frac{4}{3}\right)\sqrt{3000}\,(12")(8") / 1000$$

$$2.36k \le 3.96k \quad \checkmark\checkmark \text{ OKAY}$$

-Check minimum steel

$d = 8'' - 3'' - 0.625'' = 4.375''$ $\rightarrow a = 1.96A_s$

$\phi M_n = \phi A_s F_y (d - a/2)$

$(1.61)(12) = M_u \le 0.9 A_s (60ksi)(4.375'' - 0.98A_s)$

$19.32 \le 236.25A_s - 52.92A_s^2$

$0 \le -52.92A_s^2 + 236.25A_s - 19.32$

$A_s \ge 0.0833 \text{ in}^2$

$\hookrightarrow$ #5 @ 12" O.C. continuous and 3-#5 continuous bars achieve minimum area and will not be changed.

$\frac{A_s = 0.31}{(12'')(8'')} = 0.00323 > \rho_{min} = 0.0018$

✓✓ STEEL OKAY

-Check shrinkage:

$a = 1.96(0.31) = 0.6076$

$c = \frac{a}{\beta_1} = \frac{0.6076}{0.85} = 0.715$

$\varepsilon_s = \frac{0.003}{0.715}(4.375'' - 0.715'') = 0.01557 \frac{in}{in} \ge 0.005$ ✓ OKAY

IN CONCLUSION, THE WF3 HEIGHT CAN BE REDUCED BY 4" TO A TOTAL OF 8" IF THE STEEL IS KEPT CONSTANT.

ACI Manual referenced from CE 397A notes from FALL 2013.

APPENDIX H: LIFECYCLE ESTIMATES

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - CERAMIC TILE LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Repair ($)	Replace ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$161,372.51	$ -	$ -	$ -	$ -	$ 161,372.51	1.000000	$ 161,372.51
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ -	$ -	$ -	$ -	$ -	0.620921	$ -
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ -	$ -	$3,799.00	$ -	$ 3,799.00	0.385543	$ 1,464.68
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ -	$ -	$ -	$ -	$ -	0.239392	$ -
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ -	$ -	$3,799.00	$ -	$ 3,799.00	0.148644	$ 564.70
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ -	$ -	$ -	$ -	$ -	0.092296	$ -
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ -	$ -	$3,799.00	$ -	$ 3,799.00	0.057309	$ 217.72
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ -	$ -	$ -	$ -	$ -	0.035584	$ -
36	$ -	$ -	$ -	$ -	$ -	$ -	0.032349	$ -
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ -	$ -	$3,799.00	$ -	$ 3,799.00	0.022095	$ 83.94
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ -	$ -	$ -	$ -	$ -	0.013719	$ -
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$3,799.00	$ -	$ 3,799.00	0.008519	$ 32.36
							PRESENT VALUE LIFECYCLE COST	***$ 163,735.90***

Figure 93: Ceramic Tile LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - PAINT LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Repair ($)	Replace ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 9,313.80	$ -	$ -	$ -	$ -	$ 9,313.80	1.000000	$ 9,313.80
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.683013	$ 11,983.20
5	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.620921	$ 29,184.67
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.466507	$ 8,184.69
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.385543	$ 18,121.38
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.318631	$ 5,590.25
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.239392	$ 11,251.95
16	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.217629	$ 3,818.22
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ 64,546.80	$ -	$ 892.39	$ -	$ 65,439.19	0.148644	$ 9,727.12
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.101526	$ 1,781.23
25	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.092296	$ 4,338.11
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.069343	$ 1,216.60
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.057309	$ 2,693.63
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.047362	$ 830.96
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.035584	$ 1,672.53
36	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.032349	$ 567.55
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ 64,546.80	$ -	$ 892.39	$ -	$ 65,439.19	0.022095	$ 1,445.87
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.015091	$ 264.77
45	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.013719	$ 644.83
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ 17,544.60	$ -	$ -	$ -	$ 17,544.60	0.010307	$ 180.84
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ 47,002.20	$ -	$ -	$ -	$ 47,002.20	0.008519	$ 400.39
							PRESENT VALUE LIFECYCLE COST	***$ 123,212.59***

Figure 94: Paint LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - POLISHED CONCRETE LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Repair ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 97,800.00	$ -	$ -	$ -	$ -	$ 97,800.00	1.000000	$ 97,800.00
1	$ -	$ 6,065.39	$ 400.00	$ -	$ -	$ 6,465.39	0.909091	$ 5,877.63
2	$ -	$ 6,065.39	$ 432.00	$ -	$ -	$ 6,497.39	0.826446	$ 5,369.74
3	$ -	$ 6,065.39	$ 466.56	$ -	$ -	$ 6,531.95	0.751315	$ 4,907.55
4	$ -	$ 6,065.39	$ 503.88	$ -	$ -	$ 6,569.27	0.683013	$ 4,486.90
5	$ -	$ 6,065.39	$ 544.20	$ -	$ -	$ 6,609.59	0.620921	$ 4,104.03
6	$ -	$ 6,065.39	$ 587.73	$ -	$ -	$ 6,653.12	0.564474	$ 3,755.51
7	$ -	$ 6,065.39	$ 634.75	$ -	$ -	$ 6,700.14	0.513158	$ 3,438.23
8	$ -	$ 6,065.39	$ 685.53	$ -	$ -	$ 6,750.92	0.466507	$ 3,149.35
9	$ -	$ 6,065.39	$ 740.37	$ -	$ -	$ 6,805.76	0.424098	$ 2,886.31
10	$ -	$ 6,065.39	$ 799.60	$ -	$ -	$ 6,864.99	0.385543	$ 2,646.75
11	$ -	$ 6,065.39	$ 863.57	$ -	$ -	$ 6,928.96	0.350494	$ 2,428.56
12	$ -	$ 6,065.39	$ 932.66	$ -	$ -	$ 6,998.05	0.318631	$ 2,229.79
13	$ -	$ 6,065.39	$ 1,007.27	$ -	$ -	$ 7,072.66	0.289664	$ 2,048.70
14	$ -	$ 6,065.39	$ 1,087.85	$ -	$ -	$ 7,153.24	0.263331	$ 1,883.67
15	$ -	$ 6,065.39	$ 1,174.88	$ -	$ -	$ 7,240.27	0.239392	$ 1,733.26
16	$ -	$ 6,065.39	$ 1,268.87	$ -	$ -	$ 7,334.26	0.217629	$ 1,596.15
17	$ -	$ 6,065.39	$ 1,370.38	$ -	$ -	$ 7,435.77	0.197845	$ 1,471.13
18	$ -	$ 6,065.39	$ 1,480.01	$ -	$ -	$ 7,545.40	0.179859	$ 1,357.11
19	$ -	$ 6,065.39	$ 1,598.41	$ -	$ -	$ 7,663.80	0.163508	$ 1,253.09
20	$ -	$ 6,065.39	$ 1,726.28	$ -	$ -	$ 7,791.67	0.148644	$ 1,158.18
21	$ -	$ 6,065.39	$ 1,864.38	$ -	$ -	$ 7,929.77	0.135131	$ 1,071.55
22	$ -	$ 6,065.39	$ 2,013.53	$ -	$ -	$ 8,078.92	0.122846	$ 992.46
23	$ -	$ 6,065.39	$ 2,174.62	$ -	$ -	$ 8,240.01	0.111678	$ 920.23
24	$ -	$ 6,065.39	$ 2,348.59	$ -	$ -	$ 8,413.98	0.101526	$ 854.23
25	$ -	$ 6,065.39	$ 2,536.47	$ -	$336,000.00	$ 344,601.86	0.092296	$ 31,805.37
26	$ -	$ 6,065.39	$ 2,739.39	$ -	$ -	$ 8,804.78	0.083905	$ 738.77
27	$ -	$ 6,065.39	$ 2,958.54	$ -	$ -	$ 9,023.93	0.076278	$ 688.32
28	$ -	$ 6,065.39	$ 3,195.22	$ -	$ -	$ 9,260.61	0.069343	$ 642.16
29	$ -	$ 6,065.39	$ 3,450.84	$ -	$ -	$ 9,516.23	0.063039	$ 599.90
30	$ -	$ 6,065.39	$ 3,726.91	$ -	$ -	$ 9,792.30	0.057309	$ 561.18
31	$ -	$ 6,065.39	$ 4,025.06	$ -	$ -	$ 10,090.45	0.052099	$ 525.70
32	$ -	$ 6,065.39	$ 4,347.07	$ -	$ -	$ 10,412.46	0.047362	$ 493.16
33	$ -	$ 6,065.39	$ 4,694.83	$ -	$ -	$ 10,760.22	0.043057	$ 463.30
34	$ -	$ 6,065.39	$ 5,070.42	$ -	$ -	$ 11,135.81	0.039143	$ 435.88
35	$ -	$ 6,065.39	$ 5,476.05	$ -	$ -	$ 11,541.44	0.035584	$ 410.69
36	$ -	$ 6,065.39	$ 5,914.14	$ -	$ -	$ 11,979.53	0.032349	$ 387.53
37	$ -	$ 6,065.39	$ 6,387.27	$ -	$ -	$ 12,452.66	0.029408	$ 366.21
38	$ -	$ 6,065.39	$ 6,898.25	$ -	$ -	$ 12,963.64	0.026735	$ 346.58
39	$ -	$ 6,065.39	$ 7,450.11	$ -	$ -	$ 13,515.50	0.024304	$ 328.49
40	$ -	$ 6,065.39	$ 8,046.12	$ -	$ -	$ 14,111.51	0.022095	$ 311.79
41	$ -	$ 6,065.39	$ 8,689.81	$ -	$ -	$ 14,755.20	0.020086	$ 296.38
42	$ -	$ 6,065.39	$ 9,384.99	$ -	$ -	$ 15,450.38	0.018260	$ 282.13
43	$ -	$ 6,065.39	$ 10,135.79	$ -	$ -	$ 16,201.18	0.016600	$ 268.94
44	$ -	$ 6,065.39	$ 10,946.66	$ -	$ -	$ 17,012.05	0.015091	$ 256.73
45	$ -	$ 6,065.39	$ 11,822.39	$ -	$ -	$ 17,887.78	0.013719	$ 245.41
46	$ -	$ 6,065.39	$ 12,768.18	$ -	$ -	$ 18,833.57	0.012472	$ 234.89
47	$ -	$ 6,065.39	$ 13,789.63	$ -	$ -	$ 19,855.02	0.011338	$ 225.12
48	$ -	$ 6,065.39	$ 14,892.80	$ -	$ -	$ 20,958.19	0.010307	$ 216.03
49	$ -	$ 6,065.39	$ 16,084.23	$ -	$ -	$ 22,149.62	0.009370	$ 207.55
50	$ -	$ 6,065.39	$ 17,370.97	$ -	$ -	$ 23,436.36	0.008519	$ 199.64
							PRESENT VALUE LIFECYCLE COST	$ 200,958.00

Figure 95: Polished Concrete LCC Estimate

Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Repair ($)	Replace ($)	Annual Net Cash Flow	Present Value Factor	PV
CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - LINOLEUM LIFE CYCLE COSTS								
0	$113,400.00	$ 2,320.59	$ -	$ -	$ -	$ 115,720.59	1.000000	$ 115,720.59
1	$ -	$ 2,320.59	$ 200.00	$ -	$ -	$ 2,520.59	0.909091	$ 2,291.45
2	$ -	$ 2,320.59	$ 216.00	$ -	$ -	$ 2,536.59	0.826446	$ 2,096.36
3	$ -	$ 2,320.59	$ 233.28	$ -	$ -	$ 2,553.87	0.751315	$ 1,918.76
4	$ -	$ 2,320.59	$ 251.94	$ -	$ -	$ 2,572.53	0.683013	$ 1,757.07
5	$ -	$ 2,320.59	$ 272.10	$ -	$ -	$ 2,592.69	0.620921	$ 1,609.86
6	$ -	$ 2,320.59	$ 293.87	$ -	$ -	$ 2,614.46	0.564474	$ 1,475.79
7	$ -	$ 2,320.59	$ 317.37	$ -	$ -	$ 2,637.96	0.513158	$ 1,353.69
8	$ -	$ 2,320.59	$ 342.76	$ -	$ -	$ 2,663.35	0.466507	$ 1,242.47
9	$ -	$ 2,320.59	$ 370.19	$ -	$ -	$ 2,690.78	0.424098	$ 1,141.15
10	$ -	$ 2,320.59	$ 399.80	$ -	$ -	$ 2,720.39	0.385543	$ 1,048.83
11	$ -	$ 2,320.59	$ 431.78	$ -	$ -	$ 2,752.37	0.350494	$ 964.69
12	$ -	$ 2,320.59	$ 466.33	$ -	$ -	$ 2,786.92	0.318631	$ 888.00
13	$ -	$ 2,320.59	$ 503.63	$ -	$ -	$ 2,824.22	0.289664	$ 818.08
14	$ -	$ 2,320.59	$ 543.92	$ -	$ -	$ 2,864.51	0.263331	$ 754.32
15	$ -	$ 2,320.59	$ 587.44	$ -	$ -	$ 2,908.03	0.239392	$ 696.16
16	$ -	$ 2,320.59	$ 634.43	$ -	$ -	$ 2,955.02	0.217629	$ 643.10
17	$ -	$ 2,320.59	$ 685.19	$ -	$ -	$ 3,005.78	0.197845	$ 594.68
18	$ -	$ 2,320.59	$ 740.00	$ -	$ 340,200.00	$ 343,260.59	0.179859	$ 61,738.43
19	$ -	$ 2,320.59	$ 799.20	$ -	$ -	$ 3,119.79	0.163508	$ 510.11
20	$ -	$ 2,320.59	$ 863.14	$ -	$ -	$ 3,183.73	0.148644	$ 473.24
21	$ -	$ 2,320.59	$ 932.19	$ -	$ -	$ 3,252.78	0.135131	$ 439.55
22	$ -	$ 2,320.59	$ 1,006.77	$ -	$ -	$ 3,327.36	0.122846	$ 408.75
23	$ -	$ 2,320.59	$ 1,087.31	$ -	$ -	$ 3,407.90	0.111678	$ 380.59
24	$ -	$ 2,320.59	$ 1,174.29	$ -	$ -	$ 3,494.88	0.101526	$ 354.82
25	$ -	$ 2,320.59	$ 1,268.24	$ -	$ -	$ 3,588.83	0.092296	$ 331.23
26	$ -	$ 2,320.59	$ 1,369.70	$ -	$ -	$ 3,690.29	0.083905	$ 309.64
27	$ -	$ 2,320.59	$ 1,479.27	$ -	$ -	$ 3,799.86	0.076278	$ 289.84
28	$ -	$ 2,320.59	$ 1,597.61	$ -	$ -	$ 3,918.20	0.069343	$ 271.70
29	$ -	$ 2,320.59	$ 1,725.42	$ -	$ -	$ 4,046.01	0.063039	$ 255.06
30	$ -	$ 2,320.59	$ 1,863.45	$ -	$ -	$ 4,184.04	0.057309	$ 239.78
31	$ -	$ 2,320.59	$ 2,012.53	$ -	$ -	$ 4,333.12	0.052099	$ 225.75
32	$ -	$ 2,320.59	$ 2,173.53	$ -	$ -	$ 4,494.12	0.047362	$ 212.85
33	$ -	$ 2,320.59	$ 2,347.42	$ -	$ -	$ 4,668.01	0.043057	$ 200.99
34	$ -	$ 2,320.59	$ 2,535.21	$ -	$ -	$ 4,855.80	0.039143	$ 190.07
35	$ -	$ 2,320.59	$ 2,738.03	$ -	$ -	$ 5,058.62	0.035584	$ 180.01
36	$ -	$ 2,320.59	$ 2,957.07	$ -	$ 340,200.00	$ 345,477.66	0.032349	$ 11,175.92
37	$ -	$ 2,320.59	$ 3,193.63	$ -	$ -	$ 5,514.22	0.029408	$ 162.16
38	$ -	$ 2,320.59	$ 3,449.13	$ -	$ -	$ 5,769.72	0.026735	$ 154.25
39	$ -	$ 2,320.59	$ 3,725.06	$ -	$ -	$ 6,045.65	0.024304	$ 146.94
40	$ -	$ 2,320.59	$ 4,023.06	$ -	$ -	$ 6,343.65	0.022095	$ 140.16
41	$ -	$ 2,320.59	$ 4,344.90	$ -	$ -	$ 6,665.49	0.020086	$ 133.89
42	$ -	$ 2,320.59	$ 4,692.50	$ -	$ -	$ 7,013.09	0.018260	$ 128.06
43	$ -	$ 2,320.59	$ 5,067.90	$ -	$ -	$ 7,388.49	0.016600	$ 122.65
44	$ -	$ 2,320.59	$ 5,473.33	$ -	$ -	$ 7,793.92	0.015091	$ 117.62
45	$ -	$ 2,320.59	$ 5,911.19	$ -	$ -	$ 8,231.78	0.013719	$ 112.93
46	$ -	$ 2,320.59	$ 6,384.09	$ -	$ -	$ 8,704.68	0.012472	$ 108.56
47	$ -	$ 2,320.59	$ 6,894.82	$ -	$ -	$ 9,215.41	0.011338	$ 104.49
48	$ -	$ 2,320.59	$ 7,446.40	$ -	$ -	$ 9,766.99	0.010307	$ 100.67
49	$ -	$ 2,320.59	$ 8,042.11	$ -	$ -	$ 10,362.70	0.009370	$ 97.10
50	$ -	$ 2,320.59	$ 8,685.48	$ -	$ -	$ 11,006.07	0.008519	$ 93.76
						PRESENT VALUE LIFECYCLE COST		***$ 216,926.62***

Figure 96: Linoleum LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL -VCT LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 44,515.47	$ -	$ -	$ -	$ -	$ 44,515.47	1.000000	$ 44,515.47
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.620921	$ 14,682.93
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.385543	$ 9,116.94
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.239392	$ 5,660.90
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ 148,630.98	$ -	$ 148,630.98	0.179859	$ 26,732.59
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.148644	$ 3,514.98
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.092296	$ 2,182.52
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.057309	$ 1,355.18
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.035584	$ 841.46
36	$ -	$ -	$ -	$ 148,630.98	$ -	$ 148,630.98	0.032349	$ 4,808.09
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.022095	$ 522.48
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ -	$ -	$ -	$23,647.00	$ 23,647.00	0.013719	$ 324.42
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$ -	$ -	$ -	0.008519	$ -
							PRESENT VALUE LIFECYCLE COST	***$ 114,257.95***

Figure 97: VCT LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - CARPET LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 77,514.50	$ -	$ -	$ -	$ -	$ 77,514.50	1	$ 77,514.50
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.620921	$ 1,790.86
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.385543	$ 1,111.98
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.239392	$ 690.45
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.148644	$ 428.72
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ 2,884.20	$ -	$ 133,539.75	$ -	$ 136,423.95	0.092296	$ 12,591.38
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.057309	$ 165.29
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.035584	$ 102.63
36	$ -	$ -	$ -	$ -	$ -	$ -	0.032349	$ -
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.022095	$ 63.73
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ 2,884.20	$ -	$ -	$ -	$ 2,884.20	0.013719	$ 39.57
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$ -	$ -	$ -	0.008519	$ -
							PRESENT VALUE LIFECYCLE COST	***$ 94,499.12***

Figure 98: Carpet LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - ARMSTRONG SCHOOL ZONE FINE FISSURED LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 121,864.87	$ -	$ -	$ -	$ -	$ 121,864.87	1.000000	$ 121,864.87
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ -	$ -	$ -	$ -	$ -	0.620921	$ -
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ -	$ -	$ 2,437.30	$ -	$ 2,437.30	0.385543	$ 939.68
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ -	$ -	$ -	$ -	$ -	0.239392	$ -
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ -	$ -	$ 2,437.30	$ -	$ 2,437.30	0.148644	$ 362.29
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ -	$ -	$ -	$ -	$ -	0.092296	$ -
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ -	$ -	$ 121,864.91	$ -	$ 121,864.91	0.057309	$ 6,983.90
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ -	$ -	$ -	$ -	$ -	0.035584	$ -
36	$ -	$ -	$ -	$ -	$ -	$ -	0.032349	$ -
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ -	$ -	$ 2,437.30	$ -	$ 2,437.30	0.022095	$ 53.85
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ -	$ -	$ -	$ -	$ -	0.013719	$ -
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$ -	$ -	$ -	0.008519	$ -
							PRESENT VALUE LIFECYCLE COST	***$ 130,204.60***

Figure 99: Armstrong School Zone Fine Fissured Ceiling Tile LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - ULTIMA CEILING TILE LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$175,864.93	$ -	$ -	$ -	$ -	$ 175,864.93	1.000000	$ 175,864.93
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ -	$ -	$ -	$ -	$ -	0.620921	$ -
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ -	$ -	$ 3,517.30	$ -	$ 3,517.30	0.385543	$ 1,356.07
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ -	$ -	$ -	$ -	$ -	0.239392	$ -
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ -	$ -	$ 3,517.30	$ -	$ 3,517.30	0.148644	$ 522.82
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ -	$ -	$ -	$ -	$ -	0.092296	$ -
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ -	$ -	$ 175,864.93	$ -	$ 175,864.93	0.057309	$ 10,078.56
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ -	$ -	$ -	$ -	$ -	0.035584	$ -
36	$ -	$ -	$ -	$ -	$ -	$ -	0.032349	$ -
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ -	$ -	$ 3,517.30	$ -	$ 3,517.30	0.022095	$ 77.71
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ -	$ -	$ -	$ -	$ -	0.013719	$ -
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$ -	$ -	$ -	0.008519	$ -
							PRESENT VALUE LIFECYCLE COST	$ 187,900.10

Figure 100: Armstrong Ultima Ceiling Tile LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - CURVED DRYWALL CEILING (PAINT) LIFE CYCLE COSTS								
Year	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$ 57,837.50	$ -	$ -	$ -	$ -	$ 57,837.50	1.000000	$ 57,837.50
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ -	$ -	$ -	$ -	$ -	0.826446	$ -
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ -	$ -	$ -	$ -	$ -	0.683013	$ -
5	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.620921	$ 13,372.86
6	$ -	$ -	$ -	$ -	$ -	$ -	0.564474	$ -
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ -	$ -	$ -	$ -	$ -	0.466507	$ -
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.385543	$ 8,303.49
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ -	$ -	$ -	$ -	$ -	0.318631	$ -
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ -	$ -	$ -	$ -	$ -	0.263331	$ -
15	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.239392	$ 5,155.82
16	$ -	$ -	$ -	$ -	$ -	$ -	0.217629	$ -
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ -	$ -	$ -	$ -	$ -	0.179859	$ -
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ 760.33	$ -	$ -	$21,537.12	$ 22,297.45	0.148644	$ 3,314.37
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ -	$ -	$ -	$ -	$ -	0.122846	$ -
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ -	$ -	$ -	$ -	$ -	0.101526	$ -
25	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.092296	$ 1,987.79
26	$ -	$ -	$ -	$ -	$ -	$ -	0.083905	$ -
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ -	$ -	$ -	$ -	$ -	0.069343	$ -
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.057309	$ 1,234.26
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ -	$ -	$ -	$ -	$ -	0.047362	$ -
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ -	$ -	$ -	$ -	$ -	0.039143	$ -
35	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.035584	$ 766.38
36	$ -	$ -	$ -	$ -	$ -	$ -	0.032349	$ -
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ -	$ -	$ -	$ -	$ -	0.026735	$ -
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ 760.33	$ -	$ -	$21,537.12	$ 22,297.45	0.022095	$ 492.66
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ -	$ -	$ -	$ -	$ -	0.018260	$ -
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ -	$ -	$ -	$ -	$ -	0.015091	$ -
45	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.013719	$ 295.47
46	$ -	$ -	$ -	$ -	$ -	$ -	0.012472	$ -
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ -	$ -	$ -	$ -	$ -	0.010307	$ -
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ -	$ -	$ -	$21,537.12	$ 21,537.12	0.008519	$ 183.47
						PRESENT VALUE LIFECYCLE COST		***$ 92,944.07***

Figure 101: Curved Drywall Ceiling LCC Estimate

CARDINAL WUERL NORTH CATHOLIC HIGH SCHOOL - LINEAR WOOD CEILING LIFE CYCLE COSTS								
	Capital Costs	Maintenance ($/yr)	Energy ($/year)	Replacement ($)	Refinish ($)	Annual Net Cash Flow	Present Value Factor	PV
0	$129,837.50	$ -	$ -	$ -	$ -	$ 129,837.50	1.000000	$ 129,837.50
1	$ -	$ -	$ -	$ -	$ -	$ -	0.909091	$ -
2	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.826446	$ 410.74
3	$ -	$ -	$ -	$ -	$ -	$ -	0.751315	$ -
4	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.683013	$ 339.46
5	$ -	$ -	$ -	$ -	$ -	$ -	0.620921	$ -
6	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.564474	$ 280.54
7	$ -	$ -	$ -	$ -	$ -	$ -	0.513158	$ -
8	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.466507	$ 231.85
9	$ -	$ -	$ -	$ -	$ -	$ -	0.424098	$ -
10	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.385543	$ 191.62
11	$ -	$ -	$ -	$ -	$ -	$ -	0.350494	$ -
12	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.318631	$ 158.36
13	$ -	$ -	$ -	$ -	$ -	$ -	0.289664	$ -
14	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.263331	$ 130.88
15	$ -	$ -	$ -	$ -	$ -	$ -	0.239392	$ -
16	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.217629	$ 108.16
17	$ -	$ -	$ -	$ -	$ -	$ -	0.197845	$ -
18	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.179859	$ 89.39
19	$ -	$ -	$ -	$ -	$ -	$ -	0.163508	$ -
20	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.148644	$ 73.88
21	$ -	$ -	$ -	$ -	$ -	$ -	0.135131	$ -
22	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.122846	$ 61.05
23	$ -	$ -	$ -	$ -	$ -	$ -	0.111678	$ -
24	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.101526	$ 50.46
25	$ -	$ -	$ -	$ 2,596.75	$ -	$ 2,596.75	0.092296	$ 239.67
26	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.083905	$ 41.70
27	$ -	$ -	$ -	$ -	$ -	$ -	0.076278	$ -
28	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.069343	$ 34.46
29	$ -	$ -	$ -	$ -	$ -	$ -	0.063039	$ -
30	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.057309	$ 28.48
31	$ -	$ -	$ -	$ -	$ -	$ -	0.052099	$ -
32	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.047362	$ 23.54
33	$ -	$ -	$ -	$ -	$ -	$ -	0.043057	$ -
34	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.039143	$ 19.45
35	$ -	$ -	$ -	$ -	$ -	$ -	0.035584	$ -
36	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.032349	$ 16.08
37	$ -	$ -	$ -	$ -	$ -	$ -	0.029408	$ -
38	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.026735	$ 13.29
39	$ -	$ -	$ -	$ -	$ -	$ -	0.024304	$ -
40	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.022095	$ 10.98
41	$ -	$ -	$ -	$ -	$ -	$ -	0.020086	$ -
42	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.018260	$ 9.08
43	$ -	$ -	$ -	$ -	$ -	$ -	0.016600	$ -
44	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.015091	$ 7.50
45	$ -	$ -	$ -	$ -	$ -	$ -	0.013719	$ -
46	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.012472	$ 6.20
47	$ -	$ -	$ -	$ -	$ -	$ -	0.011338	$ -
48	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.010307	$ 5.12
49	$ -	$ -	$ -	$ -	$ -	$ -	0.009370	$ -
50	$ -	$ 497.00	$ -	$ -	$ -	$ 497.00	0.008519	$ 4.23
							PRESENT VALUE LIFECYCLE COST	$ 132,423.68

Figure 102: Linear Wood Ceiling LCC Estimate

APPENDIX I: ARMSTRONG LINEAR WOOD CATALOG

CEILING&WALL | SYSTEMS

Between us, ideas become reality™

WOODWORKS® Linear

Veneered Planks and Panels
Solid Wood Panels

- Three different ways to achieve a linear look
- Choose traditional planks, or fast, easy-to-install panels
- NEW Unique, new tapered visual available on veneered panels
- FSC Certified: products represent responsible production and consumption practices from the forest to the consumer
- Shorter lead times and lower cost than custom millwork
- Custom veneers and stain matching available

Armstrong®

WOODWORKS® Linear – Planks

Natural Variations™, Constants™, & Bamboo

WoodWorks Linear 8' x 3-3/4" in Custom Constants Light Cherry;
Fox Lake District Library, Fox Lake, IL

Additional Attributes of WoodWorks Linear Planks

- Standard wood plank in 2 widths; nominal 4-1/2" and 6" modules, with traditional 3/4" reveals
- Standard factory-applied acoustical fleece
- Install in the ceiling, on the wall, or create 90º angled or curved ceiling-to-wall transitions (one-foot minimum radius)
- Create upturns for continuous visuals and clouds with veneer-wrapped WoodWorks Trim
- Suspension system and planks from one manufacturer; improved for 30-50% faster installation
- California Air Resources Board (CARB) compliant
- 100% Biobased content certified by USDA BioPreferred® Products program (preferred for government projects)
- Class A Fire Resistance
- Custom veneers and stain matching available; for details, contact Architectural Specialties at 1 877 ARMSTRONG, select options 1-1-4

WoodWorks Linear 3-3/4" Ceiling System in Natural Variations Maple; Custom Installation at NaviNet, Inc., Boston, MA

Veneer Selection

Due to printing limitations, shade may vary from actual product.

Natural Variations
(Real Wood Veneers)

Beech (NBE) · Maple (NMP) · Light Cherry (NLC) · Dark Cherry (NDC)

Constants
(Real Wood Veneers)

Maple (CMA) · Cherry (CCY) · Walnut (CWA)

Bamboo
(Rapidly Renewable)

Patina (BAP) · Native** (BAN)

** A premium veneer option managed through Architectural Specialties due to the potential for significant color variation panel to panel. Mininum order quantity and extended lead time may apply.

You can also create beautiful curved looks with a faceted suspension system. Due to its non-standard suspension system, these S-Service items are ordered through Architectural Specialties at 1 877 ARMSTRONG, select options 1-1-4.

Cover Photo: WoodWorks Linear Ceiling System in Natural Variations Light Cherry;
Fine Fissured™ Square Lay-in on Prelude® XL® suspension system; Side Street Inn, Honolulu, HI

WOODWORKS® Linear – Planks

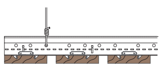
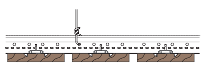
Natural Variations™, Constants™, & Bamboo

Colors

NV Beech (NBE)	NV Dark Cherry (NDC)	Constants Walnut (CWA)
NV Maple (NMP)	Constants Maple (CMA)	Bamboo Patina (BAP)
NV Light Cherry (NLC)	Constants Cherry (CCY)	Bamboo Native (BAN)

Linear Planks Visual Selection

Performance Selection Dots represent highest level of performance

Edge Profile	Item Number ◆	Dimensions	Acoustics NRC	Fire Rating
WOODWORKS Linear – Nominal 4-1/2" Module				
	6440W1_ _ _	8' x 3-3/4" x 3/4" with 3/4" reveal	0.50 0.65** ●	Class A
	6640W1_ _ _ (FSC®-certified)	8' x 3-3/4" x 3/4" with 3/4" reveal	0.50 0.65** ●	Class A
WOODWORKS Linear – Nominal 6" Module				
	6460W1 _ _ _	8' x 5-1/4" x 3/4" with 3/4" reveal	0.40 0.50**	Class A
	6660W1 _ _ _ (FSC-certified)	8' x 5-1/4" x 3/4" with 3/4" reveal	0.40 0.50**	Class A

◆ When specifying or ordering, please include the appropriate three-letter color suffix (e.g., 6460W1 N M P)

** Adding acoustical infill (item 8200100, 5479, or 5823) for 4-1/2" module increases the NRC to 0.65. Adding acoustical fiberglass infill for 6" module increases the NRC to 0.50.

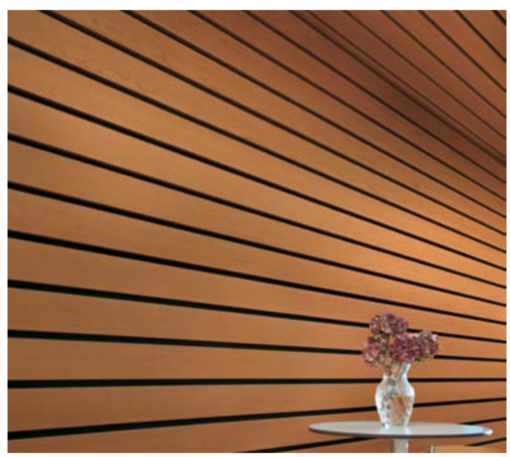
Suspension System

Item Number	Description	Dimensions	Pieces/Carton
5370	12' HD Linear Carriers (concealed) with integral clips (factory-applied) for nominal 4-1/2" modules	12' x 15/16" x 1-11/16"	10 (Approx. 240 SF/ctn installed with planks)
5371	12' HD Linear Carriers (concealed) with integral clips (factory-applied) for nominal 6" modules	12' x 15/16" x 1-11/16"	10 (Approx. 240 SF/ctn installed with planks)

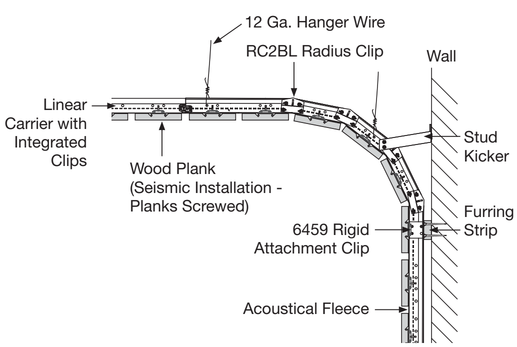
Note: For radiused applications, use standard panels and HD Linear Carriers faceted 12" on center with RC2BL clips.

Ceiling-to-Wall Transitions

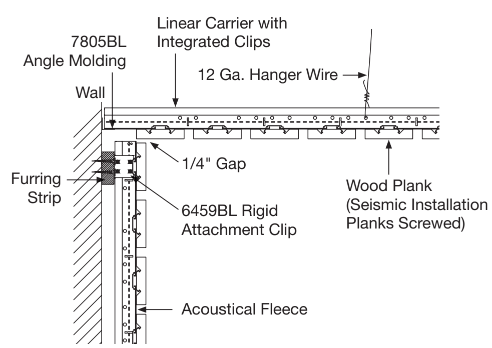
WoodWorks Linear 8' x 3-3/4" in Natural Variations Light Cherry; Ceiling-to-Wall Faceted Transition



WoodWorks Linear 8' x 3-3/4" in Natural Variations Light Cherry; Ceiling-to-Wall 90° Angle Transition



Faceted Ceiling-to-Wall System Assembly



90° Ceiling-to-Wall System Assembly

WOODWORKS® Linear – Planks

Natural Variations™, Constants™, & Bamboo

Recycled Content: 92%

armstrong.com/greengenie

LEED® Credits							LEED for Schools	
Energy	Waste Mgmt	Recycled Content	Local Materials	Renewable Materials	Certified Wood*	Low Emitting*	Acoustics	Low Emitting or CHPS
		✔	✔	✔	✔	✔		✔

Location Dependent *Options Available

Colors

NV Beech (NBE)	NV Dark Cherry (NDC)	Constants Walnut (CWA)
NV Maple (NMP)	Constants Maple (CMA)	Bamboo Patina (BAP)
NV Light Cherry (NLC)	Constants Cherry (CCY)	Bamboo Native (BAN)

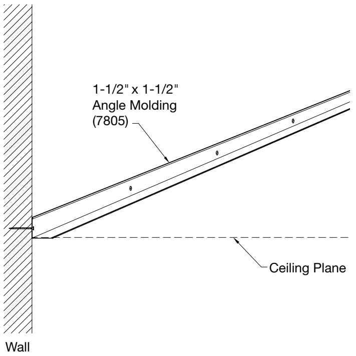
Accessories

Item Number	Description	Dimensions	Pieces/Carton
5843	Linear Wood Panel Splice	—	100
5659W1 _ _ _ ◆	4" WoodWorks Trim (with aluminum substrate)	4" x 10'	6
5660W1 _ _ _ ◆	6" WoodWorks Trim (with aluminum substrate)	6" x 10'	6
5948	Linear and Channeled Trim Connector Clip	N/A	30
RC2BL	Radius Clip for faceted suspension system applications (Black)	—	205 pcs/bucket
7805BL**	10' Angle Molding (Tech Black)	10' x 1-1/2" x 1-1/2"	30
7823BL**	10' Shadow Molding (Tech Black)	10' x 2" x 1-1/4" x 3/4"	10
FXSPLICE	Splice Plate with Setscrews for Trim	N/A	10
6408_ _ _ ◆	3/4" Edge Banding (factory-applied available upon request)	3/4" x 25'	25 foot roll
6459BL	Rigid Attachment Clip (Black)	5-1/2" x 1-3/4"	25
92715A620	Self-tapping Screws (Black)	#2 x 3/4" Length	25
7891	12 Gauge Hanger Wire	12' Length	140
8200100	Flberglass Infill Bag (Black - Gloss)	2' x 2' x 1'	12
5479	BioAcoustic™ Infill Panel (Beige - Matte)	2' x 2' x 5/8"	12
5823	BioAcoustic Infill Panel (Black - Matte)	2' x 2' x 5/8"	12

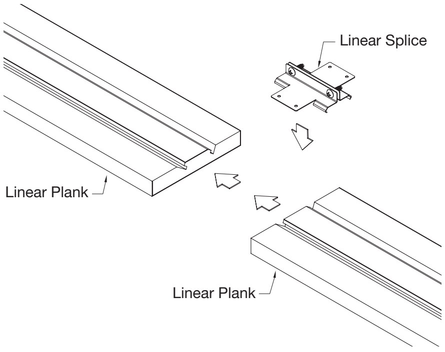
◆ When specifying or ordering, include the appropriate three-letter color suffix that coordinates with your WoodWorks ceiling (e.g., 5659W1 B A P)

** This color is a special order item with these moldings.

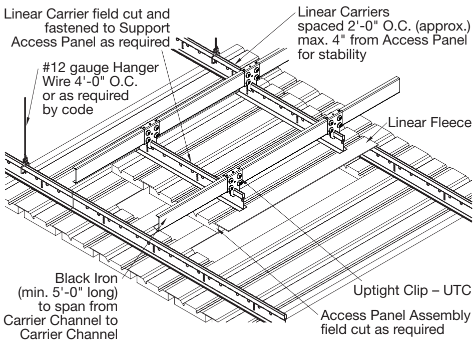
Linear Planks Accessory Details



Angle Molding (Item 7805BL) Detail



Linear Splice (Item FXSPLICE) Detail



Access Panel Assembly

Linear Planks Physical Data

Material
Fire retardant particle board with face-cut veneers. FSC®-certified fire retardant particle board with face-cut veneers (SW-COC-3601). For more information about FSC-certified products or to view our FSC certification letter, visit armstrong.com/woodworksfsc

Factory-applied black fleece on each plank to cover the reveal.

Surface Finish
Clear or tinted semigloss coating

Fire Performance
ASTM E84 surface burning characteristics, HPVA Certified with audit program per ASTM E84. Flame Spread Index 25 or less. Smoke Developed Index 50 or less.

CAN/ULC S102 surface burning characteristics. Flame Spread Rating 25 or less. Smoke Developed Classification 50 or less.

Linear wood, as with other architectural features located at the ceiling, may obstruct or skew the planned fire sprinkler water distribution pattern, or possibly delay or accelerate the activation of the sprinkler or fire detection systems by channeling heat from a fire either toward or away from the device. Designers and installers are advised to consult a fire protection engineer, NFPA 13, and local codes for guidance where automatic fire detection and suppression systems are present.

ASTM E1264 Classification
Composite – Fire Class A

Seismic Restraint
Linear wood has been engineered, tested, and approved in all seismic areas.

Application Considerations
Variation among panels may occur due to the natural characteristics of the wood and grain.

It is very important that WoodWorks planks are climatized prior to installation. Relative humidity between 25% and 55% and temperatures between 50˚F and 86˚F must be maintained.

Installation Considerations
Installation can use staggered, random joints for a monolithic appearance or consistent lengths for a modular style. For expansion, a 3/4" gap is recommended at every 24 foot run of plank. See installation instructions LA-297443 at armstrong.com/installation.

Specification Consideration
Attention: For FSC-certified wood products to maintain their CoC certification, products must be sold to a CoC-certified distributor or directly to the installing contractor. Failure to do so breaks the CoC.

Warranty
One (1) year limited warranty.
Details: armstrong.com/warranty

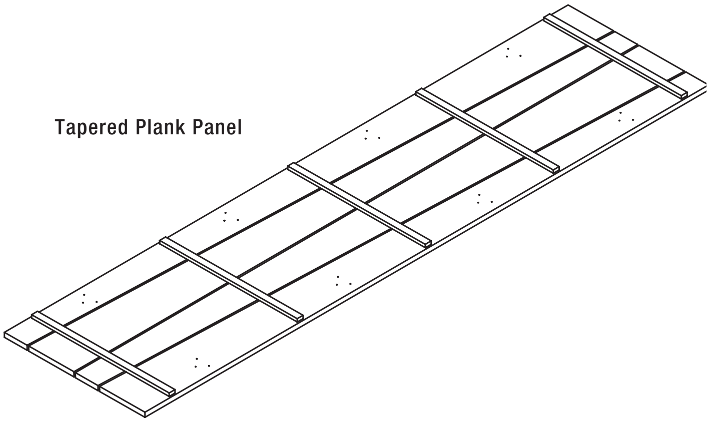
Weight/Square Feet
6440, 6640 – 2.88 lbs/SF
6460, 6660 – 2.89 lbs/SF
(Bulk packaged)

WoodWorks Linear Veneer panels in tapered visual and Natural Variations Light Cherry finish.

Additional Attributes of WoodWorks Linear Veneered Panels

- Unique tapered planks or traditional wood planks in nominal 4" or 6" width
- Create continuous looks and clouds with veneer-wrapped and painted aluminum trim
- Hook-on panels (for standard 15/16" suspension) provide safe and secure downward accessibility
- Complete standard system from one manufacturer (grid/panels/trim)
- Factory edge banded for superior quality
- California Air Resources Board (CARB) compliant
- 100% Biobased content certified by USDA BioPreferred® Product program
- BioAcoustic™ infill available for increased acoustical performance
- Acoustical fleece available as an option
- Class A Fire Resistance

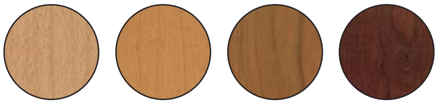
Tapered Plank Panel



Veneer Selection

Due to printing limitations, shade may vary from actual product.

Natural Variations
(Real Wood Veneers)



Beech (NBE) | Maple (NMP) | Light Cherry (NLC) | Dark Cherry (NDC)

Constants
(Real Wood Veneers)

Maple (CMA) | Cherry (CCY) | Walnut (CWA)

Bamboo
(Rapidly Renewable)

Patina (BAP) | Native* (BAN)

* A premium veneer option managed through Architectural Specialties due to the potential for significant color variation panel to panel. Mininum order quantity and extended lead time may apply.

In addition to these standard options, there may be other sizes and veneers available. Contact the Armstrong Architectural Specialties project management team for details at 1 877 ARMSTRONG and select options 1-1-4.

WOODWORKS® Linear – Panels NEW

Natural Variations™, Constants™, & Bamboo

Recycled Content: 92%

armstrong.com/greengenie

LEED® Credits							LEED for Schools	
Energy	Waste Mgmt	Recycled Content	Local Materials	Renewable Materials	Certified Wood*	Low Emitting*	Acoustics	Low Emitting or CHPS
		✔	✔	✔	✔	✔	✔	✔

Location Dependent * Options Available

Colors

NV Beech (NBE)	NV Dark Cherry (NDC)	Constants Maple (CMA)
NV Maple (NMP)	Bamboo Patina (BAP)	Constants Cherry (CCY)
NV Light Cherry (NLC)	Bamboo Native (BAN)	Constants Walnut (CWA)

Visual Selection

Acoustical Performance

Dots represent highest level of acoustical performance

Edge Profile	Item Number◆	Description	Dimensions Nominal W x L x H	NRC**
FSC®-certified WOODWORKS Linear Veneered Panels				
3/4" Reveal	6690W1 _ _ _	Nominal 4" wide planks	2' x 8' x 3/4"	0.45
1/4" Reveal	6691W1 _ _ _	Nominal 6" wide planks	2' x 8' x 3/4"	0.20
	6692W1 _ _ _	Tapered planks	2' x 8' x 3/4"	0.20

EXAMPLE:

6690W1 NLC

Panel Dimension/Type: 2' x 8' Nominal 4" wide planks

Finish: Natural Variations Light Cherry

◆ When specifying or ordering, include the appropriate three-letter color suffixes.

For veneers, sizes, and perforation patterns available as special order, call 1 877 ARMSTRONG and select options 1-1-4.
To view more perforation information and build swatches in real time, visit armstrong.com/swatchit.

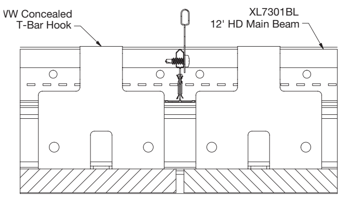
** NRC achieved with BioAcoustical™ infill (item 6657).

Suspension System

15/16" Standard: Prelude® BL (Tech Black)

Item Number	Description	Dimensions	Pieces/Carton
5986	T-Bar Hook†	Nominal 4" x 2" x 3"	50
91070A244	Wood Screws	5/8"	100
6091	Safety Cable	24" x 3/32"	50
SH12	Support Hanger	12' x 2"	12

† For 2' x 8' panel, install 8 hooks. Note: Three screws per hook.
Note: Refer to installation instructions at armstrong.com/installation for a better understanding of suspension requirements.



Installation Detail

Accessories

Item Number	Description	Dimensions Nominal	Color	Pieces/Carton
6603W1_ _ _	WoodWorks Concealed Trim◆◆	6" x 10'	Standard Veneers (see above) and Black (BL)	6
FXTBC	T-Bar Connector Clip	N/A	N/A	10
FX4SPLICE	Splice Plate with Setscrews	N/A	N/A	10
5823	BioAcoustic™ Infill Panel	2' x 2' x 5/8"	Black	12
6408_ _ _◆	Edge Banding	25' x 3/4"	Standard Veneers (see above)	1

◆ When specifying or ordering, include the two- or three-letter color suffix that coordinates with your WoodWorks ceiling (6408 N M P)
◆◆ Trim cartons include FXTBC Clips and FX4SPLICE Plates.

Linear Veneered Panels Physical Data

Material
FSC-certified fire retardant particle board with face-cut veneers (SW-COC-003601). For more information about FSC-certified products or to view our FSC certification letter, visit armstrong.com/woodworksfsc

6603 - Face-cut veneer or black paint on aluminum laminate substrate

Surface Finish
Clear or tinted semigloss coating

Fire Performance
ASTM E84 surface burning characteristics, HPVA Certified with audit program per ASTM E84. Flame Spread Index 25 or less. Smoke Developed Index 50 or less.

CAN/ULC S102 surface burning characteristics. Flame Spread Rating 25 or less. Smoke Developed Classification 50 or less.

ASTM E1264 Classification
Composite – Fire Class A

Design Considerations
Cloud installations with total panel width less than 6' wide are not recommended.

Cloud installations with total panel length less than 16' wide cannot be done.

Application Considerations
Variation among panels may occur due to the natural characteristics of the wood and grain.

Use of large wood panels may result in deflection up to 1/8" and alignment inconsistency due to size and ambient conditions.

It is very important that WoodWorks panels are climatized prior to installation. Relative humidity between 25% and 55%, and temperatures between 50˚F and 86˚F must be maintained throughout the life of the product.

Specification Consideration
Attention: For FSC-certified wood products to maintain their CoC certification, products must be sold to a CoC-certified distributor or directly to the installing contractor. Failure to do so breaks the CoC.

Seismic Installation
These systems have been engineered, tested, and meet the requirements for applications in Seismic Design Categories D, E, and F.

Warranty
One (1) year limited warranty. Details: armstrong.com/warranty

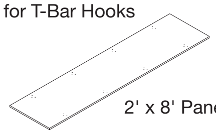
Weight/Square Feet
6690, 6691, 6692 – 2.75 lbs/SF; bulk packed per order.
Suspension, hardware, and accessories ordered separately.

WOODWORKS® Linear – Panels NEW

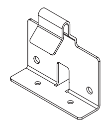
Natural Variations™, Constants™, & Bamboo

How to Install WoodWorks Linear Veneered Panels

Step 1: Select Panel

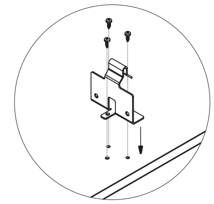


Step 2: Order T-Bar Hooks and Screws Based on Panel Size

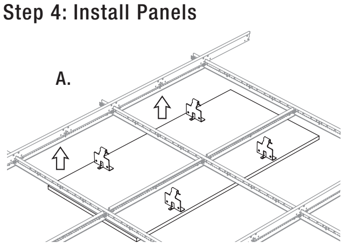


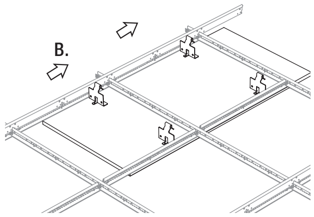
Panel Size	Number of Hooks Needed	Number of Screws Needed*
2' x 8'	8	24
*3 screws per hook		

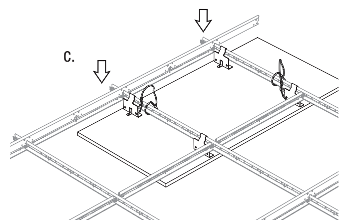
Step 3: Install Hooks on Panels



Step 4: Install Panels

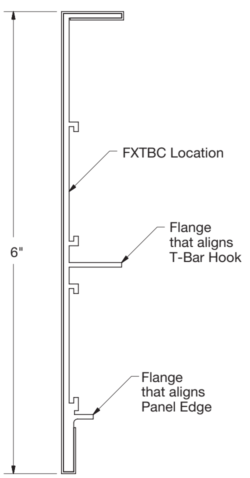


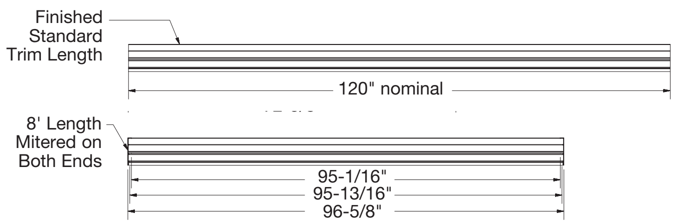




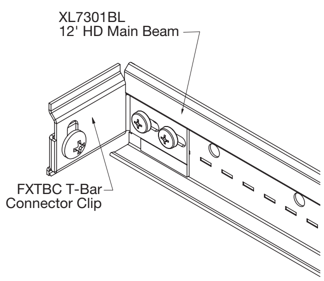
How to Install Trim

Step 1: Cut and Miter Trim

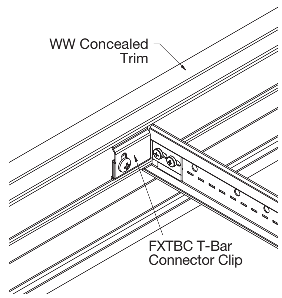




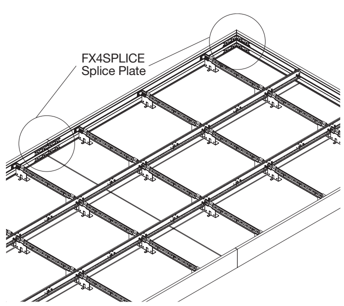
Step 2: Attach Clips to Ends of Main Beams and Cross Tees



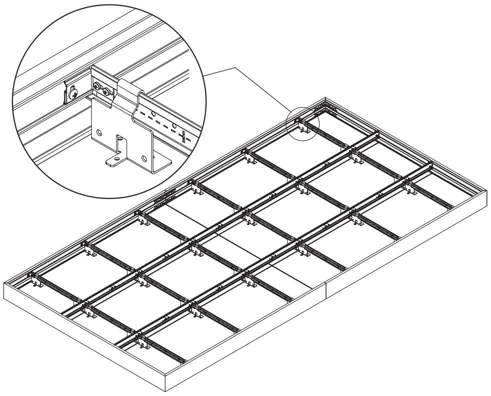
Step 3: Attach Trim to Clips

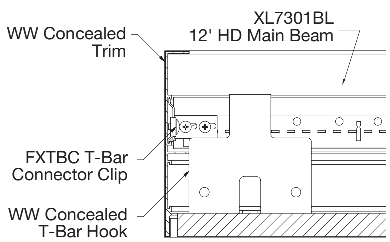


Step 4: Install Splice Plates



Step 5: Install Panels



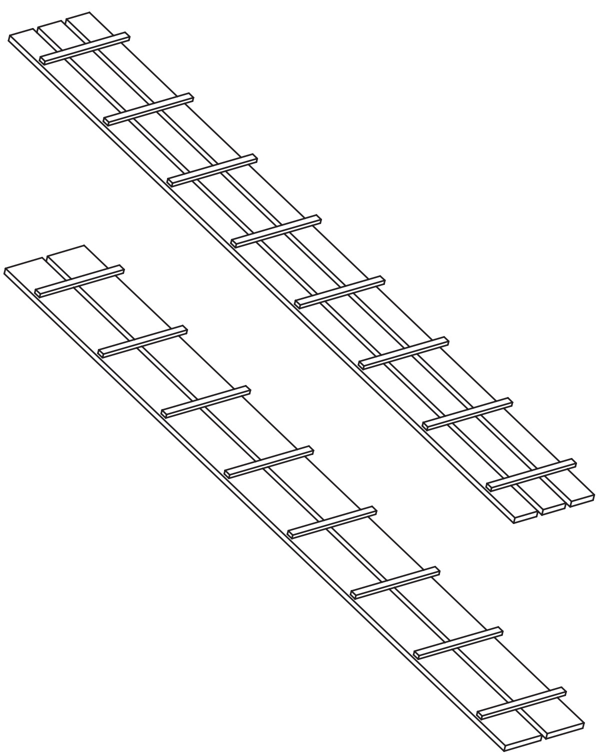


WOODWORKS® Linear – Solid Wood Panels

Additional Attributes of WoodWorks Linear Solid Wood Panels

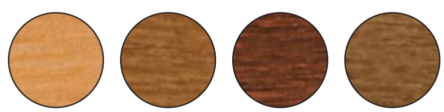
- Two plank widths – nominal 3" and nominal 5" – in four rich finishes
- Fast, easy installation – screw into suspension system or install with backer clip
- Create continuous looks and clouds with solid wood trim
- Complete standard system from one manufacturer
- BioAcoustic™ infill available for increased acoustical performance
- Acoustical fleece available as an option

WoodWorks Linear Solid Wood panels in Grille Dark Cherry.



Finish Selection

Due to printing limitations, shade may vary from actual product.



Grille Maple (GMP)	Grille Light Cherry (GLC)	Grille Dark Cherry (GDC)	Grille Walnut (GWN)

In addition to these standard options, there are more finish and size choices available as custom options. Contact the Armstrong Architectural Specialties project management team for details at 1 877 ARMSTRONG and select prompts 1-1-4.

WOODWORKS® Linear – Solid Wood Panels

armstrong.com/greengenie

LEED® Credits						LEED for Schools	
Energy	Waste Mgmt	Recycled Content	Local Materials	Renewable Materials	Daylight & Views	Acoustics	Low Emitting or CHPS
			✔ Location Dependent			✔	

Finishes

Grille Maple (GMP)
Grille Light Cherry (GLC)
Grille Dark Cherry (GDC)
Grille Walnut (GWN)

Visual Selection

Performance Selection

Dots represent highest level of performance.

Edge Profile	Item Number ◆	Description	Dimensions Nominal W x L x H	Acoustics NRC*
WOODWORKS Linear Solid Wood Panels				
	6693W1 _ _ _	Nominal 3" wide planks	1' x 8' x 3/4"	0.60
	6694W1 _ _ _	Nominal 5" wide planks	1' x 8' x 3/4"	0.50

* NRC achieved with acoustical infill (Item 6657).

NOTE: For additional color and size options, or acoustical felt available as a custom option, call Architectural Specialties at 1 877 ARMSTRONG and select options 1-1-4.

** When specifying or ordering, include the three-letter color suffix that coordinates with your WoodWorks ceiling: (e.g., 5671 G M P)

* When specifying or ordering, include the appropriate three-letter color suffix.

Suspension Systems

15/16"	Prelude® XL® (Black recommended)

Wood is a natural product and will exhibit natural variations in color, grain, and texture, and knot holes of up to 1/2" in diameter.



Accessories

Item Number	Description	Dimensions Nominal W x L x H	Color	Pieces/Carton
7146 _ _ _ ◆	Solid Wood Trim	4" x 120" x 3/4"	See Finishes Above	Bulk
5687†	Backer Clip	3/8" x 11/16" x 7/8"	N/A	250 pcs/pail
5671 _ _ _ ◆	Ledger	1" x 96" x 1/4"	See Finishes Above	Bulk
7891	12 Gauge Soft Hanger Wire	12' Length	N/A	140
92715A620	Self-tapping Screws	#2 x 3/4" Length	Black	25
6657	BioAcoustic™ Infill Panel	11" x 4' x 5/8"	Black (Matte)	10

◆ When specifying or ordering, include the three-letter color suffix that coordinates with your WoodWorks ceiling: (e.g., 5671 G M P)

† Backer clip should only be used when installing panels with 3" wide nominal planks.

Linear Solid Wood Panels Physical Data

Material
Planks and Backers – solid Pacific Albus

Surface Finish
Clear or tinted semigloss coating

Fire Performance
Solid Hardwood Blades and Backers – ASTM E84 surface burning characteristics. Flame Spread Index 200 or less. Smoke Developed Index 450 or less.

For improved Flame Spread performance, intumescent treatment is available.

Fire performance will vary between wood species.

Composite Linear Solid Wood Panels product testing has not been completed, since results will vary on a project-by-project basis. Contact TechLine at 1 877 ARMSTRONG for details.

Woodworks Linear Solid Wood Panels, as with other architectural features located at the ceiling, may obstruct or skew the planned fire sprinkler water distribution pattern, or possibly delay or accelerate the activation of the sprinkler or fire detection systems by channeling heat from a fire either toward or away from the device. Designers and installers are advised to consult a fire protection engineer, NFPA 13, and local codes for guidance where automatic fire detection and suppression systems are present.

Seismic Restraint
Woodworks Linear Solid Wood Panels have been engineered, tested, and approved in all seismic areas.

Application Considerations
Variation among panels may occur due to the natural characteristics of the wood and grain.

Design Considerations
It is very important that WoodWorks panels are climatized prior to installation. Relative humidity between 25% and 55% and temperatures between 50˚F and 86˚F must be maintained.

Installation Consideration
System is designed to have a 1" gap between panels.

Backer clip can only be used for installations of the panel with 3" nominal planks (Item 6693)

Warranty
One (1) year limited warranty. Details: armstrong.com/warranty

Weight; Square Feet/Carton
6693 – 1.25 lbs/SF
6694 – 1.25 lbs/SF
(bulk packed)

APPENDIX J: RS MEANS FACILITIES MAINTENANCE & REPAIR COST DATA 2014 PHOTOS

C3013 210 — Acoustical Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair acoustical tile - (2% of walls)**	25	1 CARP	C.S.F.							
	Remove damaged tile				1.067		39		39	52	64
	Install new tile				2.737	237	125		362	430	500
	Total				3.804	237	164		401	**482**	**564**
0030	**Refinish acoustical tile**	10	1 PORD	C.S.F.							
	Wipe surface				.894	6	35		41	53	64.50
	Prepare surface				.894	6	35		41	53	64.50
	Refinish surface				1.529	25	60		85	106	128
	Total				3.317	37	130		167	**212**	**257**
0040	**Replace acoustical tile**	60	2 CARP	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	56.50
	Remove old tiles				1.067		39		39	52	64
	Install new tile				2.737	237	125		362	430	500
	Remove scaffold				.750		34.50		34.50	46	56.50
	Total				5.304	237	233		470	**574**	**677**

C3013 212 — Stucco

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair stucco wall - (2% of walls)**	20	1 BRIC	S.Y.							
	Prepare surface				.023		.90		.90	1.17	1.44
	Repair stucco				.532	3.60	21.33	1.89	26.82	33.50	41
	Place and remove mask and drops				.067		2.70		2.70	3.42	4.14
	Total				.621	3.60	24.93	1.89	30.42	**38.09**	**46.58**
0030	**Refinish stucco wall**	4	1 PORD	S.Y.							
	Wash surface				.023		.90		.90	1.17	1.44
	Prepare surface				.033		1.35		1.35	1.71	2.07
	Refinish surface, brushwork, 2 coats				.138	2.25	5.40		7.65	9.55	11.55
	Place and remove mask and drops				.033		1.35		1.35	1.71	2.07
	Total				.227	2.25	9		11.25	**14.14**	**17.13**

C3013 212 — Stucco

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	2014 Bare Costs: Labor	2014 Bare Costs: Equipment	2014 Bare Costs: Total	Total In-House	Total w/O&P
0040	**Replace stucco wall**	75	2 BRIC	S.Y.							
	Set up and secure scaffold				.130		5.95		5.95	7.95	9.80
	Remove stucco				.279		12.78		12.78	17.10	21
	Replace stucco				1.200	6.55	48	3.59	58.14	73	89
	Remove scaffold				.130		5.95		5.95	7.95	9.80
	Total				1.739	6.55	72.68	3.59	82.82	106	129.80
4120	**Spray refinish stucco wall**	5	1 PORD	S.Y.							
	Wash surface				.023		.90		.90	1.17	1.44
	Prepare surface				.033		1.35		1.35	1.71	2.07
	Refinish surface, spray, 2 coats				.049	2.52	1.98		4.50	5.30	6.30
	Place and remove mask and drops				.033		1.35		1.35	1.71	2.07
	Total				.138	2.52	5.58		8.10	9.89	11.88

C3013 213 — Plaster

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	2014 Bare Costs: Labor	2014 Bare Costs: Equipment	2014 Bare Costs: Total	Total In-House	Total w/O&P
0010	**Repair plaster wall - (2% of walls)**	13	1 PLAS	S.Y.							
	Remove damage				.468		17.15		17.15	23	28
	Replace two coat plaster finish, incl. lath				.752	6.05	30	2.25	38.30	48	58.50
	Total				1.220	6.05	47.15	2.25	55.45	71	86.50
0030	**Refinish plaster wall**	4	1 PORD	S.Y.							
	Prepare surface				.033		1.35		1.35	1.71	2.07
	Paint / seal surface, brushwork, 1 coat				.063	.54	2.52		3.06	3.87	4.64
	Place and remove mask and drops				.033		1.35		1.35	1.71	2.07
	Total				.129	.54	5.22		5.76	7.29	8.78
0040	**Replace plaster wall**	75	2 PLAS	S.Y.							
	Set up, secure and take down ladder				.130		5.95		5.95	7.95	9.80
	Remove material				.468		17.15		17.15	23	28
	Replace two coat plaster wall, incl. lath				.752	6.05	30	2.25	38.30	48	58.50
	Total				1.350	6.05	53.10	2.25	61.40	78.95	96.30

Remove material										
Replace two coat plaster wall, incl. lath				.752	6.05	30	2.25	38.30	48	58.50
Total				1.350	6.05	53.10	2.25	61.40	78.95	96.30

C30 INTERIOR FINISHES | C3013 | Wall Finishes

C3013 214 | Drywall

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair 5/8″ drywall - (2% of walls)**	20	1 CARP	S.F.							
	Remove damage				.008		.29		.29	.39	.48
	Replace 5/8″ drywall, taped and finished				.022	.32	.99		1.31	1.67	2.02
	Total				.030	.32	1.28		1.60	**2.06**	**2.50**
0030	**Refinish drywall**	4	1 PORD	S.F.							
	Place and remove mask and drops				.004		.15		.15	.19	.23
	Prepare surface				.004		.15		.15	.19	.23
	Paint surface, brushwork, 1 coat				.007	.06	.28		.34	.43	.52
	Total				.014	.06	.58		.64	**.81**	**.98**
0040	**Replace 5/8″ drywall**	75	2 CARP	S.F.							
	Set up, secure and take down ladder				.014		.66		.66	.88	1.09
	Remove drywall				.008		.29		.29	.39	.48
	Replace 5/8″ drywall, taped and finished				.022	.32	.99		1.31	1.67	2.02
	Total				.044	.32	1.94		2.26	**2.94**	**3.59**
0050	**Office painting, 10′ x 12′, 10′ high walls**	5	1 PORD	Ea.							
	Spread drop cloths				.004		.15		.15	.19	.23
	Prepare drywall partitions				1.628		66		66	83.50	101
	Clean drywall partitions				.220	2.02	8.07		10.09	13	15.70
	Paint drywall partitions, roller + brush, 1 coat				3.062	26.40	123.20		149.60	189	227
	Remove drop cloths				.004		.15		.15	.19	.23
	Total				4.918	28.42	197.57		225.99	**285.88**	**344.16**
0060	**Office painting, 10′ x 15′, 10′ high walls**	5	1 PORD	Ea.							
	Spread drop cloths				.005		.19		.19	.24	.29
	Prepare drywall partitions				1.850		75		75	95	115
	Clean drywall partitions				.250	2.29	9.18		11.47	14.75	17.85
	Paint drywall partitions, roller + brush, 1 coat				3.480	30	140		170	215	258
	Remove drop cloths				.005		.19		.19	.24	.29
	Total				5.589	32.29	224.56		256.85	**325.23**	**391.43**

C3013 214 Drywall

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
2030	**Refinish drywall, 12' to 24' high**	5	2 PORD	S.F.							
	Set up and secure scaffold				.015		.69		.69	.92	1.13
	Place and remove mask and drops				.004		.15		.15	.19	.23
	Prepare surface				.004		.15		.15	.19	.23
	Paint surface, roller + brushwork, 1 coat				.007	.06	.28		.34	.43	.52
	Remove scaffold				.015		.69		.69	.92	1.13
	Total				.044	.06	1.96		2.02	**2.65**	**3.24**
3030	**Refinish drywall, over 24' high**	5	2 PORD	S.F.							
	Set up and secure scaffold				.023		1.04		1.04	1.37	1.70
	Place and remove mask and drops				.004		.15		.15	.19	.23
	Prepare surface				.004		.15		.15	.19	.23
	Paint surface, roller + brushwork, 1 coat				.007	.06	.28		.34	.43	.52
	Remove scaffold				.023		1.04		1.04	1.37	1.70
	Total				.059	.06	2.66		2.72	**3.55**	**4.38**

C3013 215 Fiberglass Panels, Rigid

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair glass cloth fiberglass panels - (2% of walls)**	9	1 CARP	C.S.F.							
	Remove damaged fiberglass panels				2.600		95		95	127	157
	Install new fiberglass panel				6.710	760	308		1,068	1,250	1,450
	Total				9.310	760	403		1,163	**1,377**	**1,607**
0040	**Replace glass cloth fiberglass panels**	35	2 CARP	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	56.50
	Remove old panels				2.600		95		95	127	157
	Remove old furring				.516		19		19	25	31
	Install new furring				2.101	42	96		138	174	211
	Install new glass cloth fiberglass panels				6.710	760	308		1,068	1,250	1,450
	Remove scaffold				.750		34.50		34.50	46	56.50
	Total				13.427	802	587		1,389	**1,668**	**1,962**

Remove scaffold	.750		34.50		34.50	46	56.50
Total	13.427	802	587		1,389	1,668	1,962

C30 INTERIOR FINISHES | C3013 | Wall Finishes

C3013 220 | Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	2014 Bare Costs Labor	2014 Bare Costs Equipment	2014 Bare Costs Total	Total In-House	Total w/O&P
0010	**Repair 4" x 4" thin set ceramic tile - (2% of walls)**	10	1 TILF	C.S.F.							
	Remove damaged tiles				2.600		95		95	127	157
	Replace tile / grout				10.947	210	412		622	750	915
	Total				13.547	210	507		717	877	1,072
0020	**Replace 4" x 4" thin set ceramic tile**	75	1 TILF	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	56.50
	Remove tiles				2.600		95		95	127	157
	Replace tile / grout				10.947	210	412		622	750	915
	Remove scaffold				.750		34.50		34.50	46	56.50
	Total				15.047	210	576		786	969	1,186

C3013 230 | Plywood Paneling

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	2014 Bare Costs Labor	2014 Bare Costs Equipment	2014 Bare Costs Total	Total In-House	Total w/O&P
0010	**Repair plywood paneling - (2% of walls)**	10	1 CARP	C.S.F.							
	Remove damaged paneling				1.156		42		42	56	70
	Replace paneling				4.952	83	227		310	395	475
	Total				6.108	83	269		352	451	545
0020	**Refinish plywood paneling**	10	1 PORD	C.S.F.							
	Place mask and drops				.500		20		20	26	32
	Sand & paint, brushwork, 1 coat				.990	6	39		45	58	70.50
	Remove mask and drops				.500		20		20	26	32
	Total				1.990	6	79		85	110	134.50
0040	**Replace plywood paneling**	30	2 CARP	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	58.50
	Remove damaged paneling				1.156		42		42	56	70
	Replace paneling				4.952	83	227		310	395	475
	Remove scaffold				.750		34.50		34.50	46	58.50
	Total				7.608	83	338		421	543	668

Prepare surface				.003		.13	.13	.17	.21
Varnish, 3 coats, brushwork, sanding included				.025	.28	.97	1.25	1.57	1.91
Total				.028	.28	1.10	1.38	1.74	2.12

C30 INTERIOR FINISHES | C3023 | Floor Finishes

C3023 112 | Concrete, Finished

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	Refinish concrete floor	25	2 CEFI	C.S.F.							
	Add topping to existing floor 1 "				6.933	52	275	49	376	465	560
	Total				6.933	52	275	49	376	465	560

C3023 405 | Epoxy Flooring

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	Replace epoxy flooring	15	2 CEFI	C.S.F.							
	Strip existing flooring				3.200		147		147	196	241
	Repair and seal floor				12.735	397	487	18	902	1,100	1,300
	Total				15.935	397	634	18	1,049	1,296	1,541

C3023 410 | Vinyl Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	Replace vinyl tile flooring	18	1 TILF	S.Y.							
	Remove damaged floor tile				.234		8.55		8.55	11.45	14.15
	Prepare surface				.645		24.30		24.30	30.50	38.50
	Install new tiles				.187	7.74	7.83		15.57	18.45	22
	Total				1.067	7.74	40.68		48.42	60.40	74.65

C3023 412 | Vinyl Sheet

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	Replace vinyl sheet flooring	18	1 TILF	S.Y.							
	Remove damaged floor tile				.234		8.55		8.55	11.45	14.15
	Prepare surface				.645		24.30		24.30	30.50	38.50
	Install new vinyl sheet				.407	36.90	17.10		54	62	73
	Total				1.286	36.90	49.95		86.85	103.95	125.65

C3023 414 Rubber Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	**Replace rubber tile floor**	18	1 TILF	S.Y.							
	Remove damaged floor tile				.234		8.55		8.55	11.45	14.15
	Prepare surface				.645		24.30		24.30	30.50	38.50
	Install new tiles				1.040	110.25	43.65		153.90	176	207
	Total				1.920	110.25	76.50		186.75	**217.95**	**259.65**

C3023 418 Rubber / Vinyl Trim

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Replace rubber cove base**	9	1 TILF	L.F.							
	Remove damaged base				.017		.64		.64	.85	1.04
	Clean up debris				.001		.01		.01	.01	.01
	Install new base				.025	1.26	1.07		2.33	2.74	3.26
	Total				.044	1.26	1.72		2.98	**3.60**	**4.31**

C3023 420 Ceramic Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Ceramic tile floor repairs - (2% of floors)**	15	1 TILF	C.S.F.							
	Regrout ceramic tile floors				16.640	15	625		640	810	1,000
	Total				16.640	15	625		640	**810**	**1,000**
0020	**Replace 2" x 2" thin set ceramic tile floor**	50	1 TILF	C.S.F.							
	Remove damaged floor tile				2.600		95		95	127	157
	Prepare surface				7.172		270		270	340	425
	Install new tiles				10.947	580	412		992	1,150	1,375
	Total				20.719	580	777		1,357	**1,617**	**1,957**

C3023 428 Ceramic Trim

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	**Replace ceramic trim**	50	2 TILF	L.F.							
	Remove ceramic tile trim				.015		.55		.55	.73	.90
	Clean up debris				.010		.46		.46	.60	.74
	Install new ceramic tile trim				.229	3.68	8.60		12.28	14.90	18.15
	Total				.253	3.68	9.61		13.29	**16.23**	**19.79**

C3023 430 Terrazzo

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0100	**Terrazzo floor repairs - (2% of floors)**	15	1 MSTZ	S.F.							
	Chip existing terrazzo				.089		3.27		3.27	4.35	5.35
	Place terrazzo				.166	3.08	6.35	3.02	12.45	14.45	17.15
	Remove debris				.004		.16		.16	.21	.26
	Total				.260	3.08	9.78	3.02	15.88	**19.01**	**22.76**
0200	**Replace terrazzo floor**	75	2 MSTZ	C.S.F.							
	Break-up existing terrazzo				5.943		218		218	290	360
	Remove debris				.433		16		16	21.50	26
	Load into truck				.650		24.25	14	38.25	46.50	55.50
	Place terrazzo				16.640	308	635	302	1,245	1,450	1,725
	Total				23.666	308	893.25	316	1,517.25	**1,808**	**2,166.50**

C3023 438 Terrazzo Trim

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	**Replace precast terrazzo trim**	75	2 MSTZ	L.F.							
	Remove old terrazzo trim				.023		.85		.85	1.13	1.39
	Clean area				.010		.46		.46	.60	.74
	Install new precast terrazzo trim				.416	16.85	17.35		34.20	40.50	48.50
	Total				.449	16.85	18.66		35.51	**42.23**	**50.63**

C3023 478 Wood Trim

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs				Total In-House	Total w/O&P
						Material	Labor	Equipment	Total		
0010	**Repair 1″ x 3″ wood trim**	13	1 CARP	L.F.							
	Remove wood				.021		.76		.76	1.02	1.25
	Install new trim				.173	4.56	7.96		12.52	15.60	18.75
	Total				.194	4.56	8.72		13.28	**16.62**	**20**
0030	**Refinish 1″ x 3″ wood trim**	7	1 PORD	L.F.							
	Prepare surface				.003		.13		.13	.17	.21
	Varnish, 3 coats, brushwork, sanding included				.025	.28	.97		1.25	1.57	1.91
	Total				.028	.28	1.10		1.38	**1.74**	**2.12**
0040	**Replace 1″ x 3″ wood trim**	75	2 CARP	L.F.							
	Remove wood				.021		.76		.76	1.02	1.25
	Install new trim				.173	4.56	7.96		12.52	15.60	18.75
	Prepare surface				.003		.13		.13	.17	.21
	Varnish, 3 coats, brushwork, sanding included				.025	.28	.97		1.25	1.57	1.91
	Total				.222	4.84	9.82		14.66	**18.36**	**22.12**

C3023 510 Carpet

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs				Total In-House	Total w/O&P
						Material	Labor	Equipment	Total		
0020	**Replace carpet**	8	2 TILF	S.Y.							
	Remove damaged carpet				.094		3.42		3.42	4.59	5.65
	Install new carpet				.138	38	5.80		43.80	49	56.50
	Total				.232	38	9.22		47.22	**53.59**	**62.15**

C3033 105 Plaster

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair plaster ceiling - (2% of ceilings)**	12	1 PLAS	S.Y.							
	Set up, secure and take down ladder				.130		5.95		5.95	7.95	9.80
	Remove damaged ceiling				.267		9.81		9.81	13.05	16.10
	Replace plaster, 2 coats on lath				.752	5.65	30	2.25	37.90	47.50	58
	Total				1.149	5.65	45.76	2.25	53.66	**68.50**	**83.90**
0030	**Refinish plaster ceiling**	10	1 PORD	S.Y.							
	Set up, secure and take down ladder				.130		5.95		5.95	7.95	9.80
	Place mask and drops				.033		1.35		1.35	1.71	2.07
	Sand & paint				.089	.54	3.51		4.05	5.20	6.35
	Total				.252	.54	10.81		11.35	**14.86**	**18.22**
0040	**Replace plaster ceiling**	75	2 PLAS	S.Y.							
	Set up and secure scaffold				.130		5.95		5.95	7.95	9.80
	Remove ceiling				.267		9.81		9.81	13.05	16.10
	Replace plaster, 2 coats on lath				.752	5.65	30	2.25	37.90	47.50	58
	Remove scaffold				.130		5.95		5.95	7.95	9.80
	Total				1.279	5.65	51.71	2.25	59.61	**76.45**	**93.70**

C3033 107 Gypsum Wall Board

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair gypsum board ceiling - (2% of ceilings)**	20	1 CARP	C.S.F.							
	Set up, secure and take down ladder				1.300		59.50		59.50	79.50	98
	Remove damaged gypsum board				2.737		100		100	134	165
	Replace 5/8" gypsum board, taped and finished				3.382	41	155		196	252	305
	Total				7.419	41	314.50		355.50	**465.50**	**568**
0020	**Refinish gypsum board ceiling, up to 12' high**	20	1 PORD	C.S.F.							
	Set up, secure and take down ladder				1.300		59.50		59.50	79.50	98
	Wash surface				.250		10		10	13	16
	Sand & paint				.990	6	39		45	58	70.50
	Place and remove mask and drops				.370		15		15	19	23
	Total				2.910	6	123.50		129.50	**169.50**	**207.50**

C30 INTERIOR FINISHES | C3033 | Ceiling Finishes

C3033 107 — Gypsum Wall Board

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0040	**Replace gypsum board ceiling, up to 12′ high**	40	2 CARP	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	56.50
	Remove damaged gypsum board				2.737		100		100	134	165
	Replace 5/8" gypsum board ceiling, taped and finished				3.382	41	155		196	252	305
	Remove scaffold				.750		34.50		34.50	46	56.50
	Total				7.619	41	324		365	478	583
2020	**Refinish gypsum board ceiling, 12′ to 24′ high**	5	2 PORD	C.S.F.							
	Set up and secure scaffold				1.500		69		69	91.50	113
	Place and remove mask and drops				.370		15		15	19	23
	Prepare surface				.370		15		15	19	23
	Paint surface, roller + brushwork, 1 coat				.696	6	28		34	43	51.50
	Remove scaffold				1.500		69		69	91.50	113
	Total				4.436	6	196		202	264	323.50
3020	**Refinish gypsum board ceiling, over 24′ high**	5	2 PORD	C.S.F.							
	Set up and secure scaffold				2.250		103.50		103.50	137	170
	Place and remove mask and drops				.370		15		15	19	23
	Prepare surface				.370		15		15	19	23
	Paint surface, roller + brushwork, 1 coat				.696	6	28		34	43	51.50
	Remove scaffold				2.250		103.50		103.50	137	170
	Total				5.936	6	265		271	355	437.50

C3033 108 — Acoustic Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs: Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Acoustic tile repairs - (2% of ceilings)**	9	1 CARP	C.S.F.							
	Set up, secure and take down ladder				1.300		59.50		59.50	79.50	98
	Remove damaged tile				1.067		39		39	52	64
	Install new tile				2.737	237	125		362	430	500
	Total				5.104	237	223.50		460.50	561.50	662

C3033 108 Acoustic Tile

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0020	**Replace acoustic tile ceiling, non fire-rated**	20	1 CARP	C.S.F.							
	Set up, secure and take down scaffold				.750		34.50		34.50	46	56.50
	Remove old ceiling tiles				.500		18		18	24	30
	Remove old ceiling grid				.625		23		23	31	38
	Install new ceiling grid				1.000	70	46		116	138	163
	Install new ceiling tiles				1.280	125	59		184	216	252
	Sweep and clean debris				.520		26.50		26.50	34.50	43
	Total				4.675	195	207		402	**489.50**	**582.50**
0030	**Refinish acoustic tile ceiling/grid (unoccupied area)**	5	2 PORD	C.S.F.							
	Protect exposed surfaces and mask light fixtures				.800		31.50		31.50	41	51
	Refinish acoustic tiles, roller + brush, 1 coat				.267	.01	10.50		10.51	13.70	16.90
	Total				1.067	.01	42		42.01	**54.70**	**67.90**
0040	**Refinish acoustic tile ceiling/grid (occupied area)**	5	2 PORD	C.S.F.							
	Protect exposed surfaces and mask light fixtures				3.200		127		127	164	203
	Refinish acoustic tiles, roller + brush, 1 coat				.320	.01	12.70		12.71	16.40	20.50
	Total				3.520	.01	139.70		139.71	**180.40**	**223.50**
2030	**Refinish acoustic tile ceiling, 12' to 24' high**	5	2 PORD	C.S.F.							
	Set up and secure scaffold				1.500		69		69	91.50	113
	Place and remove mask and drops				.100		2		2	2.60	3
	Paint surface, roller + brushwork, 1 coat				.267	.01	10.50		10.51	13.70	16.90
	Remove scaffold				1.500		69		69	91.50	113
	Total				3.367	.01	150.50		150.51	**199.30**	**245.90**
3030	**Refinish acoustic tile ceiling, over 24' high**	5	2 PORD	C.S.F.							
	Set up and secure scaffold				2.250		103.50		103.50	137	170
	Place and remove mask and drops				.100		2		2	2.60	3
	Paint surface, roller + brushwork, 1 coat				.267	.01	10.50		10.51	13.70	16.90
	Remove scaffold				2.250		103.50		103.50	137	170
	Total				4.867	.01	219.50		219.51	**290.30**	**359.90**

C3033 109 Acoustic Tile, Fire-Rated

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Replace acoustic tile ceiling, fire-rated**	20	1 CARP	C.S.F.							
	Set up, secure and take down scaffold				.750		34.50		34.50	46	56.50
	Remove old ceiling tiles				.500		18		18	24	30
	Remove old grid system				.625		23		23	31	38
	Install new grid system				1.200	84	55.20		139.20	166	195
	Install new ceiling tiles				1.185	95	54		149	177	208
	Sweep & clean debris				.520		26.50		26.50	34.50	43
	Total				4.780	179	211.20		390.20	**478.50**	**570.50**

C3033 120 Wood

	System Description	Freq. (Years)	Crew	Unit	Labor Hours	2014 Bare Costs Material	Labor	Equipment	Total	Total In-House	Total w/O&P
0010	**Repair wood ceiling - (2% of ceilings)**	10	1 CARP	C.S.F.							
	Set up, secure and take down ladder				1.300		59.50		59.50	79.50	98
	Remove damaged ceiling				1.455		53		53	71	88
	Replace wood				5.200	149	238		387	480	580
	Total				7.955	149	350.50		499.50	**630.50**	**766**
0030	**Refinish wood ceiling**	6	1 PORD	C.S.F.							
	Set up and secure scaffold				.375		17.25		17.25	23	28.50
	Wash surface				.286		11		11	15	18
	Sand & paint, brushwork, 1 coat				.990	6	39		45	58	70.50
	Place and remove mask and drops				.370		15		15	19	23
	Remove scaffold				.375		17.25		17.25	23	28.50
	Total				2.396	6	99.50		105.50	**138**	**168.50**
0040	**Replace wood ceiling**	50	2 CARP	C.S.F.							
	Set up and secure scaffold				.750		34.50		34.50	46	56.50
	Remove damaged ceiling				1.455		53		53	71	88
	Replace wood				5.200	149	238		387	480	580
	Remove scaffold				.750		34.50		34.50	46	56.50
	Total				8.155	149	360		509	**643**	**781**

APPENDIX K: DEPTH #3 INTERVIEW QUESTIONS

The following questions will be asked to owners, architects, and contractors if not already answered by contributors at the PACE conference:

1. What inefficiencies exist now for transferring information between phases effectively?
2. What information needs to be turned over for facility management?
3. What takes the most time and effort to compile and transfer?
4. What relationships or contracts may be hampering the process for efficient transfer of information?
5. What workflows would be of high value to define more clearly and make repeatable?
6. What infrastructure or tool support is needed to make these workflows consistent and interoperable?
7. What were the goals at CWNCHS and were they executed?
8. What could've been done to improve the process?

The following questions will be asked to maintenance professionals and facility managers:

1. Have you ever been involved in the turnover from construction to occupancy?
2. How efficiently was the required operations and maintenance information delivered to you?
3. How could it be delivered better?
4. Were you ever involved in the training process before occupancy?
5. What is the earliest you've been involved in a turnover process?
6. Do you think you have more to offer earlier on?
7. Are you computer literate?
8. Do you have any experience with 3D modeling or reading construction drawings?
9. Would you be willing to learn to do this?

APPENDIX L: TPO SPECIFICATION

SECTION 075423 - THERMOPLASTIC POLYOLEFIN (TPO) ROOFING

PART 1 - GENERAL

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.

1.2 SUMMARY

A. Section Includes:

1. Adhered thermoplastic polyolefin (TPO) roofing system.
2. Vapor retarder.
3. Roof insulation.

B. Section includes the installation of insulation strips in ribs of roof deck. Insulation strips are furnished under Section 053100 "Steel Decking."

C. Related Sections:

1. Section 018113.23 "Sustainable Design Requirements-LEED for Schools" for additional LEED requirements.
2. Section 018119 "Indoor Air Quality Requirements"
3. Section 061000 "Rough Carpentry" for wood nailers, curbs, and blocking; and for wood-based, structural-use roof deck panels.
4. Section 077100 "Roof Specialties" for copings, roof-edge flashings, roof-edge drainage systems, reglets and counter flashings.
5.~~4.~~ Section 077129 "Manufactured Roof Expansion Joints" for proprietary manufactured roof expansion-joint assemblies.
6.~~5.~~ Section 221423 "Storm Drainage Piping Specialties" for roof drains.

1.3 DEFINITIONS

A. Roofing Terminology: Definitions in ASTM D 1079 and glossary in NRCA's "The NRCA Roofing and Waterproofing Manual" apply to work of this Section.

1.4 PREINSTALLATION MEETINGS

A. Preliminary Roofing Conference: Before starting roof deck construction, conduct conference at Project site.

1. Meet with Owner, Architect, Owner's insurer if applicable, testing and inspecting agency representative, roofing Installer, roofing system manufacturer's representative, deck Installer, and installers whose work interfaces with or affects roofing, including installers of roof accessories and roof-mounted equipment.
2. Review methods and procedures related to roofing installation, including manufacturer's written instructions.
3. Review and finalize construction schedule, and verify availability of materials, Installer's personnel, equipment, and facilities needed to make progress and avoid delays.
4. Review deck substrate requirements for conditions and finishes, including flatness and fastening.
5. Review structural loading limitations of roof deck during and after roofing.
6. Review base flashings, special roofing details, roof drainage, roof penetrations, equipment curbs, and condition of other construction that affects roofing system.
7. Review governing regulations and requirements for insurance and certificates if applicable.
8. Review temporary protection requirements for roofing system during and after installation.
9. Review roof observation and repair procedures after roofing installation.

B. Preinstallation Roofing Conference: Conduct conference at Project site.

1. Meet with Owner, Architect, Owner's insurer if applicable, testing and inspecting agency representative, roofing Installer, roofing system manufacturer's representative, deck Installer, and installers whose work interfaces with or affects roofing, including installers of roof accessories and roof-mounted equipment.
2. Review methods and procedures related to roofing installation, including manufacturer's written instructions.
3. Review and finalize construction schedule, and verify availability of materials, Installer's personnel, equipment, and facilities needed to make progress and avoid delays.
4. Examine deck substrate conditions and finishes for compliance with requirements, including flatness and fastening.
5. Review structural loading limitations of roof deck during and after roofing.
6. Review base flashings, special roofing details, roof drainage, roof penetrations, equipment curbs, and condition of other construction that affects roofing system.
7. Review governing regulations and requirements for insurance and certificates if applicable.
8. Review temporary protection requirements for roofing system during and after installation.
9. Review roof observation and repair procedures after roofing installation.

1.5 ACTION SUBMITTALS

A. Product Data: For each type of product.

B. LEED Submittals:

1. Credit SS 7.2: Product data of roofing system to demonstrate that Solar Reflectance Index of all areas except those covered by mechanical plant, shading devices, and renewable technologies and designated vegetated roofs.

2. Credits MR 4.1 & 4.2: For products having recycled content, documentation indicating percentages by weight of post-consumer and pre-consumer recycled content

a. Include statement indicating costs for each product containing recycled content.

3. Credit MR 5.1 & 5.2: For products manufactured within 500 miles of project site *and* whose raw materials are extracted, harvested or recovered, within 500 miles of the project site, documentation indicating the location and distance of material manufacturer and point of extraction, harvest, or recovery for each raw material from the Project site.

a. Include statement indicating cost for each regional material and the fraction by weight that is considered regional.

C. Shop Drawings: For roofing system. Include plans, elevations, sections, details, and attachments to other work, including:

1. Base flashings and membrane terminations.
2. Tapered insulation, including slopes.
3. Roof plan showing orientation of steel roof deck and orientation of roofing, fastening spacings, and patterns for mechanically fastened roofing.
4. Insulation fastening patterns for corner, perimeter, and field-of-roof locations.

D. Samples for Verification: For the following products:

1. Sheet roofing, of color required.
2. Walkway pads or rolls, of color required.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: For Installer and manufacturer.

B. Manufacturer Certificates: Signed by roofing manufacturer certifying that roofing system complies with requirements specified in "Performance Requirements" Article.

1. Submit evidence of compliance with performance requirements.

C. Product Test Reports: For components of roofing system, tests performed by manufacturer and witnessed by a qualified testing agency.

D. Research/Evaluation Reports: For components of roofing system, from ICC-ES.

E. Field quality-control reports.

F. Sample Warranties: For manufacturer's special warranties.

1.7 CLOSEOUT SUBMITTALS

A. Maintenance Data: For roofing system to include in maintenance manuals.

1.8 QUALITY ASSURANCE

A. Manufacturer Qualifications: A qualified manufacturer that is UL listed for roofing system identical to that used for this Project.

B. Installer Qualifications: A qualified firm that is approved, authorized, or licensed by roofing system manufacturer to install manufacturer's product and that is eligible to receive manufacturer's special warranty.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Deliver roofing materials to Project site in original containers with seals unbroken and labeled with manufacturer's name, product brand name and type, date of manufacture, approval or listing agency markings, and directions for storing and mixing with other components.

B. Store liquid materials in their original undamaged containers in a clean, dry, protected location and within the temperature range required by roofing system manufacturer. Protect stored liquid material from direct sunlight.

1. Discard and legally dispose of liquid material that cannot be applied within its stated shelf life.

C. Protect roof insulation materials from physical damage and from deterioration by sunlight, moisture, soiling, and other sources. Store in a dry location. Comply with insulation manufacturer's written instructions for handling, storing, and protecting during installation.

D. Handle and store roofing materials, and place equipment in a manner to avoid permanent deflection of deck.

1.10 FIELD CONDITIONS

A. Weather Limitations: Proceed with installation only when existing and forecasted weather conditions permit roofing system to be installed according to manufacturer's written instructions and warranty requirements.

1.11 WARRANTY

A. Special Warranty: Manufacturer agrees to repair or replace components of roofing system that fail in materials or workmanship within specified warranty period.

1. Special warranty includes roofing, base flashings, roof insulation, fasteners, cover boards, substrate board, roofing accessories, and other components of roofing system.
2. Warranty Period: 20 years from date of Substantial Completion.
3. Coordinate Special Warranty with Section 077100 – Roof Specialties.

B. Special Project Warranty: Submit roofing Installer's warranty, on warranty form at end of this Section, signed by Installer, covering the Work of this Section, including all components of roofing system such as roofing, base flashing, roof insulation, fasteners, cover boards, substrate boards, vapor retarders, roof pavers, and walkway products, for the following warranty period:

1. Warranty Period: Five years from date of Substantial Completion.

PART 2 - PRODUCTS

SEE ***C-RFI-0363-00*** FOR CHANGES MADE TO SPECIFIED ROOFING MATERIALS.

SPECS HAVE BEEN UPDATED TO REFLECT CHANGES IN C-RFI-0363-00

2.1 MANUFACTURERS

A. Basis-of-Design Product: Subject to compliance with requirements, provide Carlisle Syn Tec Incorporated; Sure-Weld (TPO) adhered roofing system or comparable product by one of the following:

1. Firestone Building Products.
2. GAF Materials Corporation.
3. GenFlex Roofing Systems.
4. Versico Incorporated.

B. Source Limitations: Obtain components for roofing system from same manufacturer as membrane roofing.

2.2 PERFORMANCE REQUIREMENTS

A. General Performance: Installed roofing and base flashings shall withstand specified uplift pressures, thermally induced movement, and exposure to weather without failure due to defective manufacture, fabrication, installation, or other defects in construction. Roofing and base flashings shall remain watertight.

1. Accelerated Weathering: Roofing system shall withstand 2000 hours of exposure when tested according to ASTM G 152, ASTM G 154, or ASTM G 155.
2. Impact Resistance: Roofing system shall resist impact damage when tested according to ASTM D 3746 or ASTM D 4272.

B. Material Compatibility: Roofing materials shall be compatible with one another and adjacent materials under conditions of service and application required, as demonstrated by roofing manufacturer based on testing and field experience.

C. Roofing System Design: Tested by a qualified testing agency to resist the following uplift pressures:

1. Corner Uplift Pressure: 40 lbf/sq. ft.
2. Perimeter Uplift Pressure: 40 lbf/sq. ft.
3. Field-of-Roof Uplift Pressure: 40 lbf/sq. ft.

D. FM Global Listing: Roofing, base flashings, and component materials shall comply with requirements in FM Global 4450 or FM Global 4470 as part of a built-up roofing system, and shall be listed in FM Global's "RoofNav" for Class 1 or noncombustible construction, as applicable. Identify materials with FM Global markings.

1. Fire/Windstorm Classification: Class 1A-90.
2. Hail-Resistance Rating: SH.

E. Roofing system in all areas except those covered by mechanical plant, shading devices, and renewable technologies and designated vegetated roofs shall comply with the following requirements Solar Reflectance Index (SRI):

1. Low sloped roof (< 2:12): SRI of at least 78
2. High sloped roof (> = 2:12): SRI of at least 29

F. Energy Star Listing: Roofing system shall be listed on the DOE's ENERGY STAR "Roof Products Qualified Product List" for low-slope roof products.

G. Energy Performance: Roofing system shall have an initial solar reflectance index of not less than 0.78 and an emissivity of not less than 0.86 when tested according to CRRC-1.

H. Exterior Fire-Test Exposure: ASTM E 108 or UL 790, Class A; for application and roof slopes indicated; testing by a qualified testing agency. Identify products with appropriate markings of applicable testing agency.

I. Fire-Resistance Ratings: Comply with fire-resistance-rated assembly designs indicated. Identify products with appropriate markings of applicable testing agency.

J. Roof System Assembly:

1. Vapor retarder adhesive backed attached to metal deck.
2. Substrate board mechanically attached to metal deck. See ***C-RFI-0406-00*** for modification.
3. One base layer of insulation.
4. One top layer of insulation mechanically fastened through both layers of insulation to metal deck.
5. TPO fully adhered to second layer of insualtion.

2.3 TPO ROOFING

A. Fabric-Reinforced TPO Sheet: ASTM D 6878, internally fabric- or scrim-reinforced, uniform, flexible TPO sheet.

1. Thickness: 60 mils (1.5 mm), nominal.
2. Exposed Face Color: White.

2.4 AUXILIARY ROOFING MATERIALS

A. General: Auxiliary materials recommended by roofing system manufacturer for intended use and compatible with roofing.

1. Liquid-type auxiliary materials shall comply with VOC limits of authorities having jurisdiction.
2. Adhesives and sealants that are not on the exterior side of weather barrier shall comply with the following limits for VOC content:

   a. Plastic Foam Adhesives: 50 g/L.
   b. Gypsum Board and Panel Adhesives: 50 g/L.
   c. Multipurpose Construction Adhesives: 70 g/L.
   d. Fiberglass Adhesives: 80 g/L.
   e. Single-Ply Roof Membrane Adhesives: 250 g/L.
   f. Single-Ply Roof Membrane Sealants: 450 g/L.
   g. Nonmembrane Roof Sealants: 300 g/L.
   h. Sealant Primers for Nonporous Substrates: 250 g/L.
   i. Sealant Primers for Porous Substrates: 775 g/L.
   j. Other Adhesives and Sealants: 250 g/L.

3. Adhesives and sealants that are not on the exterior side of weather barrier shall comply with the testing and product requirements of the California Department of Public Health's (formerly, the California Department of Health Services') "Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental Chambers."

B. Sheet Flashing: Manufacturer's standard unreinforced TPO sheet flashing, 55 mils (1.4 mm) thick, minimum, of same color as TPO sheet.

C. Bonding Adhesive: Manufacturer's standard, water based.

D. Slip Sheet: Manufacturer's standard, of thickness required for application.

E. Metal Termination Bars: Manufacturer's standard, predrilled stainless-steel or aluminum bars, approximately 1 by 1/8 inch (25 by 3 mm) thick; with anchors.

F. Metal Battens: Manufacturer's standard, aluminum-zinc-alloy-coated or zinc-coated steel sheet, approximately 1 inch wide by 0.05 inch thick (25 mm wide by 1.3 mm thick), prepunched.

G. Fasteners: Factory-coated steel fasteners and metal or plastic plates complying with corrosion-resistance provisions in FM Global 4470, designed for fastening roofing to substrate, and acceptable to roofing system manufacturer.

H. Miscellaneous Accessories: Provide pourable sealers, preformed cone and vent sheet flashings, preformed inside and outside corner sheet flashings, T-joint covers, lap sealants, termination reglets, and other accessories.

2.5 SUBSTRATE BOARDS

~~A. Substrate Board: ASTM C 1396/C 1396M, Type X gypsum board, 5/8 inch (16 mm) thick.~~

A. Substrate Board: ASTM C 1177M, glass-mat, water-resistant gypsum substrate, Type X, 5/8 inch (16 mm) thick. Paper-faced substrate boards are not permitted.

1. Products: Subject to compliance with requirements, provide one of the following:

a. Georgia-Pacific Corporation: Dens Deck or approved comparable product.

B. Fasteners: Factory-coated steel fasteners and metal or plastic plates complying with corrosion-resistance provisions in FM Global 4470, designed for fastening substrate board to roof deck.

2.6 VAPOR RETARDER

~~A. Polyethylene Film: ASTM D 4397, 6 mils (0.15 mm) thick, minimum, with maximum permeance rating of 0.13 perm (7.5 ng/Pa x s x sq. m).~~

~~1. Tape: Pressure-sensitive tape of type recommended by vapor-retarder manufacturer for sealing joints and penetrations in vapor retarder.~~
~~2. Adhesive: Manufacturer's standard lap adhesive, FM Global approved for vapor-retarder application.~~

A. Self-Adhering Sheet Membrane: ASTM D5147, minimum of 30 mil – thick sheet, SBS modified bitumen adhesive, factory – laminated to a tri-laminate woven, high density polyethylene top surface, polymeric release liner protects the adhesive; Firestone Building Products; V-Force Item Number W56358900V or approved comparable product.

1. Attach to substrate board. See ***C-RFI-0406-00*** for modification.

2.7 ROOF INSULATION

A. General: Preformed roof insulation boards manufactured by TPO roofing manufacturer, selected from manufacturer's standard sizes suitable for application, of thicknesses indicated and that produce FM Global-approved roof insulation.

B. Polyisocyanurate Board Insulation: ASTM C 1289, Type II, Class 1, Grade 2, felt or glass-fiber mat facer on both major surfaces.

1. Base layer: 3 inches thick.
2. Top layer: 3 inches thick.
3. Total R-Value: 37 for 6 inch total thickness.

C. Provide preformed saddles, crickets, tapered edge strips, and other insulation shapes where indicated for sloping to drain. Fabricate to slopes indicated.

2.8 INSULATION ACCESSORIES

A. General: Roof insulation accessories recommended by insulation manufacturer for intended use and compatibility with roofing.

B. Fasteners: Factory-coated steel fasteners and metal or plastic plates complying with corrosion-resistance provisions in FM Global 4470, designed for fastening roof insulation and cover boards to substrate, and acceptable to roofing system manufacturer.

C. Insulation Adhesive: Insulation manufacturer's recommended adhesive formulated to attach roof insulation to substrate or to another insulation layer as follows:

1. Full-spread spray-applied, low-rise, two-component urethane adhesive.

~~D. Cover Board: DOC PS 2, Exposure 1, oriented strand board, 7/16 inch (11 mm) thick.~~

2.9 ASPHALT MATERIALS

A. Roofing Asphalt: ASTM D 312, Type III or Type IV.

B. Asphalt Primer: ASTM D 41/D 41M.

2.10 WALKWAYS

A. Flexible Walkways: Factory-formed, nonporous, heavy-duty, slip-resisting, surface-textured walkway pads or rolls, approximately 3/16 inch (5 mm) thick and acceptable to roofing system manufacturer.

PART 3 - EXECUTION

3.1 EXAMINATION

A. Examine substrates, areas, and conditions, with Installer present, for compliance with requirements and other conditions affecting performance of the Work:

1. Verify that roof openings and penetrations are in place, curbs are set and braced, and roof-drain bodies are securely clamped in place.
2. Verify that wood blocking, curbs, and nailers are securely anchored to roof deck at penetrations and terminations and that nailers match thicknesses of insulation.
3. Verify that surface plane flatness and fastening of steel roof deck complies with requirements in Section 053100 "Steel Decking."
4. Verify that minimum concrete drying period recommended by roofing system manufacturer has passed.
5. Verify that concrete substrate is visibly dry and free of moisture. Test for capillary moisture by plastic sheet method according to ASTM D 4263.
6. Verify that concrete-curing compounds that will impair adhesion of roofing components to roof deck have been removed.

B. Proceed with installation only after unsatisfactory conditions have been corrected.

3.2 PREPARATION

A. Clean substrate of dust, debris, moisture, and other substances detrimental to roofing installation according to roofing system manufacturer's written instructions. Remove sharp projections.

B. Prevent materials from entering and clogging roof drains and conductors and from spilling or migrating onto surfaces of other construction. Remove roof-drain plugs when no work is taking place or when rain is forecast.

C. Install insulation strips according to acoustical roof deck manufacturer's written instructions.

3.3 ROOFING INSTALLATION, GENERAL

A. Install roofing system according to roofing system manufacturer's written instructions.

B. Complete terminations and base flashings and provide temporary seals to prevent water from entering completed sections of roofing system at the end of the workday or when rain is forecast. Remove and discard temporary seals before beginning work on adjoining roofing.

3.4 SUBSTRATE BOARD INSTALLATION

A. Install substrate board with long joints in continuous straight lines, perpendicular to roof slopes with end joints staggered between rows. Tightly butt substrate boards together.

1. Fasten substrate board to top flanges of steel deck according to recommendations in FM Global's "RoofNav" and FM Global Loss Prevention Data Sheet 1-29 for specified Windstorm Resistance Classification.
2. Fasten substrate board to top flanges of steel deck to resist uplift pressure at corners, perimeter, and field of roof according to roofing system manufacturers' written instructions.

3.5 VAPOR-RETARDER INSTALLATION

~~A. Polyethylene Film: Loosely lay polyethylene-film vapor retarder in a single layer over area to receive vapor retarder, side and end lapping each sheet a minimum of 2 inches (50 mm) and 6 inches (150 mm), respectively. Continuously seal side and end laps with adhesive.~~

~~B. Completely seal vapor retarder at terminations, obstructions, and penetrations to prevent air movement into roofing system.~~

A. Install adhesive-backed vapor retarder in a single layer over area to receive vapor retarder, side and end lapping each sheet a minimum of 2 inches (50 mm) and 6 inches (150 mm), respectively, in accordance with manufacturer’s printed instructions.

3.6 INSULATION INSTALLATION

A. Coordinate installing roofing system components so insulation is not exposed to precipitation or left exposed at the end of the workday.

B. Comply with roofing system and insulation manufacturer's written instructions for installing roof insulation.

C. Install insulation under area of roofing to achieve required thickness. Where overall insulation thickness is 2.7 inches (68 mm) or greater, install two or more layers with joints of each succeeding layer staggered from joints of previous layer a minimum of 6 inches (150 mm) in each direction.

1. Where installing composite and noncomposite insulation in two or more layers, install noncomposite board insulation for bottom layer and intermediate layers, if applicable, and install composite board insulation for top layer.

D. Trim surface of insulation where necessary at roof drains so completed surface is flush and does not restrict flow of water.

E. Install insulation with long joints of insulation in a continuous straight line with end joints staggered between rows, abutting edges and ends between boards. Fill gaps exceeding 1/4 inch (6 mm) with insulation.

1. Cut and fit insulation within 1/4 inch (6 mm) of nailers, projections, and penetrations.

See ***C-RFI-0406-00*** for modification.

F. Mechanically Fastened and Adhered Insulation: Install each layer of insulation to deck using mechanical fasteners specifically designed and sized for fastening specified board-type roof insulation to deck type.

1. Fasten first layer of insulation according to requirements in FM Global's "RoofNav" for specified Windstorm Resistance Classification.
2. Fasten first layer of insulation to resist uplift pressure at corners, perimeter, and field of roof.
3. Set each subsequent layer of insulation in a solid mopping of hot roofing asphalt, applied within plus or minus 25 deg F (14 deg C) of equiviscous temperature.
4. Set each subsequent layer of insulation in ribbons of bead-applied insulation adhesive, firmly pressing and maintaining insulation in place.
5. Set each subsequent layer of insulation in a uniform coverage of full-spread insulation adhesive, firmly pressing and maintaining insulation in place.

~~G. Loosely Laid Insulation: Loosely lay insulation units over substrate.~~

~~H. Install cover boards over insulation with long joints in continuous straight lines with end joints staggered between rows. Offset joints of insulation below a minimum of 6 inches (150 mm) in each direction. Loosely butt cover boards together and fasten to roof deck.~~

~~1. Fasten cover boards according to requirements in FM Global's "RoofNav" for specified Windstorm Resistance Classification.~~
~~2. Fasten cover boards to resist uplift pressure at corners, perimeter, and field of roof.~~

3.7 ADHERED ROOFING INSTALLATION

A. Adhere roofing over area to receive roofing according to roofing system manufacturer's written instructions. Unroll roofing and allow to relax before retaining.

B. Start installation of roofing in presence of roofing system manufacturer's technical personnel.

C. Accurately align roofing, and maintain uniform side and end laps of minimum dimensions required by manufacturer. Stagger end laps.

D. Bonding Adhesive: Apply to substrate and underside of roofing at rate required by manufacturer, and allow to partially dry before installing roofing. Do not apply to splice area of roofing.

E. In addition to adhering, mechanically fasten roofing securely at terminations, penetrations, and perimeter of roofing.

F. Apply roofing with side laps shingled with slope of roof deck where possible.

G. Seams: Clean seam areas, overlap roofing, and hot-air weld side and end laps of roofing and sheet flashings according to manufacturer's written instructions, to ensure a watertight seam installation.

1. Test lap edges with probe to verify seam weld continuity. Apply lap sealant to seal cut edges of sheet.
2. Verify field strength of seams a minimum of twice daily, and repair seam sample areas.
3. Repair tears, voids, and lapped seams in roofing that do not comply with requirements.

H. Spread sealant bed over deck-drain flange at roof drains, and securely seal roofing in place with clamping ring.

3.8 BASE FLASHING INSTALLATION

A. Install sheet flashings and preformed flashing accessories, and adhere to substrates according to roofing system manufacturer's written instructions.

B. Apply bonding adhesive to substrate and underside of sheet flashing at required rate, and allow to partially dry. Do not apply to seam area of flashing.

C. Flash penetrations and field-formed inside and outside corners with cured or uncured sheet flashing.

D. Clean seam areas, overlap, and firmly roll sheet flashings into the adhesive. Hot-air weld side and end laps to ensure a watertight seam installation.

E. Terminate and seal top of sheet flashings and mechanically anchor to substrate through termination bars.

3.9 WALKWAY INSTALLATION

A. Flexible Walkways: Install walkway products in locations indicated. Heat weld to substrate or adhere walkway products to substrate with compatible adhesive according to roofing system manufacturer's written instructions.

B. Roof-Paver Walkways: Install walkway roof pavers according to manufacturer's written instructions in locations indicated, to form walkways. Leave 3 inches (75 mm) of space between adjacent roof pavers.

3.10 FIELD QUALITY CONTROL

A. Testing Agency: Owner will engage a qualified testing agency to inspect substrate conditions, surface preparation, membrane application, flashings, protection, and drainage components, and to furnish reports to Architect.

1. Electric Field Vector Mapping (EFVM): Testing agency shall survey entire roof area for potential leaks using electric field vector mapping (EFVM).

***C-RFI-0406-00*:** Owner has declined EFVM.

~~B. Flood Testing: Flood test each roofing area for leaks, according to recommendations in ASTM D 5957, after completing roofing and flashing but before overlying construction is placed. Install temporary containment assemblies, plug or dam drains, and flood with potable water.~~

~~1. Flood to an average depth of 2-1/2 inches (65 mm) with a minimum depth of 1 inch (25 mm) and not exceeding a depth of 4 inches (100 mm). Maintain 2 inches (50 mm) of clearance from top of base flashing.~~
~~2. Flood each area for 48 hours.~~
~~3. After flood testing, repair leaks, repeat flood tests, and make further repairs until roofing and flashing installations are watertight.~~

B. Spray-water Testing: Spray-water test each roofing area for leaks, according to manufacturer's recommendations, after completing roofing and flashing but before overlying construction is placed. Install temporary containment assemblies, plug or dam drains, and spray with potable water.

1. Spray each area for 24 hours.
2. After spray testing, repair leaks, repeat spray tests, and make further repairs until roofing and flashing installations are watertight.

C. Final Roof Inspection: Arrange for roofing system manufacturer's technical personnel to inspect roofing installation on completion.

D. Repair or remove and replace components of roofing system where inspections indicate that they do not comply with specified requirements.

E. Additional testing and inspecting, at Contractor's expense, will be performed to determine if replaced or additional work complies with specified requirements.

3.11 PROTECTING AND CLEANING

A. Protect roofing system from damage and wear during remainder of construction period. When remaining construction does not affect or endanger roofing, inspect roofing for deterioration and damage, describing its nature and extent in a written report, with copies to Architect and Owner.

B. Correct deficiencies in or remove roofing system that does not comply with requirements, repair substrates, and repair or reinstall roofing system to a condition free of damage and deterioration at time of Substantial Completion and according to warranty requirements.

C. Clean overspray and spillage from adjacent construction using cleaning agents and procedures recommended by manufacturer of affected construction.

3.12 ROOFING INSTALLER'S WARRANTY (PROVIDED BY MANUFACTURER)

END OF SECTION 075423

APPENDIX M: DURO-LAST PVC SPECIFICATION GENERATOR PAGES

3-Part Specification
Division 07 54 19 - Polyvinyl-Chloride Roofing

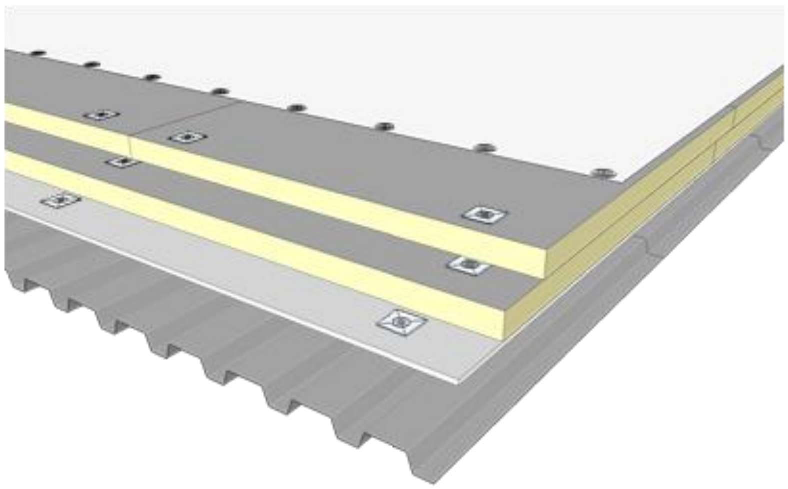
CWNCHS

232 E Fairmount Ave
State College, PA 16801

125,000

Prepared For:

Prepared By: Alec Hanley
PSU



Roof Assembly Description

- **PVC thermoplastic membrane**
  Membrane Thickness: 50 mil
  Color: White
  Attachment: Attached with mechanical fasteners
- **Glass-faced polyisocyanurate (flat)**
  Attachment: Attached with mechanical fasteners
- **Fiberglass-faced roof board**
  Thickness: 5/8 inch
  Attachment: Attached with mechanical fasteners
- **Steel Roof Deck**

PART 1 GENERAL

1.1 SECTION INCLUDES

A. PVC thermoplastic membrane attached with mechanical fasteners.

B. Glass-faced polyisocyanurate (flat), attached with mechanical fasteners.

C. Fiberglass-faced roof board, attached with mechanical fasteners.

D. Prefabricated flashings, corners, parapets, stacks, vents, and related details.

E. Fasteners, adhesives, and other accessories required for a complete roofing installation.

F. Traffic Protection.

1.2 REFERENCES

A. NRCA - The NRCA Roofing and Waterproofing Manual.

B. ASCE 7 - Minimum Design Loads For Buildings And Other Structures.

C. UL - Roofing Materials and Systems Directory, Roofing Systems (TGFU.R10128).

D. ASTM C 1289 - Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board.

E. ASTM D 751 - Standard Test Methods for Coated Fabrics.

F. ASTM D 4434 - Standard Specification for Poly(Vinyl Chloride) Sheet Roofing.

G. ASTM E 108 - Standard Test Methods for Fire Tests of Roof Coverings.

H. ASTM E 119 - Standard Test Methods for Fire Tests of Building Construction and Materials.

1.3 SYSTEM DESCRIPTION

A. General: Provide installed roofing membrane and base flashings that remain watertight; do not permit the passage of water; and resist specified uplift pressures, thermally induced movement, and exposure to weather without failure.

B. Material Compatibility: Provide roofing materials that are compatible with one another under conditions of service and application required, as demonstrated by roofing membrane manufacturer based on testing and field experience.

C. Physical Properties:

1. Roof product must meet the requirements of Type III PVC sheet roofing as defined by ASTM D 4434 and must meet or exceed the following physical properties.
2. Thickness: 50 mil, nominal, in accordance with ASTM D 751.
3. Thickness Over Scrim: ≥ 28 mil in accordance with ASTM D 751.
4. Breaking Strengths: ≥ 390 lbf. (MD) and ≥ 438 lbf. (XMD) in accordance with ASTM D 751, Grab Method.
5. Elongation at Break: ≥ 31% (MD) and ≥ 31% (XMD) in accordance with ASTM D 751, Grab Method.
6. Heat Aging in accordance with ASTM D 3045: 176 °F for 56 days. No sign of cracking, chipping or crazing. (In accordance with ASTM D 4434).

7. Factory Seam Strength: ≥ 417 lbf. in accordance with ASTM D 751, Grab Method.
8. Tearing Strength: ≥ 132 lbf. (MD) and ≥ 163 lbf. (XMD) in accordance with ASTM D 751, Procedure B.
9. Low Temperature Bend (Flexibility): Pass at -40 °F in accordance with ASTM D 2136.
10. Accelerated Weathering: No cracking, checking, crazing, erosion or chalking after 5,000 hours in accordance with ASTM G 154.
11. Linear Dimensional Change: < 0.5% in accordance with ASTM D 1204 at 176 ± 2 °F for 6 hours.
12. Water Absorption: < 1.7% in accordance with ASTM D 570 at 158 °F for 166 hours.
13. Static Puncture Resistance: ≥ 56 lbs. in accordance with ASTM D 5602.
14. Dynamic Puncture Resistance: ≥ 14.7 ft-lbf. in accordance with ASTM D 5635.

D. Cool Roof Rating Council (CRRC):

1. Membrane must be listed on CRRC website.
    a. Initial Solar Reflectance: ≥ 88%
    b. Initial Thermal Emittance: ≥ 87%
    c. Initial Solar Reflective Index (SRI): ≥ 111
    d. 3-Year Aged Solar Reflectance: ≥ 68%
    e. 3-Year Aged Thermal Emittance: ≥ 84%
    f. 3-Year Aged Solar Reflective Index (SRI): ≥ 82

E. Insulation

1. Provide overall thermal resistance for roofing system as follows:
    a. Average R-value: 37.
2. Install using a minimum of two layers.
3. Configuration as indicated on the Drawings.

1.4 SUBMITTALS

A. Submit under provisions of Section 01300.

B. Data sheets on each product to be used, including:

1. Preparation instructions and recommendations.
2. Storage and handling requirements and recommendations.
3. Installation methods.
4. Maintenance requirements.

C. Shop Drawings: Indicate insulation pattern, overall membrane layout, field seam locations, joint or termination detail conditions, and location of fasteners.

D. Verification Samples: For each product specified, two samples, representing actual product, color, and finish.

1. 4 inch by 6 inch sample of roofing membrane, of color specified.
2. 4 inch by 6 inch sample of walkway pad.
3. Termination bar, fascia bar with cover, drip edge and gravel stop if to be used.
4. Each fastener type to be used for installing membrane, insulation/recover board, termination bar and edge details.

E. Installer Certification: Certification from the roofing system manufacturer that Installer is approved, authorized, or licensed by manufacturer to install roofing system.

F. Manufacturer's warranties.

1.5 QUALITY ASSURANCE

A. Perform work in accordance with manufacturer's installation instructions.

B. Manufacturer Qualifications: A manufacturer specializing in the production of PVC membranes systems and utilizing a Quality Control Manual during the production of the membrane roofing system that has been approved by and is inspected by Underwriters Laboratories.

C. Installer Qualifications: Company specializing in installation of roofing systems similar to those specified in this project and approved by the roofing system manufacturer.

D. Source Limitations: Obtain components for membrane roofing system from roofing membrane manufacturer.

E. There shall be no deviations from the roof membrane manufacturer's specifications or the approved shop drawings without the prior written approval of the manufacturer.

1.6 REGULATORY REQUIREMENTS

A. Conform to applicable code for roof assembly wind uplift and fire hazard requirements.

B. Fire Exposure: Provide membrane roofing materials with the following fire-test-response characteristics. Materials shall be identified with appropriate markings of applicable testing and inspecting agency.

1. Exterior Fire-Test Exposure:
   a. Class A; ASTM E 108, for application and roof slopes indicated.
2. Fire-Resistance Ratings: Comply with ASTM E 119 for fire-resistance-rated roof assemblies of which roofing system is a part.
3. Conform to applicable code for roof assembly fire hazard requirements.

C. Wind Uplift:

1. Roofing System Design: Provide a roofing system designed to resist uplift pressures calculated according to the current edition of the ASCE-7 Specification *Minimum Design Loads for Buildings And Other Structures*.

1.7 PRE-INSTALLATION MEETING

A. Convene meeting not less than one week before starting work of this section.

B. Review methods and procedures related to roof deck construction and roofing system including, but not limited to, the following.

1. Meet with Owner, Architect, Owner's insurer if applicable, testing and inspecting agency representative, roofing installer, roofing system manufacturer's representative, deck installer, and installers whose work interfaces with or affects roofing including installers of roof accessories and roof-mounted equipment.
2. Review and finalize construction schedule and verify availability of materials, installer's personnel, equipment, and facilities needed to make progress and avoid delays.
3. Examine deck substrate conditions and finishes for compliance with requirements, including flatness and fastening.
4. Review structural loading limitations of roof deck during and after roofing.
5. Review base flashings, special roofing details, roof drainage, roof penetrations, equipment curbs, and condition of other construction that will affect roofing system.
6. Review governing regulations and requirements for insurance and certificates if applicable.
7. Review temporary protection requirements for roofing system during and after installation.
8. Review roof observation and repair procedures after roofing installation.

1.8 DELIVERY, STORAGE AND HANDLING

A. Deliver roofing materials to Project site in original containers with seals unbroken and labeled with manufacturer's name, product brand name and type, date of manufacture, and directions for storing and mixing with other components.

B. Store liquid materials in their original undamaged containers in a clean, dry, protected location and within the temperature range required by roofing system manufacturer. Protect stored liquid material from direct sunlight.

C. Protect roof insulation materials from physical damage and from deterioration by sunlight, moisture, soiling, and other sources. Store in a dry location. Comply with insulation manufacturer's written instructions for handling, storing, and protecting during installation.

D. Store roof materials and place equipment in a manner to avoid permanent deflection of deck.

E. Store and dispose of solvent-based materials, and materials used with solvent-based materials, in accordance with requirements of local authorities having jurisdiction.

1.9 WARRANTY

A. Contractor's Warranty: The contractor shall warrant the roof application with respect to workmanship and proper application for two (2) years from the effective date of the warranty issued by the manufacturer.

B. Manufacturer's Warranty: Must be no-dollar limit type and provide for completion of repairs, replacement of membrane or total replacement of the roofing system at the then-current material and labor prices throughout the life of the warranty. In addition the warranty must meet the following criteria:

1. Warranty Period: 20 years from date issued by the manufacturer.
2. No exclusion for damage caused by ponding water.
3. No exclusion for damage caused by biological growth.
4. Issued direct from and serviced by the roof membrane manufacturer.

5. Transferable for the full term of the warranty.

PART 2 PRODUCTS

2.1 MANUFACTURER

A. All roofing system components to be provided or approved by roof system manufacturer.

B. Acceptable Manufacturers:

1. Duro-Last, Inc.
2.
3.

2.2 ROOFING SYSTEM COMPONENTS

A. Roofing Membrane: PVC thermoplastic membrane conforming to ASTM D 4434, type III, fabric-reinforced, PVC. Membrane properties as follows:

1. Thickness:
    a. 50 mil.
2. Exposed Face Color:
    a. White.

B. Accessory Materials: Provide accessory materials supplied by or approved for use by roof system manufacturer

1. Sheet Flashing: Manufacturer's standard reinforced PVC sheet flashing.
2. Factory Prefabricated Flashings: manufactured using Manufacturer's PVC membrane.
    a. Stack Flashings.
    b. Curb Flashings.
    c. Inside and Outside Corners.
    d. Membrane Scupper Liners.
3. Sealants and Adhesives: Compatible with roofing system and supplied by roof system manufacturer.
    a. Caulk.
    b. Strip Mastic.
4. Slip Sheet: Compatible with roofing system and supplied by roof system manufacturer.
5. Fasteners and Plates: Factory-coated steel fasteners and metal or plastic plates meeting corrosion-resistance provisions in FMG 4470, designed for fastening membrane and insulation to substrate. Supplied by roof system manufacturer.
    a. #14 Heavy Duty Fasteners.
    b. Steel Membrane Plates.
    c. 3 inch Metal Plates.
6. Termination and Edge Details: Supplied by roof system manufacturer.
    a. Termination Bar.

7. Vinyl Coated Metal: 24 gauge, hot-dipped galvanized, grade 90 metal with a minimum of 17 mil of PVC roofing membrane laminated to one side.
8. Two-Way Roof Vents: Supplied by roof system manufacturer. Install a minimum of 1 vent for each 1,000 ft² (93 m²) of roof area.

C. Substrate Board:

1. Glass-mat-faced, water-resistant gypsum substrate conforming to ASTMC 1177/C 1177M.
    a. 5/8 inch thick.

D. Walkways:

1. Provide non-skid, maintenance-free walkway pads in areas of heavy foot traffic and around mechanical equipment.
    a. Walkway Pad.

2.3 ROOF INSULATION

A. General:

1. Provide preformed roof insulation boards that comply with requirements and referenced standards, as selected from manufacturer's standard sizes.
2. Provide preformed saddles, crickets, and other insulation shapes where indicated for sloping to drain. Fabricate to slopes indicated.

B. Polyisocyanurate Board Insulation: Complying with ASTM C 1289, Type II, felt or glass-fiber mat facer on both major surfaces. Material as supplied by roof system manufacturer.

1. Glass-faced polyisocyanurate (flat).
2. Glass-faced polyisocyanurate (flat).

2.4 ROOF INSULATION ACCESSORIES

A. General: Provide roof insulation accessories approved by the roof membrane manufacturer and as recommended by insulation manufacturer for the intended use.

B. Fasteners: Provide factory-coated steel fasteners and metal or plastic plates meeting corrosion-resistance provisions in FMG 4470, designed for fastening insulation and/or insulation cover boards in conformance to specified design requirements.

PART 3 EXECUTION

3.1 EXAMINATION

A. Verify that the surfaces and site conditions are ready to receive work.

B. Verify that the deck is supported and secured.

C. Verify that the deck is clean and smooth, free of depressions, waves, or projections, and properly sloped to drains, valleys, eaves, scuppers or gutters.

D. Verify that the deck surfaces are dry and free of standing water, ice or snow.

E. Verify that all roof openings or penetrations through the roof are solidly set.

F. If substrate preparation is the responsibility of another contractor, notify Architect of unsatisfactory preparation before proceeding.

3.2 PREPARATION

A. Clean surfaces thoroughly prior to installation.

B. Prepare surfaces using the methods recommended by the manufacturer for achieving the best result for the substrate under the project conditions.

C. Surfaces shall be clean, smooth, free of fins, sharp edges, loose and foreign material, oil, grease, and bitumen.

3.3 INSTALLATION

A. Install insulation in accordance with the roof manufacturer's requirements.

B. Separation Board: Fiberglass-faced roof board.

1. Use only fasteners, stress plates and fastening patterns accepted for use by the roof manufacturer. Fastening patterns must meet applicable design requirements.

    a. Install fasteners in accordance with the roof manufacturer’s requirements. Fasteners that are improperly installed must be replaced or corrected.

    b. Attach boards in parallel courses with end joints staggered 50% and adjacent boards butted together with no gaps greater than ¼ inch.

C. Insulation: Glass-faced polyisocyanurate (flat).

1. Install insulation in accordance with the roof manufacturer’s requirements.

2. Insulation shall be adequately supported to sustain normal foot traffic without damage.

3. Where field trimmed, insulation shall be fitted tightly around roof protrusions with no gaps greater than ¼ inch.

4. No more insulation shall be applied than can be covered with the roof membrane by the end of the day or the onset of inclement weather.

5. If more than one layer of insulation is used, all joints between subsequent layers shall be offset by at least 6 inches.

6. Mechanical Attachment: Use only fasteners, stress plates and fastening patterns accepted for use by the roof manufacturer. Fastening patterns must meet applicable design requirements.

    a. Install fasteners in accordance with the roof manufacturer’s requirements. Fasteners that are improperly installed must be replaced or corrected.

7. Mechanically attach Glass-faced polyisocyanurate (flat) insulation boards in parallel courses with end joints staggered 50% and adjacent boards butted together with no gaps greater than ¼ inch.

D. Roof Membrane: 50 mil, PVC thermoplastic membrane.

1. Use only fasteners, stress plates and fastening patterns accepted for use by the roof manufacturer. Fastening patterns must meet the applicable design requirements.

2. Install fasteners in accordance with the roof manufacturer’s requirements. Fasteners that are improperly installed shall be replaced or corrected.

3. Mechanically fasten membrane to the structural deck utilizing fasteners and fastening patterns that in accordance with the roof manufacturer’s requirements.

4. Cut membrane to fit neatly around all penetrations and roof projections.

5. Unroll roofing membrane and positioned with a minimum 6 inch overlap.

E. Seaming:

1. Weld overlapping sheets together using hot air. Minimum weld width is 1-1/2 inches.
2. Check field welded seams for continuity and integrity and repair all imperfections by the end of each work day.

F. Membrane Termination/Securement: All membrane terminations shall be completed in accordance with the membrane manufacturer's requirements.

1. Provide securement at all membrane terminations at the perimeter of each roof level, roof section, curb flashing, skylight, expansion joint, interior wall, penthouse, and other similar condition.
2. Provide securement at any angle change where the slope or combined slopes exceeds two inches in one horizontal foot.

G. Flashings: Complete all flashings and terminations as indicated on the drawings and in accordance with the membrane manufacturer's requirements.

1. Provide securement at all membrane terminations at the perimeter of each roof level, roof section, curb flashing, skylight, expansion joint, interior wall, penthouse, and other similar condition.
    a. Do not apply flashing over existing thru-wall flashings or weep holes.
    b. Secure flashing on a vertical surface before the seam between the flashing and the main roof sheet is completed.
    c. Extend flashing membrane a minimum of 6 inches (152 mm) onto the main roof sheet beyond the mechanical securement.
    d. Use care to ensure that the flashing does not bridge locations where there is a change in direction (e.g. where the parapet meets the roof deck).
2. Penetrations:
    a. Flash all pipes, supports, soil stacks, cold vents, and other penetrations passing through the roofing membrane as indicated on the Drawings and in accordance with the membrane manufacturer's requirements.
    b. Utilize custom prefabricated flashings supplied by the membrane manufacturer.
    c. Existing Flashings: Remove when necessary to allow new flashing to terminate directly to the penetration.
3. Pipe Clusters and Unusual Shapes:
    a. Clusters of pipes or other penetrations which cannot be sealed with prefabricated membrane flashings shall be sealed by surrounding them with a prefabricated vinyl-coated metal pitch pan and sealant supplied by the membrane manufacturer.
    b. Vinyl-coated metal pitch pans shall be installed, flashed and filled with sealant in accordance with the membrane manufacturer's requirements.
    c. Pitch pans shall not be used where prefabricated or field fabricated flashings are possible.

H. Roof Drains:

1. Coordinate installation of roof drains and vents specified in Section 15146 - Plumbing Specialties.
2. Remove existing flashing and asphalt at existing drains in preparation for sealant and membrane.

3. Provide a smooth clean surface on the mating surface between the clamping ring and the drain base.

I. Edge Details:

1. Provide edge details as indicated on the Drawings. Install in accordance with the membrane manufacturer’s requirements.
2. Join individual sections in accordance with the membrane manufacturer’s requirements.
3. Coordinate installation of metal flashing and counter flashing specified in Section 07620.
4. Manufactured Roof Specialties: Coordinate installation of copings, counter flashing systems, gutters, downspouts, and roof expansion assemblies specified in Section 07710.

J. Walkways:

1. Install walkways in accordance with the membrane manufacturer’s requirements.
2. Provide walkways where indicated on the Drawings.
3. Install walkway pads at roof hatches, access doors, rooftop ladders and all other traffic concentration points regardless of traffic frequency. Provided in areas receiving regular traffic to service rooftop units or where a passageway over the surface is required.
4. Do not install walkways over flashings or field seams until manufacturer’s warranty inspection has been completed.

K. Water cut-offs:

1. Provide water cut-offs on a daily basis at the completion of work and at the onset of inclement weather.
2. Provide water cut-offs to ensure that water does not flow beneath the completed sections of the new roofing system.
3. Remove water cut-offs prior to the resumption of work.
4. The integrity of the water cut-off is the sole responsibility of the roofing contractor.
5. Any membrane contaminated by the cut-off material shall be cleaned or removed.

3.4 FIELD QUALITY CONTROL

A. The membrane manufacturer’s representative shall provide a comprehensive final inspection after completion of the roof system. All application errors shall be addressed and final punch list completed.

3.5 PROTECTION

A. Protect installed roofing products from construction operations until completion of project.

B. Where traffic is anticipated over completed roofing membrane, protect from damage using durable materials that are compatible with membrane.

C. Repair or replace damaged products after work is completed.

END OF SECTION