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Comprehensive Architectural Engineering Senior Project II
Construction Management
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Senior Thesis

Final Report

Abstract: The investigations and recommendations of this report clearly showed potential areas of cost savings, building design and scheduling improvements during the planning and implementation phases of building construction of the LH.O project. In particular, the analyses in the areas of soil remediation, a mechanical redesign, electrical prefabrications, and greater use of BIM showed areas of potential projects improvements and lessons learned for similar projects in the future.

LancasterHistory.org
Lancaster, PA

LancasterHistory.org

Lancaster County's Historical Society & President James Buchanan's Wheatland

PROJECT OVERVIEW

Owner:	LancasterHistory.org
General Contractor:	Benchmark Construction
Architect:	Centerbook Architects
Structural Engineer:	Gibble Norden Champion Brown
Civil Engineer:	David Miller & Associates
MEPF Engineer:	Altieri Sebor Wiebor
Project Cost:	$13.5 Million
Size & Height:	32,068 SF | 34 Feet

ARCHITECTURAL FEATURES

- Saw-tooth roof with 3 clerestory windows
- Brick veneer facade
- Renovation (14,121 SF):
  - Expanded library & reading room
  - Rare book room
- Addition (19,755 SF):
  - Research facilities & archival
  - Exhibition galleries
  - Multi-use educational auditorium.
  - Collection storage & conservation
- LEED Gold Certified rating

MECHANICAL SYSTEM

- DOAP with enthalpy wheel & 3 VAV ACU's
- Natural-gas high efficiency condensing boiler
- Open-loop water to air geothermal system

ELECTRICAL/LIGHTING SYSTEM

- 1600 Amperes 120/240 Delta, 3 phase, 4 wire MDB
- Eleven 120/240V panel boards feeding the buildings systems
- Artificial lights are almost exclusively LEDs or Fluorescents
- Photovoltaic system
- 80kW 100KVA generator

FIRE PROTECTION SYSTEM

- 500 GPM split-case fire pump
- Laser smoke detection w/ wet & dry sprinkler systems

STRUCTURAL SYSTEM

- Cast-in-place concrete column footings, slab on grade and foundation walls
- Precast hollow core plank at ground level
- CMU shear walls
- HSS 12X8X1/2 columns
- W12X16, HSS 12X8X1/2, 16X8X1/2 & 14X6X1/2 beams
- W12X40 girders
- Arced Glulam beams & LVL rafters

DM/A GNCB AltieriSeborWieber LLC BENCHMARK Construction Company, Inc. CENTERBROOK

ERIC R. BUCKWALTER

Construction Management

http://www.engr.psu.edu/ae/thesis/portfolios/2013/erb5074/index.html

Executive Summary:

This report provides detailed overviews of four technical analyses conducted for the LancasterHistory.org project that involved a renovation and addition to the existing Lancaster Historical Society Building located in Lancaster, Pennsylvania. These analyses include a critical industry research topic and demonstrate two breadth areas.

The four technical analyses provided in this report include:

1) A study of soil remediation effects on constructability and schedule
2) A review of whether a conventional mechanical system would be more cost effective than an open-loop geothermal system
3) An examination of whether the application of MEPF prefabrication would increase constructability and shorten the project schedule
4) An analysis of whether a greater use of Building information Modeling could have benefitted the parties during the project

The study of soil remediation is conducted because unsuitable soils caused construction issues and schedule delays early into the project. This analysis includes critical research in the form of a case study to show the importance of a well conducted geotechnical report. Also, it includes a structural breadth regarding subsurface design. The analysis shows that an alternate soil remediation approach is the best resolution.

The second analysis investigates LH.O's potential for a conventional mechanical system to replace its geothermal one, considering value. This is because the geothermal system had not been able to meet performance requirements at the time of the investigation. The analysis includes a mechanical breadth regarding value. The implemented open loop geothermal is found to have a much higher initial cost, but has much lower future annual energy costs.

Application of prefabrication presented an opportunity for LH.O because its MEPF systems are fairly complex. It is discovered that plumbing and electrical systems lend themselves to prefabrication, and it is determined that various electrical assemblies could be prefabricated in order to reduce construction schedule and improve constructability.

The final analysis detailed in this report considers a greater use of BIM on LH.O. This analysis is intended to increase value for the project. A greater use of seven BIM utilizations in pre-construction and in construction is deemed valuable from a cost and constructability standpoint.

Acknowledgements:

This report is done in memory of my Grandfather, Raymond R. Buckwalter, a general contractor who gave me a love of building and a desire to succeed in the construction industry, and in memory of my Great Grandfather, Ivan Buckwalter who served as his construction manager. Together these men built a myriad of large commercial, residential and industrial projects in eastern Pennsylvania from 1952-2000.

Also, I would like to thank my family and friends for their continued support and for always believing in me. To the Penn State faculty, I learned more in my past five years of college than I have my entire life, and I only hope that I can give back to the University as it has given to me. To my peers, I can't believe you all have put up with me for this long, but I appreciate you all putting in the hard work just as I have. We are destined for greatness.

Thank you to all of the industry professionals who have dedicated their time and offered guidance. In particular, thank you to Benchmark Construction, Centerbrook Architects, Advantage Engineers, Altieri Sebor Wieber, DM/A, D.H. Funk & Sons LLC, SP Construction & Design, Gibble Norden Champion Brown.

Last, but certainly not least, thank you Tom and Robin for everything. None of this would be possible without you. Tom, I know Ray would be proud.

Contents:

Project Overview:

Project Description

The LancasterHistory.Org (LH.O) project includes both a renovation and addition to the existing Lancaster Historical Society Building. Additional infrastructure is required, as the organization adjoins with the neighboring Buchanan Estate, forming the Lancaster Campus of History (LCH). The 32,068 square foot project includes 14,121 square feet of renovation work and a 2-story 19,755 square foot addition. The renovation expands the existing library and includes a rare book room. The addition includes research facilities & archive, exhibition galleries, a multi-use educational auditorium, offices and additional space for collection storage & conservation. In addition to expanding infrastructure, LH.O has invested in upgrading various building systems. The upgrade includes complex mechanical & electric systems, reducing its environmental & energy impacts and helping it reach LEED gold certification.

The project is being delivered via a Design-Bid-Build method for $13.5 million, having a 14 month construction schedule. The delivery method is actually more of a Design-Fundraising-Bid-Financing-Build structure, because the building is a cultural one and is funded entirely by private donations and state grants. Project start was October 3, 2011, and substantial completion was reached on November 28, 2012 despite early schedule delays.

Located in Lancaster, Pennsylvania on a ten acre arboretum next to a historical landmark, LH.O inherits various, unavoidable construction concerns associated with the site. In addition, 2011 was one of the wettest years on file for the area (Brandt, 2012). The owner required that its various trees be protected, limiting space for construction amongst other concerns. Also, the LCH contains the Buchanan residence, a designated National Historic Landmark as of 1961. Naturally, this building had to be protected, especially because its museum remained in operation for the duration of construction.

Figure 1 - LH.O East Facade

Client Information

The owner of the project is LancasterHistory.org, which is building the project due to expansion and adjoining of the Lancaster Historical

Society and President James Buchanan's Wheatland for the Lancaster Campus of History. Cost expectations were originally $7.5 million for the entire project, which eventually grew to $13.5 million over time, requiring further donations. The quality of the project is expected to be of the highest caliber, using the latest technology and finest materials. The schedule was originally slotted as November 1st but has since been delayed to mid-January. Safety expectations are high, as the project is pretty straight forward and only two stories.

Project Delivery System

This project is being delivered via a Design-Bid-Build method. However, the structure is actually more of a Design-Fundraising-Bid-Financing-Build structure. The LancasterHistory.org project used this approach because the building is a cultural one and is funded entirely by private donations and state grants.

The owner decided to hire the General Contractor, Architect, Commissioning Agent and Geotechnical Engineer separately because LancasterHistory.org has many donors to answer to and design and the final product are of upmost importance (see Appendix 0.A). This method allows for the owner to have more control over the project, but had potential to go over budget and schedule.

The General Contractor, Benchmark, has been in operation since 1985, and has established itself as the premier construction company in Lancaster, PA. As such, it has many of its own workers on staff but also a good reputation with many local contractors that it can pick from for various tasks. For this project, an Umbrella Bond is used for the company's protection, and subcontractors receive prevailing wage. LancasterHistory.org received public funding.

Staffing Plan

The president of Benchmark Construction at the onset of LH.O construction was Bob Brandt II. Below was the project's CM and Super, who are both involved on several projects at a time. The APM was Ted Miller, who is a PSU AE graduate. He had an AA for documenting and other help. Bill, the Superintendent monitored the Foreman's progress. Jason, the Foreman, managed the carpenters for any given task completed by Benchmark.

Design Overview:

Building Systems Summary

Demolition

1988 Building

Part of the roof on the South West side is to be removed, and the existing truss must be temporarily supported. On the other part of the SW roof, dormers are to be removed and the roof filled and patched and the roof is to be stripped to plywood deck, receiving new underlayment, accessories and shingles.

The exterior wall on the South West side is to be removed down to the first floor slab, salvaging the oval window at its gable. A temporary building enclosure will be provided. The South East wall is to have a new wall opening. The slab on grade at building entrance and adjacent corners is to be removed. The water fountain on ground level is to be protected and retained.

The interior partitions, plumbing fixtures, and casework are to be removed from the ground level and lower level. Compact storage shelves and track on the lower level are to be protected and retained. (See D3.01)

1955 Building

The wall between the mechanical and selected equipment is to be removed from the lower level, and a new opening will be created at the South West exterior wall to connect to the addition. On the ground level, the millwork at door openings is to be salvaged for later use. Existing mechanical chase is to be removed and the floor and ceiling in-filled. Several interior walls are to be removed.

Structural Steel Frame

Renovations require structural steel under the concrete slab at an opening to be drilled in near the North side and by the East Stair opening, both will bear on the existing masonry walls. All beam to column connections are made with high strength bolts, and all connections must resist 50% of the maximum allowable uniform load capacity. The existing roof is to be shored during the demolition of the wall until new supports are in place. Steel lintels exposed to weather are to be hot tip galvanized.

In the roof, W12X16 beams connect the '88 building's W27X84 upturned girder to the addition's W12X40 girders. The addition's roof is comprised of HSS beams of various dimensions and thicknesses that are welded HSS columns as moment connections. The addition roof is comprised of arced glulam structures that are bolted to the columns.

Bracing is required to support concrete, canopy roofing and structural steel until entire integrated supporting structures have been completed and permanent connections to framing are secured. Temporary bracing is needed in formwork for items that are built into concrete or masonry. These are then removed after permanent steel, connections and bracing are in place and secure.

Cast in Place Concrete

The addition required a typical shallow foundation with two long retaining walls. Typical components such as foundation footings, walls, retaining walls, piers, slabs and topping slabs were all cast in place. Exposed concrete retaining walls on the lower level are board-form finished formwork with exterior-grade plywood panels placed horizontally. Cylindrical columns are formed with paper tubes. Rough form finished concrete on footings and slab edges are formed with lumber (dressed on at least two edges and one side). Topping slabs are hydraulic based and are dyed for aesthetic appearance.

Precast Concrete

Hollow core plank is used on the ground level and is tied into the lower level masonry walls with #4 U Bars and grouted.

Mechanical System

There is one large mechanical room and three smaller mechanical rooms. All of the mechanical rooms are located on the lower level of the building.

The primary mechanical system of the building is a 30-35% glycol VAV system, consisting of a direct outside air processor with a mounted humidifier, an enthalpy wheel and a desiccant wheel. It has two primary pumps and two secondary pumps, all located in the second mechanical room. It also has an expansion tank and air separator which are both located in the second mechanical room. A make-up air fan is located in the fire pump room, also on the lower level. Two of the system's three air conditioning units are all located in the large mechanical room and the third is in the third mechanical room. Each AC has its own mounted humidifier. The system's natural-gas high efficiency condensing boiler is located in the second mechanical room.

There is also closed-loop water to air geothermal condenser water system that serves the VAV DOAP and AC units, and its water solution is only 15% glycol. The system's well water loop has two pumps located on the site. It has 2 wells. The well water travels through the system's two heat exchangers, located in mechanical room four, heating or cooling condensed water circuits. The system has nine heat pumps, six in the first mechanical room, two in the third mechanical room and one that is ceiling-hung in the first stairwell. It also has a water-cooled CRC unit which is located in the server room (118). The condenser loop requires two pumps, an air separator and an expansion tank, all located in the second mechanical room.

Electrical System

The existing electrical system consisted of a 120/240, 3 Phase, 4 wire setup. All panels are removed and upgraded. The new system is 1600 Amperes 120/240 Delta, 3 phase, 4 wire, and it has an emergency diesel generator capable of 80kW/100KVA 600 Amperes.

All lighting, receptacles, switches panels, contactors, telephone outlets, data outlets, fire alarm devices and associated conduit wire are stripped from the existing building, except where noted in (DE1.0). Lighting in the lower level of the building consists of fluorescent tube down lighting. Some of the luminaires are hanging and some recessed. Many are motion activated. The ground level of the addition contains the same, but with light sensors that dim bulbs depending on natural ambient light.

Masonry

Masonry walls on the lower level consist of the walls surrounding stairwell one and its adjacent elevator shaft, the wall between the education room and the workroom, and between the staff room and the large mechanical room. Masonry from the elevator shaft carries up to ground level where the only other masonry appears on the south, east and west facades as a load bearing shear wall.

Curtain wall

The main curtain wall system consists of a brick veneer to the CMU exterior walls of the building. Between these two walls is a fluid applied air barrier and rigid insulation. There is also a glass/mahogany curtain wall at addition entrances and at clerestory north elevations. Masonry veneer anchors are located at 16" O.C. vertically and at 24" O.C. horizontally. Angle connections secure the top and bottom of the brick walls and flashing and weep holes will allow breathability and prevent efflorescence.

LEED Gold Certification

The orientation of the building was one of the first steps taken by the architect in reaching Gold status. In addition, the north facing clerestory windows paired with heavily insulated walls allows for a highly efficient building envelope. Wall surface area is minimized by putting the storage and archive areas below grade. The aforementioned mechanical system incorporates ground source heat pumps and a heat recovery unit, which are particularly important since museum require more strict conditioning equipment. The electrical system also incorporates a photovoltaic roof system to reduce energy consumption. Building materials are recycled and sourced locally wherever possible. Also, artificial lights are almost exclusively LEDs or fluorescents.

Project Cost Summary

Using RS means I was able to produce a square foot cost estimate for the LancasterHistory.org building. The design of this building is quite unique, so I combined the properties of several types of projects to get a reasonable estimate quickly. For the substructure, I used an Auditorium type building, for the building shell, I used a Library, and for the interior and services I used a Computer Data Center.

The substructure estimate uses a 24 foot high auditorium as a model. This is because the high ceiling height and material properties are very similar, including the foundations, slab on grade, excavation and basement walls. The shell estimation is based off of a two story library's superstructure, enclosure and roofing. For these structural elements, I multiplied the cost per SF by the addition's gross area, since the renovation will be unchanged for these components.

The interior of the building and the services estimates are based off of a computer data center, since the LancasterHistory.org project contains some serious MEPF equipment, including the heat exchanger, highly amped service panel and dry sprinkler system. Although there is not as much computer equipment as a data center, there is a good amount of historical paintings and artifacts that cannot get wet and must be stored under particular conditions. The renovation is gutted for MEPF, so I included its SF with the additions, minus the demo in finding the SF cost estimate.

Systems Cost Breakdown		
	Cost	Cost/SF
HVAC	$ 1,282,972.00	$ 40.01
Electrical	$ 1,136,206.00	$ 35.43
Concrete	$ 678,564.00	$ 21.16
Wood, Plastics & Composites	$ 461,428.00	$ 14.39
Exterior Improvements	$ 408,325.00	$ 12.73
Finishes	$ 391,524.00	$ 12.21
Masonry	$ 386,225.00	$ 12.04
Metals	$ 297,500.00	$ 9.28
Thermal & Moisture Protection	$ 267,337.00	$ 8.34
Plumbing	$ 169,100.00	$ 5.27
Fire Suppression	$ 104,950.00	$ 3.27

Project Cost Overview		
	Cost	Cost/SF
Construction (CC)	$ 6,290,673.00	$ 196.17
Other	$ 1,610,641.00	$ 50.23
General Conditions	$ 401,566.00	$ 12.52
Existing Conditions	$ 48,525.00	$ 1.51
Utilities	$ 116,455.00	$ 3.63
Bond	$ 56,550.00	$ 1.76
Building Permit	$ 19,241.00	$ 0.60
Change Order s	$ 204,108.00	$ 6.36
Total (TC)	$ 7,901,314.00	$ 246.39

Building Data		
	Gross Area	Footprint Area
Existing Building	15,233 SF	7,435 SF
Demolition	- 1,112 SF	-217 SF
Addition	17,947 SF	9,314 SF
Total	32,068 SF	16,532 SF

General Conditions Estimate

The General Conditions Estimate for the LancasterHistory.org project encompasses project personnel, site expenses and miscellaneous costs for the project (see Table #). The personnel involved in the project include a project manager, assistant project manager, administrative assistant, superintendent and a foreman. Project site expenses are incurred primarily from utilities but also from maintenance, company trucks and dumpsters as well as other areas. These line items are chosen by looking at the project's site plan from Tech Report 1 and from looking at the project schedule. Last, miscellaneous costs are incurred from insurance, bond and permits.

The estimate comes out to over half a million dollars ($576,641). This number was reached using RS Means, combined with information provided by Benchmark Construction. The cost of utilities, bond, permits and the general conditions total cost are known. Means was used to estimate all other costs. These costs were occasionally manipulated within reason to reach the actual general conditions total cost given by Benchmark. By comparing the general conditions cost with the total project cost for the LancasterHistory.org project, it is determined that general conditions account for only six percent (7.5%) of the original schedule.

Table 1 - General Conditions Costs

LINE ITEM	AMNT.	UNIT	RATE	TOTAL COST
PERSONELL				
Project Manager	10	WEEKS	$ 3,200	$ 48,000
Assistant Project Manager	30	WEEKS	$ 2,800	$ 84,000
Administrative Assistant	20	WEEKS	$1,550	$ 31,000
Superintendent	10	WEEKS	$ 3,560	$ 35,600
Foreman	20	WEEKS	$ 2,560	$ 51,200
SITE EXPENSES				
Utilities	1	N/A	N/A	$116,445
Site Maintenance	54	WEEKS	$ 230	$12,420
Dumpsters	30	EACH	$ 400	$12,000
Fencing	30	WEEKS	$ 100	$ 3,000
Company Trucks	54	WEEKS	$ 240	$ 12,960
Drawings & Specifications	1	N/A	N/A	$ 2,500
CPM Schedule	1	N/A	N/A	$ 4,000
Signage	1	N/A	N/A	$ 1,500
Cell Phones	13 (5)	MONTHS	$ 40	$ 2,600
Postage & Shipping	30	WKS	$ 75	$ 2,250
Porta-Johns	8	MONTHS	$ 550	$ 4,400
MISCELLANEOUS				
Insurance	1	%	$ 7,697,206	$ 76,972
Bond	1	N/A	N/A	$ 56,550
Building Permits	1	N/A	N/A	$ 19,241
TOTAL COST				$ 576,641

Construction Overview:

Existing Conditions

The Lancaster Historical Society building is located just off of President Ave in Lancaster, Pennsylvania. Combined with the Buchanan Wheatland properties, to encompass 10 acres of land, the site will pose no restrictions for space. However, there are many trees that are to be protected. The utilities are all already connected to the building except a new water main is added.

Site Layout Planning

Demolition will encompass a large amount of the project, which is why the site construction makes up two whole phases, spanning more time than the actual construction itself. Fences are put up around the site with special netting on the fence where designated trees must be protected at the owner's request. As many trees are kept intact as possible, but some lie directly where the building's addition is constructed and are relocated. This is done in an orderly fashion, as per request of the owner. A new electric line is brought in for site lighting. A new water meter and line are brought into the building to compensate the additions needs. For example, the water sprinkler system requires more pressure and a fire pump. All other utility lines are preexisting. Temporary offices are located catty-corner to the Buchanan carriage house so utilities can easily be tapped into from there.

A major constraint for this project is that the owner required the Wheatland House be operational for the duration of construction. This posed several issues for logistics, safety and productivity. A new ramp is built on the East side of the property for construction traffic to separate the project from the historical landmark. In addition, secondary fence and lock separates the project from the existing facility. Site construction around the carriage house is completed over the duration of building construction, such that it may be conducted at times which minimize facility disturbance. Signage is required to supplement fences and warn pedestrians.

The superstructure is sequenced from north to south during the erection of the steel framing and the masonry shear walls. The crane used for this phase is located on the west end of the project and does pick from trucks parked behind it. Equipment reaches the site from the south east entrance. Scaffolding is sequenced from north to south as well. In fact, the entirety of all tasks is sequenced from north to south as the addition stems out this way from the existing building.

The layout selected by the contractor is sufficient for addressing the projects constraints. Another potential layout for the project would be for the main construction entrance to be in front of the existing building. As such, backfill would go to the south side of the property, and the Wheatland residence would have minimal disturbance, and equipment would be as far from people as possible. However, this is a less likely scenario as the route would go right over utility lines, potentially causing damage. Further, it would be more of an eyesore for traffic and residences along Marietta Pike. I agree with the layout selected by Benchmark.

Local Conditions

In Lancaster County, Pennsylvania, construction is completed usually by subcontractors. For this particular project, construction parking is widely available after demolition. Prior to demolition, a new entrance is paved to support the large loads of equipment. Recycling is done wherever possible, and as much wreckage is reused in the new building as possible. There is a recycling plant less than ten minutes away from the site, where all of the wreckage and waste may be disposed of. All of this is documented per LEED requirement.

According to the geotechnical report, there were two soil samples analyzed in a laboratory. These samples include Elastic Silt with Sand and Silty Sand with Gravel. These soils caused problems for the project due to their expansive nature. This is discussed later. Additionally, a compressive strength couldn't be obtained due to moisture content on several occasions. Rock bins are decided upon to accommodate storm water.

Project Schedule Summary

The LancasterHistory.org project had a somewhat protracted schedule in order to accommodate private fundraising as well as state financing, as it is a cultural building. Benchmark Construction was awarded the LancasterHistory.org project and received notice to proceed on October 3, 2011. Their schedule breakdown consisted of four primary phases, Site construction I & II, Building Construction and Building Commissioning.

The foundation sequence requires approximately 45 days, including temporary shoring, underpinning and demolition of the existing building and construction of footers/piers and foundation walls. While shoring and underpinning the pre-existing continuous footer, existing conditions and dimensions is verified. After demolition is completed, column footers and piers go in, followed by underslab and foundation/shear walls. A foundation drain is then installed and waterproofing is installed before the foundation walls are backfilled.

The structural sequence takes about 60 days, and it includes the steel setting, exterior wall construction and glulam roof installation. During the slab below grade water proofing, the structural steel can be set, followed by precast plank installation. At this point, masonry walls are laid and grouted, while in-wall blocking and the concrete bond beam are installed. Glulam is put in place and secured then Laminated Veneer Lumber, exterior overhang and canopy framing as well. Roof Blocking and sheathing is completed during LVL installation.

Finishes in the building will take the longest time to complete, about 4 months of flooring, carpet and paint. This sequence begins with first level prime and first coat paint, followed by casework, ceramic tile, prime and first coat paint on ground level, resilient flooring, wood panels and trim, concrete stained, carpet and paint (cut and roll final cut).

Overview

The construction schedule for LancasterHistory.org is critical to the project's success, because the owner requires it to be delivered by a certain date. Notice to proceed was received by Benchmark Construction on October 3, 2011, and the project was expected to be complete thirteen months later, by November 1, 2012. This target complete date was not reached due to soil complications. Also, several change orders were requested by the owner. The detailed construction schedule in this report includes delays, and it represents the schedule as implemented by Benchmark. The schedule can be found in Appendix 0.B of this report. It details the duration of the construction, and it includes renovation work as well as construction completed for the addition. Many construction sequences overlap in order to expedite the construction process, and a summary of the construction sequencing can be found on the following page.

Sequencing

To meet the construction completion deadline, many construction sequences overlap, and there is very little float. Essentially, sequencing is completed from north to south for all categories of construction. In this way, the addition extends out from the existing building. Several enclosure activities are conducted at the same time the building structure is sequenced. As such, building Dry-in is scheduled for April 26, 2012. Lower level construction activities are completed at the same time as ground level activities to further expedite the schedule. It can be noted that building commissioning is scheduled to take an unusually large portion of time relative to project duration. It is scheduled to take 97 days, which can be attributed to the complex nature of MEPF elements of the building and the projects goal to reach LEED Gold certification.

LancasterHistory.org Construction Sequences Breakdown			
	Duration	Start	Finish
Preconstruction	15 days	3 October 2011	21 October 2011
Foundation	46 days	18 October 2011	21 December 2011
MEPF	191 days	12 December 2011	10 September 2011
Structure	88 days	12 December 2011	13 April 2012
Enclosure	59 days	6 February 2011	26 April 2012
Exterior	69 days	4 April 2012	11 July 2012
Ground Level	120 days	26 April 2012	15 October 2012
Lower Level	61 days	30 April 2012	25 July 2012
Commissioning	97 days	18 June 2012	1 November 2012

Analysis I* – Study of Soil Remediation Effects on Constructability & Schedule:

*Includes Structural Breadth (see pgs. 28-30 and Appendix 1.E, description on page 155)

Introduction

Problem Identification

Unsuitable soil conditions at LH.O negatively impacted project construction efforts and schedule. Rock-bin and pavement overexcavations were typically required on site to reach Stratum II soils as specified in civil drawings. In addition, soil could no longer be backfilled because of compatibility issues due to moisture content. As a result, CMU exterior wall installation was delayed, and the general contractor's planned dry-in milestone could not be met. Would a different soil remediation tactic improve constructability and shorten project schedule?

Background Research

Based upon conversations with the owner, general contractor, geotechnical engineer, excavation subcontractor and local soils testing agency, various soil remediation methods exist for LancasterHistory.org's problematic geology. All methods for reaching desired soil compaction are described in the project's geotechnical report, dated July 24th 2009. These methods include scarification and windrowing wet soils. An alternate remediation method, not included in the geotechnical report, would be to artificially stabilize Stratum I soil if Stratum II soils are not encountered at grade elevations.

Application Methodology

In conducting research for this technical analysis, the following steps are to be executed:

1) Analyze LH.O engineering design option schedule and constructability for feasibility
   a) Interview the GC project manager, Bob Brandt III, geotechnical engineer, Dan Schauble, and excavation project manager, Brian Ressler, to better understand issues encountered and steps taken
   b) Utilize Engineering Library resources
2) Determine special provisions research and develop structural breadth
   a) Study the construction methods conducted for the implemented soil remediation tactics
   b) Engineer practical designs for problem areas
   c) Evaluate soil remediation tactics using developed geotechnical report

3) Take-off soil quantities and establish estimates and durations for equipment
4) Schedule & Constructability Alterations and Comparison
   a) Develop alternate schedule
   b) Develop site plan
   c) Create a weighted matrix table to determine the best available solution
5) Conduct critical industry issue research
   a) Demonstrate existence of problem in modern construction projects
   b) Utilize Engineering Library resources
   c) Write a critical literature review for the industry
   d) Report geotechnical effects on construction management and project delivery

Preliminary Analysis

An analysis of soil remediation versus other construction options on the basis of schedule and constructability is required. The owner has pondered the very question. Also, Dr. Anumba and the proposal judge panel have expressed interest in this analysis. Research is feasible given the abundance of industry professionals whom are willing to contribute. Walt Schneider an AE alumnus has agreed to offer his professional opinion.

Potential Solutions

Based upon the contract between the owner and the GC, Benchmark was not required to conduct further preliminary geotechnical research. As this is a construction management proposal, only solutions in response to differing soil conditions will be presented; not geotechnical reporting. Potential solutions to unsuitable soils are as follows:

- Soil remediation
  - Excavate expansive soil and replace with non-expansive fill
  - Application of hydrated lime to swelling soil
- Structural redesign
  - Retaining Walls
  - Foundation Walls
- Combination of soil remediation & structural redesign aspects

Expected Outcome

It is anticipated that soil remediation will be the best option to resolve the issue of unsuitable soils, considering schedule and constructability. Specifically, it is anticipated that applying hydrated lime to the soil is most effective, based upon a preliminary conversation with Schneider (2012).

Schedule and Constructability Feasibility Study

Introduction

As in any construction project, delayed tasks tend to have an impact on other trades. In this instance, earth moving quantity changes require additional time and resources, and masonry wall construction is delayed. Benchmark compensated for this by pushing forward renovation activities to maintain a steady workflow, but overall cost associated with unsuitable soils, including schedule delay expenditures, may have been further reduced. To more effectively understand issues at hand, interviews are conducted regarding earthwork site plans and schedule impacts during this construction phase (see Appendix 1.B). Additional resources are also considered.

Interviews

Bob Brandt III, Project Manager, Benchmark Construction

According to Brandt, the soil remediation methods applied on site were sufficient. He cited the project's space limitations. In addition, he verified that the soil stockpile was located to the east of the addition on the site, but noted that it was quickly hauled off due to its unsuitable conditions. He mentioned that there were other activities going on at the time, but could not recall them as it had happened years ago.

Dan Schauble, Principle, Advantage Engineers

Schauble was not present on site for most of the project. Rather, soil testing was conducted by a third party, ECS Mid-Atlantic. Matt Carroll was reached for comment.

Matt Carroll, ECS Mid-Atlantic

When asked about alternate soil remediation methods, Carroll mentioned that a series of test pits along bins could have been conducted, but would generate higher front end costs. He mentioned that soil could be blended effectively in series of 1' to 1.5' deep planes, but that it would take up a great deal of time and space and require expensive equipment.

With regard to project specifics, Carroll recalled that overexcavation at the driveway was associated with moisture content and compaction issues, while overexcavation in rock bins was due to particle size distribution.

Brian Ressler, Project Manager, D.H. Funk & Sons

Brian Ressler provided relevant project details in a phone call. The one excavator used on the project was a Volvo 290 and the one excavator used was a Caterpillar 953C. Two 14 cubic yard capacity trucks were used to haul soils. Additionally, a soil slope of 1.5 to 1 was confirmed, and a soil swell factor of 1.35 was deemed high, so this was changed to 1.2 for soil quantity estimates. It was mentioned that soil windrowing was not feasible given the project's space limitations.

Engineering Resources

In considering an alternate remediation method, the United States Green Building Association website was researched. According to the site, protection of soil stockpile is necessary to prevent loss of soil. Therefore, companies providing plastic and fasteners are researched.

According to company website, Symmloc fasteners can hold plastic soil covers in place with up to 500 lbs. of force and weighs only eight ounces. It is noted that a ninety by 130 foot stockpile can be covered by a crew of three in only 2 hours. This is similar to the stockpile sizes as calculated in *Earthwork Estimates and Durations*, so this is used when figuring time and labor calculations for this remediation, or rather, prevention, approach. Plastic covers are widely available at locations such as Home Depot.

Special Provisions Research

Description

This portion of the analysis includes a study of construction methods conducted for soil remediation tactics in problematic locations, an evaluation of these methods, and proposes alternate methods for soil remediation at LH.O.

Implemented Remediation Methods

Rock Bin 3

According to Change Order Request 11 (see Appendix 1.F), this rock bin required 490 cubic yards of additional excavation to reach stratum II soils as specified in civil drawings. Benchmark decided to over-excavate the soil and replace it with crushed stone.

Building

According to Change Order Request 22B, the building and its retaining wall were backfilled with 412 and 164 cubic yards of crushed stone, respectively. This was done rather than backfilling with remediated soil from the site.

Rock Bin 2

According to Change Order Request 37, this rock bin required 200 cubic yards of additional excavation to reach stratum II soils as specified in civil drawings. In remediating the soil, Benchmark decided to over-excavated soil and replace it with crushed stone.

Pervious Paving to the East of the Addition

According to Change Order Request 11, this area required 550 cubic yards of additional excavation to reach stratum II soils as specified in civil drawings. In remediating the soil, Benchmark decided to load and haul it, replacing it with other soil from the site.

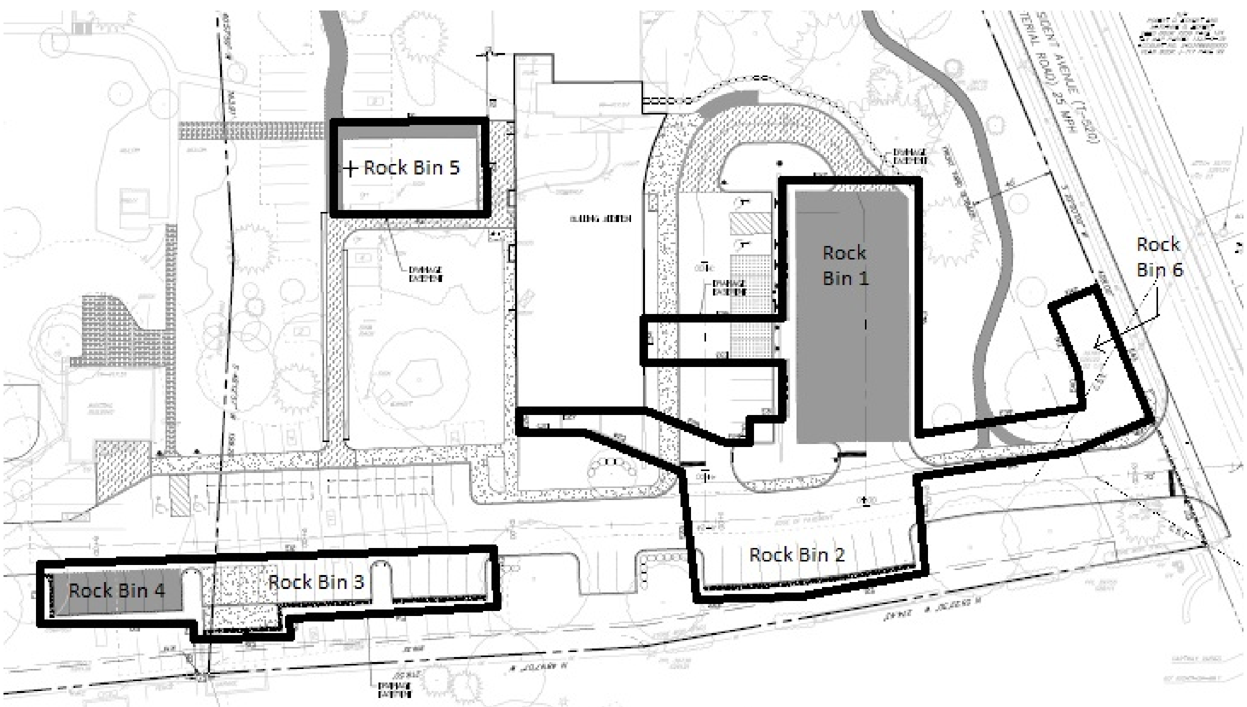

Figure 2: Rock Bin Locations

Engineering Alternate Soil Remediation Methods*

Includes Structural Breadth*

Alternate Soil Remediation Method

Based upon the Geotechnical Report provided by CMX, now Advantage Engineers, many of the soils considered unsuitable for backfill could have potentially been utilized, in that soils deemed unsuitable in one location of the project would have been deemed suitable for other project locations, thus reducing soil hauling on and off site expenses. This section describes feasibility from a geotechnical standpoint by listing known facts, then generating conclusions.

According to the soil testing agency utilized during excavation, ECS Mid-Atlantic (Carroll, 2013):

- Backfill around stormwater infiltration basins, i.e. rock bins, should be more permeable for water
- Stratum II soil has better infiltration than Stratum I, because it is more sandy

According to LH.O Geotechnical Engineering Report, dated July 7th, 2009:

- Exterior backfill around foundations should consist of fine grained on-site residual soils (pg. 7)
- Both Stratum I and Stratum II are considered to be suitable for use as structural fill (pg. 1)
- Stratum I soil has a particle size distribution of 69% fines, while Stratum II has only 55.7% fines (pg.4)
- Stratum II soil has a greater distribution of both sand and gravel than Stratum I (pg. 4)
- Stratum I soil is orange-brown in color, and Stratum I is grey to orange-brown (pg. 5)
- Expeditious backfilling or grading of low-lying areas will help minimize the potential for the development of sinkholes
- Overexcavation/Stabilization in the form of scarifying or windrowing is a remediation option if compaction cannot be reached due to soil moisture content (pg. 8)
- Stratum I soil has a natural moisture content of 26.7%, and Stratum II has a natural moisture content of 17.6% (pg. 5)
- The extent of excavations and the influx of surface water into them should be kept to a minimum (pg. 7)

Conclusions:

1. Stratum I soil should be used for exterior backfill around foundations because of its particle size distribution
2. Stratum II soil should be used for backfill in overexcavated structural areas (pervious pavement & rock bins) because of its particle size distribution
3. Excavated soils should be stockpiled in two separate piles by stratum type, when possible
4. Stockpiles should be covered using polyethylene plastic covers and fasteners to protect excavated soils from rain and reduce erosion
5. All excavations should be completed and backfilled simultaneously where possible to reduce water influx and establish greater bank of stratums to draw from as needed

Foundation & Retaining Wall Re-design (Structural Breadth)

Context

The retaining wall is decidedly not analyzed because it would most likely require FEA model due to its geometric complexities. Therefore, a typical foundation wall is selected for analysis to find whether a different structural design would be a viable option to unsuitable soil backfill. In conducting the structural analysis the wall is first checked for current design, and then the wall is redesigned using different soil loads.

Introduction

The walls are originally designed to account for at rest lateral soil loads of 120 pounds per square foot per foot of depth as indicated in the geotechnical report. Actual field conditions govern, so the fact that the backfilled soil couldn't be compacted properly due to oversaturation means that the walls would have to have been designed for soil pressures that "include the weight of the buoyant soil plus the hydrostatic loads," according to IBC 1610.1. A structural analysis involves checking the current foundation wall design and designing an alternate wall, which accounts for the additional hydrostatic forces associated with improperly compacted (saturated) soil.

Assumptions:

- Using Stratum II soil as backfill
- EFP is 45 pcf active and 100 pcf at rest, based upon IBC

- Unbalanced fill condition is 11.75 feet, measured from center of SOG to center of ground level concrete, so at- rest (100 pcf) would be used, but the geotechnical report governs, and 120 pcf is used
- 3 ksi concrete is used
- 60 ksi steel rebar

Implemented Wall Design

In running calculations for the LH.O foundation wall, the stem is analyzed first. The typical foundation wall stem is one foot four inches thick and has a soil bearing pressure of 1.41 kips per linear foot applied to it. It is found to have a maximum shear force of 5.522 kips and a maximum moment of 12.488 foot kips. Using a conservative wall thickness of 13.75 inches, the reduced shear capacity is found to be 13.6 kips which is greater than the maximum shear force by a safety factor of 2.47. This is very high, which is assumed to be because of the wall ground level connection. Additionally, the curtain wall of bricks on the building façade needs to rest on the edge of the wall and have a gap of air for material breathability.

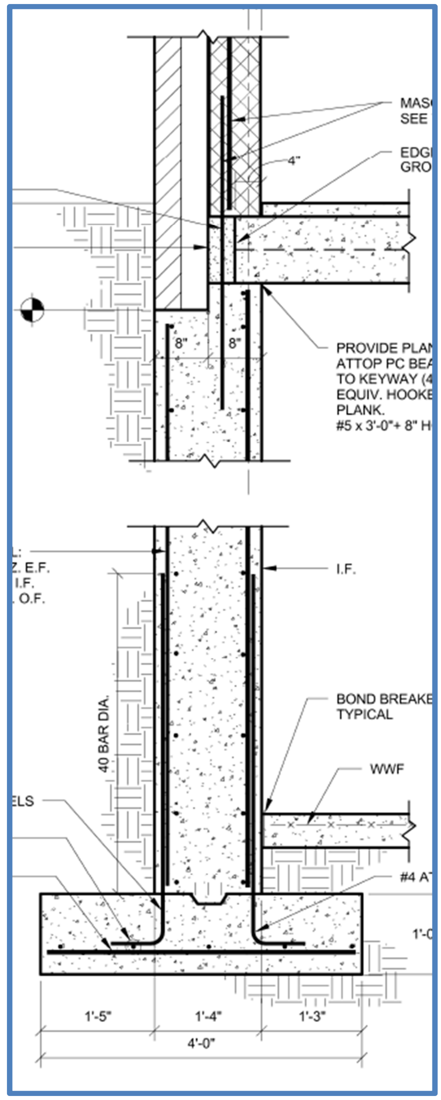

Figure 3 - Typical LH.O Foundation Wall

The rebar in the foundation wall stem is analyzed by determining the depth of the compression block of concrete and bending. This is found to be 0.3044 inches using number five rebar spaced at 18 inches. Afterwards the depth of the neutral axis is found to be 0.385 inches, which is used to find the strain on the steel. The strain on the steel is 0.10414, which is greater than 0.005, so the material factor of safety is 0.9. Using this, the reduced moment capacity for the stem is found to be 12.67 foot kips, which is barely greater than the maximum moment and is acceptable by IBC. The steel to concrete ratio of vertical reinforcement is found to be 0.00125, which is acceptable by ACI-318-11, 14.3.2.a. Additionally, the horizontal rebar is calculated at 0.00208, which passes 14.3.3.a.

The rebar in the toe is checked next, and the maximum moment on the toe is found by using the soil bearing capacity from the LH.O geotechnical report. This moment is determined to be 2.509 foot kips. The depth of the compression block becomes 0.6074, using number five rebar spaced at 9 inches on center per construction drawings. This means that the depth of the neutral axis is 0.7145 inches, and the strain is 0.0335. Again, a material factor of safety is 0.9. The reduced moment capacity is 15.582 foot kips, which greatly exceeds the maximum 2.509 foot kips applied. The spacing is checked for horizontal and longitudinal, and both pass, as they are greater than 0.0018. These calculations can be found in Appendix 1.E.

Alternate Wall Design

The same wall thickness as implemented is used, but the rebar size is reduced to code minimum. The stem's vertical number five bars spaced at 18" become number 4 bars spaced at 12". This reduces the amount of weight of material there is to be used. This change can only be made if the unit weight of soil is 105 pounds per cubic foot. This is anticipated to be the soils unit weight for Stratum II that is 85% compacted. Additionally, the toe's horizontal number five bars spaced 9" become number 4 bars spaced 9", saving a significant amount of material and installation. This alteration can be made regardless of soil compaction. Doing a quick analysis, it is estimated to save 525 pounds of rebar. These structural calculations can be seen in Appendix 1.E.

Conclusions

It is determined that LH.O foundation wall rebar could be downsized in strength if proper soil compaction is not reached. That is assuming soil unit weight is not changed, even. However, the issue at hand associated will improper backfill compaction is not in the designed strength of the foundation walls, it is in protecting the building foundation for longevity. The foundation is the most important part of any building. If soil is not properly compacted, there is potential for the foundation wall concrete to be exposed to vicious freeze-thaw cycles, which can cause cracks and may lead to spalling. Therefore, the initial cost savings associated with reducing reinforcing steel strength, given reduced loading due to improper foundation backfill compaction are irrelevant, because LH.O's foundation must be protected to ensure longevity of the building. However, it is possible that the horizontal rebar in the strip footing's toe could be downsized, saving an estimated 525 pounds of steel.

Excavations and Excavating Equipment

Introduction

To properly examine schedule and constructability issues associated with the various soil remediation approaches, a detailed take-off of earth moving quantities is required for all excavations, including the building, rock bins, and pavements. All calculations are found in Appendix A. Subsequently, estimates and durations are determined. An earthmoving estimate and duration list is established as planned and as performed.

Soil Quantity Take-offs

Building

This involves finding the average elevation within the building footprint areas and finding the volume of soil to be excavated to grade and to footings, considering soil slope. Site elevation within the footprint is estimated with a weighted average of elevations and their respective areas within the footprint. This step can be seen in figure 1. The construction drawings and specifications establish that the lower level slab-on-grade top elevation is 405.57’. The SOG is 5” deep and a 6” layer of stone is specified to go underneath it, so grade elevation is determined to be 404.65’.

The average site elevation within the building footprint between the renovation and the south façade is determined to be 415.14’. Therefore, the average excavation depth of this area is 10.49’. The area of the I grade elevation is determined by taking the building footprint area and adding additional 2’ dimensioning on each side, as specifications require that all stones are removed within this distance of building structure. Then, the volume is calculated to be 3,460 cubic yards, using 10.49’ as the depth.

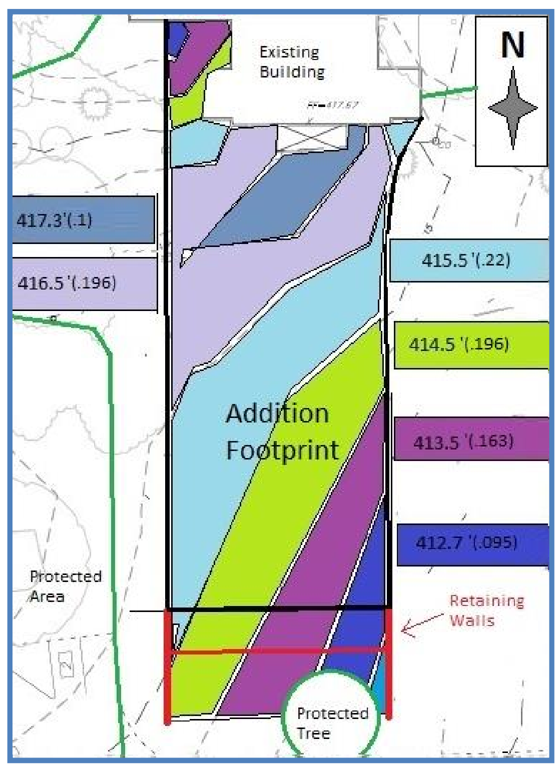

Figure 4: Addition Footprint Elevations

The same steps are conducted to find the volumes of soil to the west of the renovation/addition connection and between the retaining walls on the south side of the building, giving a volume of 163 cubic yards and 423 cubic yards, respectively.

To finalize the amount of earth to be excavated to building grade, volumes are calculated for 1.5:1 soil slopes on each side of the addition. Depths are taken from figure 1. It is assumed that protected tree root area is not encountered as an arborist cleared roots before excavation. Total slope excavations for the building are found to be 1,180 cubic yards.

Rock Bins & Pavement

The same approach to determining soil quantity of rock bins and pavement excavations are used. Dimensions and depths are taken from civil drawings. Calculations and quantities can be found in Appendix A and Appendix B, respectively. See figure 2 for rock bin locations.

Earthmoving Estimates

The soil quantity values found are used to create an Earth Moving Estimate & Duration as originally planned (see Appendix B). Labor unit prices are representative of actual cost data obtained from the excavation subcontractor. Due to the various unsuitable soils conditions encountered, these quantities require modification in accordance with actual project change orders as summarized in *Implemented Remediation Methods*. These modifications are reflected in the *Earth Moving Estimate – As Performed* in the same appendix.

Earthmoving Durations

Trucks

The maximum usable rimpull is equal to the load on drive axels times the coefficient of traction, while the maximum available rimpull is equal to the gross loaded weight times the total travel resistance. Total travel resistance is equal to the percent road grade plus/minus the percent rolling resistance (uphill or downhill). Total cycle time is determined by multiplying maximum speeds by an assumed typical speed factor, which compensates for time spent shifting, accelerating, and stopping.

The coefficient of traction is assumed to be 0.55 dry and 0.5 wet for tires, based off of traction coefficients taken from Estimating Excavation (Burch, 1997). These are averaged together, giving:

$$Coefficient\ of\ Traction = CT = 0.53$$

The trucks are assumed to be tandem axle and weigh 64,000 pounds unloaded. From the geotechnical report, Stratums I and II weigh approximately 120 pounds per cubic foot. Converting that to cubic feet and multiplying by the provided capacity of 12 cubic yards gives a payload capacity of 38,880 pounds. This is added to the unloaded weight, giving a gross loaded weight of 51.44 tons. The load on the drive axles is assumed be seventy five percent of the gross loaded weight, giving:

$$Load\ on\ Drive\ Axles = F = 77{,}160\ lbs.$$

Percent road grade is approximated, using the site topographic drawing (see Figure 3). From the stockpile to the top of rock bin 4 (greatest percent grade is used), there is an elevation change of 18 feet, covering a distance of about 300 feet. This gives a percent road grade of six percent. Rolling Resistance is assumed to be 2.5 percent, which means that total travel resistance is eight and a half percent.

$$Total\ Travel\ Resistance = TR = 8.5\%$$

$$Required\ Rimpull = RP = (102{,}880\ lbs.)(8.5\%) = 8{,}745\ lbs.$$

Based upon similar loading conditions and travel resistance from an example problem by Andres and Smith, maximum loaded speed of 14 mph and a speed factor of 0.66 are assumed (2009), and attainable loaded speed is calculated as follows:

$$Maximum\ Attainable\ Loaded\ Speed = (14\ mph)(.66) = 9.2\ mph$$

Similarly, the maximum unloaded speed downhill is assumed to be 32 mph with a speed factor of 0.75 (Andres & Smith, 2009), but there is assumed to be a maximum downhill speed of 15 mph due to site restrictions. Additionally, it is assumed that the total travel distance is 600 feet, which is measured from the stockpile to rock bin 3. From these, the maximum attainable downhill speed and total cycle time are calculated as follows:

$$Maximum\ Unloaded\ Speed\ Downhill = (15\ mph)(.75) = 11.3\ mph$$

$$Total\ Cycle\ Time = \frac{600\ feet\ round\ trip}{9.2\ mph\ (88\ ft./\ min\ @\ 1\ mph)} + \frac{600\ ft.}{11.3\ mph\ (88)} = 1.34\ min.$$

It is then accounted for that the trucks may have to stop at the flagger when yielding to oncoming traffic or pedestrians, so an additional thirty seconds is added to the cycle time. Additionally, one minute is added for cycle fixed time due to dumping and excavation slopes. This brings each truck's cycle travel time estimate to 2.84 minutes. The efficiency of each truck is assumed to be 45 minutes per hour. These quantities are used to determine the production of each truck.

$$Truck\ Production = \frac{(45\,{}^{min}/_{hour})(0.83\ shrinkage)(14\ CY\ heaped\ capacity)}{2.84\ minute\ cycle\ travel\ time} = 184.1\ CY/hour$$

As a result, the fourteen cubic yard trucks require 8.7 kips of rimpull and have an anticipated production of 195.8 cubic yards per hour for soil, assuming they are not held back from other excavating machinery. Best case scenario, the two trucks will be capable of moving double that if they are in perfect sequence between loading and dumping, which is highly unlikely due to site congestion limitations.

The same steps are conducted to determine the anticipated production of the trucks for soils that are hauled off site. Assumptions are implied in the calculations. The calculations are as follows:

$$Total\ Cycle\ Time = \frac{3\ miles\ round\ trip(5{,}280\ ft/mi)}{(9.2\ mph)(88\ ft./\,min\ @\ 1\ mph)} + \frac{15{,}840\ ft}{[(32\ mph)(0.75)](88)} + 2.84\ min = 34.9\ minutes$$

$$Truck\ Production = \frac{(45\,{}^{min}/_{hour})(0.83\ shrinkage)(14\ CY\ heaped\ capacity)}{34.9\ minute\ cycle\ travel\ time} = 15\ CY/hour$$

The same steps are conducted to determine the anticipated production of the trucks for the production of the trucks for stones that are hauled on site. Factored loaded speed is assumed to be 9.0 miles per hour and stone shrinkage is assumed to have a factor of 0.77. Other assumptions are implied in the calculations. The calculations are as follows:

$$Total\ Cycle\ Time = \frac{15{,}840\ ft}{8\ mph\ (88)} + \frac{15{,}840\ ft.}{[(32\ mph)(0.75)](88)} + 2.84 = 32.8\ min.$$

$$Truck\ Production = \frac{(45\,{}^{min}/_{hour})(0.77\ shrinkage)(14\ CY\ heaped\ capacity)}{32.8\ minute\ cycle\ travel\ time} = 14.8\ CY/hour$$

Excavator

The excavator hourly shovel handling capacity is much simpler to approximate. A chart is provided by Andres & Smith which approximates capacity based upon dipper size and soil type (2009). The dipper size for the EC290 excavator that was used on the project is 1.5 heaped cubic yards. Common earth was assumed for the soil type. This gives an approximate handling capacity of 240 cubic yards per hour.

Loader

The loader hourly shovel handling capacity is also approximated using the chart provided by Andres & Smith which approximates capacity based upon bucket size and soil type (2009). The bucket size for the Caterpillar 953C loader that was used on the project is 2 CY heaped. Common earth was assumed for the soil type. This gives an approximate handling capacity of 300 cubic yards per hour.

Duration Rate Summary

Based upon the production of the trucks and the approximated handling capacities of the excavator and loader, excavation and placement durations can be calculated. It is assumed that the trucks are capable of matching the handling capacities of the excavator and loader at all times, because the two truck's combined productivity is almost 370 cubic yards per hour which leaves enough room for error in keeping up with the loader's 300 cubic yard per hour capacity. Therefore, excavation durations are calculated using the excavator's capacity, and placement durations are calculated using the loader's capacity. These are found to be 0.004167 hours per cubic yard for excavation and 0.003333 hours per cubic yard for soil placement.

In addition, soils being hauled off-site durations are found to be controlled by their respective truck production rates. The 15 cubic yard per hour production rate is doubled giving a duration rate in hours per cubic yard of 0.03333. The same holds true for stones being hauled on-site which gives a production rate of 0.03381 for both trucks. The planned building backfill duration by Benchmark of five days is used to approximate a duration rate of 0.02525 hours per cubic yard for soil. Stone compaction is assumed to take half as much time, less the duration rate for load and haul on site. The shorter placement duration rate is based upon The Soil Compaction Handbook (2011). Therefore, the stone place and compact duration rate becomes 0.01429 cubic yards per hour.

Schedule & Constructability Alterations and Comparison

Description

This section compares the actions taken by Benchmark to remediate soils with various alternatives by cost and logistics and evaluates schedules of the alternatives. It covers the development of various site plans and schedule alterations in attempt to reduce schedule delays, site congestion issues and safety concerns. A weighted matrix table is included for the comparison of the implemented construction schedule versus an alternative schedule and soil remediation approach.

Schedule Adjustments

Based upon the conclusions drawn in *Special Provisions Research*, an alternative schedule is developed. This section shows the original schedule over the period of excavation and explains adjustments made to it.

Implemented Earthmoving Sequence

This schedule covers the time frame from rock bin 3, 4, and 6 excavations to pervious paving – parking, because it encompasses all excavations and backfill where soil remediation could present an issue. This can be seen in Appendix 1.A. Rock bins 3,4 and 6 were constructed first, followed by rock bin 2, then by rock bins 1, 3 and 5 (rock bin 3 is included again as it wasn't finished originally due to soil conditions). Backfill around the building and retaining wall was delayed by over four months of what was originally planned.

Proposed Earthmoving Schedule

It is proposed that all excavations be completed without gaps, so a sequence must be determined to maximize productivity. The sequence should address site congestion and safety concerns. The same basic sequence is followed, but earth moving task durations are longer to account for stockpiling soil and stockpile protection. Duration times are taken from Earth Moving Durations and reflect the representative times accounting for sequence change within each task. The schedule is provided to show the overall effect stockpiling and sorting soil can have. Despite the fact that it takes extra time and labor to do this, it is a preventative measure, based upon the geotechnical report's recommendations and in this case, it would have had great schedule impacts in the long run by avoiding soil testing time and saving time in backfill.

Site Plan Modeling

In attempt to show that the proposed earthmoving schedule is possible, a site plan is developed to demonstrate construction logistics and show how soil quantities can be stored on site, while preventing site congestion and addressing safety standards and considerations associated with the great deal of soil to be moved along multiple paths. This is particularly important, given the neighboring museum and the fact that many of the trees in the region are to be protected.

The construction of rock bins 3, 4 and 6 is chosen to model as a site plan because it is at this time that the most soils will have been excavated and stockpiled based upon the developed estimates and alternative schedule. Under this method, soil is stored in the same location but is kept there for much longer, and ruck and loader traffic often will coincide. Therefore it is recommended that a flagger be present on the construction site at the times of deliveries to coordinate trucks and machinery, making sure they do not get too close to the edge of excavations. A fence is installed at the museum to ensure that civilians are not entering the construction zone at any time. Additionally, proper signage is required to remind equipment operators to follow safety guidelines established as to minimize risk. The soil stockpiles are scaled to represent the amounts in the soil take off. It shows that the soil quantities are able to fit in the space. Note that stratum II is located closer to the rock bins, as this soil will be backfilled into those areas as needed. The stratum I soil is located out of the way, because it will be used for backfilling the building foundation.

Weighted Matrix Table

Assigning Weight

A weighted matrix table is provided to analyze approaches to dealing with unsuitable soil conditions. The approaches are ranked on a scale of one to ten, ten being most desirable and one being least, in categories of cost, schedule, site congestion, and safety. Because this is an analysis of constructability and schedule impacts, cost will be considered the least and given a weight of twenty five percent. Schedule is most important because of strict owner deadlines, so this will be given a weight of one hundred fifty percent. Of all constructability concerns, safety should always be considered top priority, so this will be given a weight of one hundred twenty five percent. This leaves site congestion to have a scale of one hundred percent.

Rating Justification

The implemented schedule and method of soil remediation has desirability in that it minimizes site congestion, and it improves safety. Additionally, it saves time required for loading soils, but requires additional time if soils from the site are backfilled and cannot be compacted properly. Cost will invariably go up as more soils are deported and imported from the site. As such, schedule receives a three, safety receives a six, site congestion receives an eight, and cost receives a six for this method.

The alternative soil remediation method of sorting soils and covering them every day is desirable in that it minimizes chance of encountering compaction issues, which could save schedule and cost in the long run. Front loading costs are taken into consideration because of additional labor associated with a flagger, sorting time and covering time. This is reflected giving the alternate remediation method a four for cost. Safety and site congestion issues arise, as more soil is being transported about the site, so these areas receive ratings of five each. Schedule is a hard area to rank, as it is not known whether it would have been reduced during planning, but based upon the geotechnical report, schedule is given a seven.

Table 2: Weighted Matrix - Soil Remediation

	Schedule	Safety	Site Congestion	Cost	Mean Value
Implemented Method	3	6	8	5	5.5
Alternative Method	7	5	5	4	5.25
Assigned Weight	150%	125%	100%	25%	100%
Weighted Implemented	4.5	7.5	8	1.25	**5.31**
Weighted Alternative	10.5	6.25	5	1	**5.69**

Critical Industry Issue Research

Introduction

A comprehensive geotechnical report can improve a project's constructability and shorten its schedule, depending on geographical location. Not all subsurface concerns can be realized from a report, but an effectively managed investigation and evaluation improves the odds. This could be the case for LH.O, given Lancaster's karst geology. In fact, overexcavation was often required on the project, and multiple sinkholes were encountered when drilling for the geothermal system during construction.

LH.O geothermal constructability could have improved with an enhanced geotechnical report, because rock bins and mechanical system designs could have been engineered differently ahead of time, and mechanical design changes could have potentially been avoided. However, site congestion issues and safety concerns associated with deeper excavations and system installation delays arose, so critical industry research is required to demonstrate the importance of a well conducted geotechnical report.

Preliminary Analysis

Given the potential benefits of reduced construction schedule and improved constructability, the importance of an enhanced geotechnical report will be further researched in providing critical industry issue research. The research will be aimed at whether a contractor should recommend further investigation, considering contract type. Research should also determine the impacts placed on a project's schedule and constructability, when incorporating additional, pre-construction tests and analysis of soil conditions. The goal will be to determine to what extent supplemental geotechnical information is effective, regardless of responsibility. The study should be interesting because many projects could potentially benefit from additional subsurface research and planning.

Presence of Soil Problems in the Construction Industry

Crystal Bridges Museum of American Art

It is beneficial to examine other projects with similar issues. In the case of the Crystal Bridges Museum of American Art building project, terrain, drainage, service-placement, soil and time issues seemed potentially devastating to its construction. Yet, monumental preconstruction efforts and extremely skilled management allowed for the museum's timely and on-budget completion (no matter how exorbitant its funding).

The plans for the building entailed a 201,000 square-feet of indoor space built in a blasted-out ravine set in the owner's 120 acre property in northwest Arkansas. Following LNJV's selection and funding as the project's construction team, geotechnical experts had to investigate, sample and test the soil. A site evaluation was also conducted, including a topographic survey for grades. Said subsurface and surface evaluations make up what's called the primary investigation, used to establish parameters in design. Drainage, landscape, placement of services, fill/excavation quantities are all to be considered. However, the article, "Constructing a Curvy Museum in an Arkansas Ravine" leads one to question the focus and/or extent of LNJV's primary and even secondary investigations.

While logistical battles were apparent, including a 120 foot drop separating the construction-trailers/equipment and the site, less obvious obstacles, some that might have been avoided, plagued the project. One example is the fissuring of subsurface limestone, which occurred as foundation footings went in. Of course, micropiles replaced them, but seven months were lost and costs were accumulated during said time. Further soil testing should have been completed prior to laying, using geophysical instruments and cross-hole logging.

Pegula Ice Arena

The Pegula Ice Arena project encountered problematic soils underneath its foundation as well. As a result, structure foundation was changed, causing great schedule delays and exorbitant costs. Structure foundation had to be changed as bedrock was lower than expected. This can most likely be attributed to the fact that ground penetrating radar was used in lieu of test borings in certain areas.

Engineering Library Resources

Using Penn State's the CAT, several journal articles are selected for literature review. Articles are selected in attempt to demonstrate the importance of understanding geotechnical liability implications, and to determine which soil stabilization methods are the best options for structural grades, based solely upon their effects on soil property changes. The articles included are:

1. Geotechnical Baselines: Professional Liability Implications
2. Stabilization of expansive soils for use in construction
3. Impact of cyclic wetting-drying on swelling behavior of lime-stabilized soil
4. Impact of wetting-drying cycles on swelling behavior of clayey soils modified by silica fume

Critical Literature Review

Liability

According to Hatem, geotechnical baselines are used "to establish a contractual statement of the geotechnical conditions anticipated to be encountered during underground and subsurface construction" (1998). When interpreting this data, it is important to understand the difference between geotechnical data and the baseline approach. This is because the exact same geotechnical data could result in materially different baselines, and contract determines whether geotechnical physical conditions are indicated explicitly or implicitly. The owner's degree of risk or tolerance to soil adversity is the driving factor in reporting precision due to thoroughness of testing. Regardless, subsurface condition issues in construction tend to have some of the largest cost and schedule impacts on a project (Schauble, 2013), and can lead to claims by the general contractor or by the owner. Liability depends on the data reported, diction used in reporting, and interpretation of diction.

Soil Stabilization Effects at Structural Grade

Expansive soils can cause great economic losses by damaging infrastructure, so it is important that it be taken care of during construction. There are many methods utilized in soil remediation, but this section considers soil stabilization.

Soil stabilization is defined as mixing additives in with unsuitable soils in order to change the properties of those soils. For expansive clay soils that are oversaturated, options include lime, fly ash or cement (Seco, 2010). It is determined that lime stabilized expansive clayey soil must not be used at the regions where wetting and drying cycles are significantly effective (Guney, et. Al., 2005). It was found that silica fume can help with the reduced stabilization due to wetting and drying (Kalkan, 2010).

Recommendations

Based upon the findings in the literature, it is not recommended that soil be stabilized at LancasterHistory.org. This is because the area is particularly wet. For greater understanding, concrete stabilization should also be studied. Additionally, it is not the contractor's responsibility in the case of the LancasterHistory.org project to further notify the owner, nor is the geotechnical engineer liable, because the geotechnical engineer stated various observations implicitly due to the owner's level of risk assumed.

Geotechnical Effects on Construction Management & Project Delivery

While many entities involved in the construction of LH.O were negatively impacted by subsurface conditions, these conditions cannot be determined fully until the actual work is done. It is debatable whether further testing would have reduced excavation schedule, but it would have most likely allowed for a mechanical redesign earlier on, had a deeper drill been conducted for the geotechnical report.

Summary

The planned site construction schedule for LH.O was delayed by approximately four months due to unsuitable soil conditions. This time could have been greatly abbreviated, had soil not been backfilled and re-dug up various times due to compaction issues. It is found that rock bin 2 and the driveway were the two biggest issues for LH.O.

Other construction projects such as the Crystal Bridge Museum and the Pegula Ice Arena also faced devastating schedule impacts due to site conditions. The result of these projects delays was to either bring in further management and to eat the costs. These problems and LH.Os could have potentially been avoided, but the responsibility lies within the owner's hand, whether it is to take the risk of future costs associated with soil problems. The construction manager's job is to interpret the geotechnical report provided to them, and be able to justify actions if the geotechnical diction is implied.

Recommendations

It is recommended that construction managers attempt to make the owner aware during bidding if geotechnical investigations should be more comprehensive. This way, construction companies can save themselves time spent on projects and invest in other projects, if geotechnical scheduling problems are deemed likely.

Conclusions & Recommendations

The findings of this analysis are that structural redesign or soil stabilization are not advisable for soil remediation. Both are highly impractical from constructability, cost and schedule standpoints, and have minimal added benefit. Rather, it is suggested that soil be sorted by stratum and covered with plastic to protect it from rain. Additionally, Stratum I should be backfilled for the building, whereas Stratum II should be backfilled in rock bins where overexcavation is required due to its particle size distribution. This method has the potential to save **$72,446.64** cost savings and **13 days labor** duration savings. It is recommended that a flagger be required on site for the heavy construction equipment congestion to improve flow and productivity, while ensuring safety. Further, by downsizing the number five rebar in the strip footings to number four rebar, an estimated 525 pounds of material could be saved.

Analysis II* - Investigation of a Conventional Mechanical System:

*Includes Mechanical Breadth (see pgs. 46-51, description on pg. 155)

Introduction

Problem Identification

Water wells were hit when geothermal wells were drilled at LH.O, requiring additional testing and a mechanical system re-design. The closed-loop system was scrapped because its 26 well loops would have to be encased, estimated to cost an additional $1,000,000 for the project. An open-loop system is currently being tested for, but a practical drilling location remains to be determined. Would a conventional mechanical system be more cost effective to the owner than an open-loop geothermal system?

Background Research

The project's geothermal system could have benefitted from more extensive testing done earlier on, as it is still being tested, even though the building is otherwise complete. However, more extensive testing up front was not done, and costs for the HVAC system keep going up. The original HVAC system estimate was estimated to be $1.3 million in *Technical Analysis 1*, but this number continues to go up for every test drill performed for the geothermal system. HVAC performance is required by the owner, it affects the project's LEED certification, and it impacts the overall value of LH.O. This performance may or may not be realized if another design solution is not implemented (Sarratt, 2012). In performing value engineering, a more conventional mechanical system may be considered to replace the geothermal one.

Application Methodology

In conducting research for this technical analysis, the following steps are to be executed:

1) Analyze LH.O mechanical engineering design value and consider re-design
   a) Interview the project geotechnical engineer, Dan Scheuble, and mechanical engineer, Adam Trojanowski, to better understand steps taken and issues encountered
   b) Interview Moses Ling, a PSU mechanical engineering professor, to get an impartial opinion
   c) Utilize the Engineering Library
2) Conduct a feasibility study of alternate mechanical systems (Mechanical Breadth)

3) Study of Mechanical System Life Cycle Costs
    a) Implemented geothermal system
    b) Evaporative condenser
    c) Closed circuit cooling tower
4) Compare LCC of the geothermal system versus more conventional systems
5) Determine the most valuable mechanical system that meets owner criteria

Preliminary Analysis

Value engineering is a very effective and important tool, especially when performed by the construction industry. Given the cost and performance issues associated with LH.O's mechanical system, it makes sense to consider alternate options. Performance and cost data is available from Centerbrook and Benchmark, which will be considered. Lessons learned from AE 310 and AE 475 regarding HVAC systems and value engineering show that a conventional system is practical. This is corroborated by Brandt and Anumba. A structural option AE has suggested mechanical systems for analysis found below in *Potential Solutions*. The mechanical breadth will be addressed using lessons to be learned in AE 476.

Potential Solutions

In value engineering a conventional mechanical system for LH.O, foreseeable outcomes include the following:

- Closed-loop geothermal system (encase wells)
- Open-loop geothermal with chillers
- Central plant system (cooling tower with chillers)
- Additional AHUs

Expected Outcome

It is anticipated that a central plant system will be most valuable to the LH.O project. This is predicted, given that LH.O geothermal system problems were encountered extremely late in construction. A central plant system can be more easily be designed and incorporated than other options. Its initial cost is predicted to be much lower than the options', lowering its LCC as well. System performance is expected to address owner needs.

Mechanical Design Value Analysis & Redesign Consideration

Engineer Interviews

Dan Schauble Jr., Principal, Advantage Engineers (geotechnical engineering firm)

In this interview, it was expressed that the closed loop system would most likely have been further plagued by sinkholes, but that LH.O's hydrogeological setting was found to be favorable for an open loop geothermal system, based upon the results of a geothermal well field evaluation. This document was then acquired for the sake of this report. As, mentioned in the project geotechnical report, Pennsylvania is typically a region of karst geology. Schauble clarified in the phone call that this geology has been karst for a long time, and that the effects of sinkholes are accelerated by water and drilling. The fact that any sinkholes were encountered is enough to reconsider the system*. Though not in the scope of this report, it is this writer's opinion that at least one deep well should have been drilled prior to construction, and that the wells should have been scheduled earlier in construction.

Adam Trojanowski, Project Manager, Altieri Sebor Wieber (MEP engineering firm)

It was discovered that the LH.O project's mechanical system performance would not be affected by the geothermal change, provided that there were positive well field testing results. At the time of the call, the results were pending, and the well field testing results have since proved to be positive at the time of this composition. During the call, it was found that the system was decided upon based off of performance and efficiency requirements by the project owner. These requirements were established to have been met by Trojanowski based upon results from ASW's Trane TRACE model. It was mentioned that a cooling tower would have been more thoroughly considered in the event of unsatisfactory well test results. Design airflow quantities and heating and cooling capacities were acquired for this report. A basis of design report was also provided by Trojanowski.

Moses Ling, Professor, The Pennsylvania State University (Architectural Engineering, Mechanical)

In a meeting with Professor Ling, it was discovered that implementation of a closed loop cooling tower or evaporative cooler would provide the necessary cooling loads in replacing the geothermal system, and that designs would have to be calculated and adjusted based on this condition. . Baltimore Aircoil Company (BAC) was recommended for a company to investigate for equipment sizing. This will be covered in the next section of the analysis. Additionally, it was suggested that Ferguson Township School District's HVAC LCC study be reviewed. This will be covered in *Study of Mechanical Systems' Life Cycle Cost*.

Provided a different system is implemented, it was mentioned by Professor Ling that the boiler would have to be resized to compensate for the geothermal system's heating loads that would be lost. Further, it would be impractical to add additional heat pumps or to resize them, but that if it was not too late, heat pumps could be changed from Ground Source Heat Pump (GSHP) type to Water Source Heat Pump (WSHP) if not too late in construction. This would provide some cost savings and would not have an effect on mechanical performance.

Resource Overview

A book entitled Life Cycle Costing for Facilities was borrowed from Professor Parfitt and will be considered in the LCC portion of this analysis. This book, combined with the recommended case study from Professor Ling, well field evaluation from Schauble, and design reports from Trojanowski are deemed sufficient for analysis resource acquisitions. Information gathered in this portion of the analysis establishes that chillers, closed loop geothermal, and additional AHUs or heat pumps are impractical design options. However, an evaporative cooler or closed loop cooling tower could be considered valuable, requiring further analysis in providing the best system choice for the LancasterHistory.org project.

Feasibility Study of Alternate Mechanical Systems (Mechanical Breadth)

Geothermal Load Determination

In order to design an alternate mechanical system for LH.O, system heating and cooling loads must be calculated. Flow rates and water temperatures are taken from the heat exchanger specifications in the mechanical schedule construction drawings for respective loads (see Table 2). Entering Water Temperature (EWT) and Leaving Water Temperature (LWT) are taken from hot side equipment data, because these numbers represent the building-interior system data. The load calculations are as follows:

Equation 1 - Geothermal Heating Load

$$Q_{heating} = 500(GPM)|EWT - LWT| = 500(145\ GPM)|34°\text{F} - 48°\text{F}| = 1{,}015{,}000\ {}^{BTU}/_{hr}$$

Equation 2 - Geothermal Cooling Load

$$Q_{cooling} = 500(GPM)|EWT - LWT| = 500(115\ GPM)|85.3°\text{F} - 67.3°\text{F}| =$$

$$1{,}035{,}000\ {}^{BTU}/_{hr}\left(12{,}000\frac{tons}{BTU/hr}\right) =$$

$$86.3\ tons$$

Table 3 - Heat Exchanger Specifications

UNIT NO	LOCATION	SYSTEM SERVED	HOT SIDE–COOLING MODE					COLD SIDE–COOLING MODE					HOT SIDE–HEATING MODE				
			EWT	LWT	GPM	PD	FOUL'G	EWT	LWT	GPM	PD	FOUL'G	EWT	LWT	GPM	PD	FOUL'G
HX-1	LOWER LEVEL MECH 4	HEAT PUMP CONDENSER WATER	85.3°F	67.3°F	145	10.7'	.0001	58°F	83.7°F	100	2.29'	.0002	34°F	48°F	115	8.1'	.0001
HX-2	LOWER LEVEL MECH 4	HEAT PUMP CONDENSER WATER	85.3°F	67.3°F	145	10.7'	.0001	58°F	83.7°F	100	2.29'	.0002	34°F	48°F	115	8.1'	.0001

Using the calculated loads, it is possible to design an alternate mechanical system to replace the geothermal system. In doing so, the heating load is used to resize the existing boiler, and the cooling load is used to size an evaporative cooler. A closed-loop cooling tower is an alternate option to the evaporative cooler, and it is sized by a BAC distributer representative. The resized boiler and designed evaporative cooler or closed-loop cooling tower would replace all geothermal system components up to and including the heat exchangers. In addition, the heat pump types would be changed from GSHP to WSHP, but their size would not change.

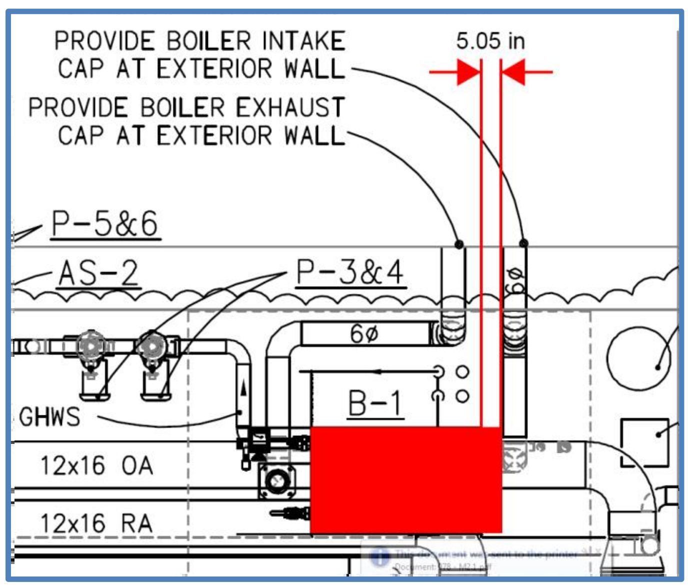

Figure 5 - Boiler Plan

Heating Load - Boiler Resize

To resize the existing boiler, the easiest alteration would be to keep the make the same as the original unit. The boiler make and model implemented at LH.O is an Aerco Modulex MLX-909H. This is a natural gas, high-efficiency condensing boiler with a maximum input of 909,000 BTU/hr., a full-fire efficiency of 92%, and a total turndown of 20:1. The next size up is a MLX-1060 which meets the design heating load calculated above. This model delivers a maximum input of 1,060,000 BTU/hr. by adding an additional thermal module while keeping its efficiency at 92%. Further, it has a total turndown of 23:1.

All other dimensions the same, the MLX-1060 is approximately 5" wider than the existing boiler, and weighs an additional 105 lbs. This could potentially require the boiler intake duct to be rerouted. In addition, its electrical requirement is 4.2 FLA, which is .6 FLA higher than the existing model. This model has the same water connection sizing, but its flow range is different. The 909 has a range of 34-84 GPM, while the 1060 has a flow range of 39-98 GPM. Also, the water volume is up 1.1 gallons.

Cooling Load Option 1 - Evaporative Cooler

In sizing an evaporative cooler to account for the lost cooling loads of the scrapped geothermal system, the make Baltimore Aircoil Company (BAC) will be examined, as recommended by (Ling). The BAC website provides a unit selection document that will be used to adjust the cooling load for sizing (see Table 4). This way, evaporator capacity factor and suction temperature factor effectively correct system tonnage to match the desired cooling performance.

Table 4 - Evaporative Capacity Factors

Condensing Pressure (psig)		Condensing Temp (°F)	Entering Wet-Bulb Temperature (°F)																
R-22	R-134a		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
155.7	95.2	85	0.79	0.82	0.86	0.82	0.95	1.01	1.08	1.16	1.26	1.39	1.55	1.75	2.03	2.44	3.08	—	—

Table 5- Suction Temperature Factors

Suction Temperature (°F)	-20	-10	0	10	20	30	40	50
Capacity Factor	120	1.16	1.13	1.09	1.06	1.03	1.00	0.98

The evaporator capacity factor is determined using entering wet bulb temperature, 74 degrees, and the system condensing temperature, 85 degrees. The condensing temperature is the EWT from the heat exchanger cooling load. The suction temperature factor is determined using a suction temperature of 20 degrees, which is the temperature difference between outside and inside air? The evaporator capacity factor is determined to be 2.03 and the suction temperature factor is determined to be 1.06. The corrected cooling loads are calculated thusly:

Equation 3 - Corrected Evaporator Tons

$$Q_{corrected} = Q_{cooling}(Evaporative\ Capacity\ Factor)(Suction\ Temperature\ Factor) =$$
$$(86.3\ tons)(2.03)(1.06) =$$
$$185.7\ tons$$

This heat rejection load is much higher than the designed load of the geothermal system which shows that an evaporative cooler may not be the most suitable option, but it will still be sized and analyzed. In sizing the system, it is important to go to the next highest size, which is a 195 ton evaporative cooler. The model number for this BAC unit is the CXVB-195-0812-10.

Cooling Load Option 2 – Closed Circuit Cooling Tower

In addition to sizing for an evaporative cooler to be used in the system, a closed circuit cooling tower is sized as an alternate option for system cooling. Because there is not a sizing chart available on the BAC website, a local sales representative is contacted in determining equipment size. Andy Tesorio of the Morin Company LLC in Camp Hill, PA was contacted via phone and e-mail. To help him size a cooling tower, heat pump specifications and system design criteria was provided. The cooling tower model selected by Tesorio is a FXV-0809B-28D-L (see Appendices 2.D-F). This unit provides 112 tons of heat rejection, which seems to be ultimately more efficient than the evaporative cooler model selected at first glance. However, the system is designed to account for 100 degree condensing temperature, which would max out the system pumps and heat pumps. Therefore, further analysis is required. This will be incorporated into the next portion of this investigation in the form of a Life Cycle Cost Comparison (LCCC).

Table 6- Annual Energy Consumption

Utility		Total
Open Loop Geothermal		
Electric		
	On-Pk Cons. (kWh)	198,145
	On-Pk Demand (kW)	87
Gas		
	On-Pk Cons. (therms)	2,505
	On-Pk Demand (therms/hr)	4
Utility		Total
Cooling Tower		
Electric		
	On-Pk Cons. (kWh)	169,699
	On-Pk Demand (kW)	63
Gas		
	On-Pk Cons. (therms)	19,711
	On-Pk Demand (therms/hr)	7
Water		
	Cons. (1000gal)	101

Study of Mechanical System Life Cycle Costs

Introduction

The first step of conducting a LCCC is to determine the initial costs of each of the various systems as designed, with an evaporative cooler, and with a closed circuit cooling tower. The designed geothermal system components are itemized using the mechanical construction drawings, schedules and specifications. The alternate system options are itemized and quantified using the findings in *Mechanical Breadth*.

System Initial Costs

Only the costs of differing mechanical system components are taken off for the comparison.

Geothermal

This system costs an estimated $268,008.40 to implement. This takes various factors of safety into the calculation, as it does not include failed test wells and testing. Additionally the piping is calculated as direct runs from the mechanical room to the wells (see Appendix 2.H). See Appendix 2.A for detailed estimate.

Closed Circuit Cooling Tower

The unit price including shipping is quoted at $74,500; including control panel & freight (see Appendix 2.D). From a recent call with Tesoriero, the estimated lead time is 5-6 weeks. Additionally, it is estimated to require $2,670.00 labor cost. The boiler is estimated to cost $26,900 from RS Means, leaving the total cost of just the mechanical equipment at $104,070. Additional costs bring the system grand total up $30,247.52 for a grand total of $134,317.52.

Energy Consumption

In order to figure out how much energy will be used by each system, Trane TRACE models are created. In creating these models, building architecture is first inputted. This is taken from architectural drawings. Next, each system is inputted using the Trane user's manual, the mechanical drawings for LH.O and from cooling tower and boiler details. Finally, energy usage is calculated, and the results can be seen in Appendix 2.C. Results are summarized in table 6.

Future Annual Energy Costs

To gain a better understanding of how much the systems will differ in cost, energy costs must be taken into consideration. This is effectively done by computing annual energy charges from local providers. Electricity kWh usage is entered into the Pennsylvania Power & Light electric company website and rates are determined for both systems. Gas is assumed to cost 42 cents per therm. Then a table is created taking into consideration future value of energy costs with adjustments for economic inflation and regional energy interest rates (see Appendix 2.C). Results are summarized in figure 6.

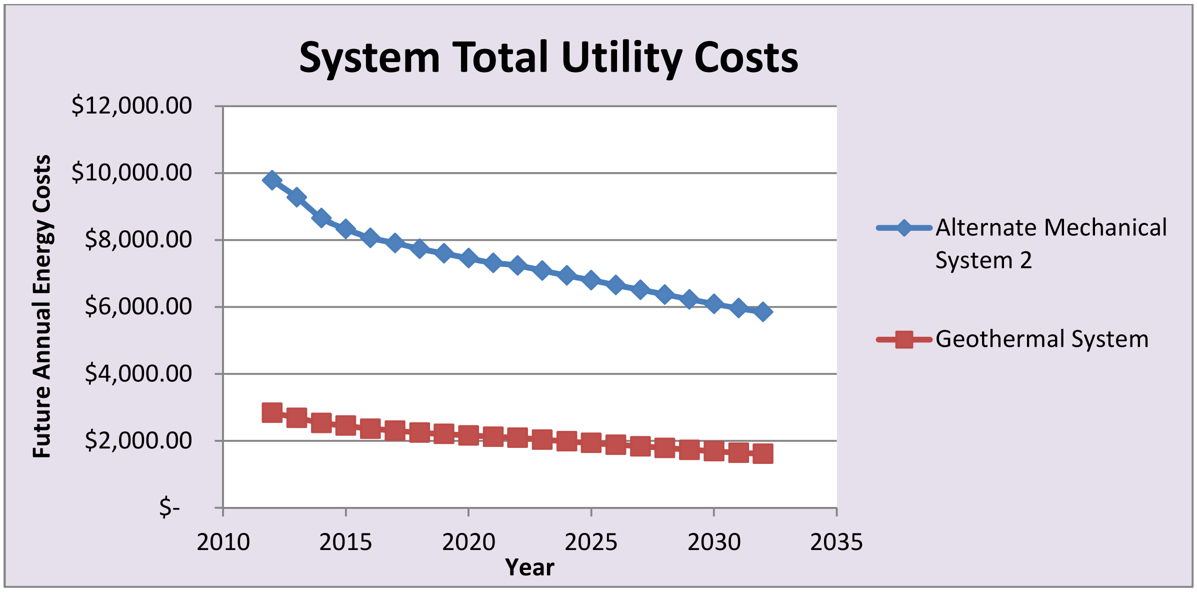

Figure 6 - Annual Energy Costs, Geothermal=Series1, Alternate=Series2

Mechanical System Design Cost Comparison

Based upon the results from the future energy analysis, it is recommended that a payback period comparison be conducted, accounting for system maintenance. The extra initial cost of the geothermal could potentially take a half century to be paid back relative to a more conventional system choice (closed loop cooling tower). However, the associated with installing the Alternate system, speaks loudly.

Conclusions & Recommendations

Assuming the owner is willing to forgo the architectural eyesore that is the 112 ton cooling tower, it is recommended to implement the alternate system instead of an open loop geothermal system, regardless of geothermal system testing. This is because the **$133,690.88** initial cost savings, not including general conditions costs associated with the **10.2 days labor savings.** Therefore, initial savings are anticipated to outweigh the high cost of energy (gas) the boiler would require. Additionally, only one LEED point would be lost by omitting the geothermal wells. A payback period is recommended for a more accurate life cycle cost analysis, assuming the owner is willing to deal with the bulky equipment.

Analysis III – Application of MEPF Prefabrication:

Introduction

Opportunity Identification

LancasterHistory.Org's design includes highly customized MEPF systems, which are fairly complex and time-consuming to install. Further, many aspects of the building are already documented in computer models. Would an application of MEPF prefabrication increase constructability and shorten project schedule for LH.O?

Background Research

Prefabricating MEPF systems can improve system constructability and shorten project schedule, depending on system types and connections. An application of MEPF prefabrication should be analyzed for the LancasterHistory.org project due to its system interactions and complexities. For example, the electric system includes eleven 120/240V panel-boards feeding the building's systems, Lutron light fixtures, and a photovoltaic system. In an interview, Brandt specifically mentioned that the panel boxes for these electrical features could have been prefabricated to facilitate installation and reduce schedule (2012).

Though not addressed in the Brandt interview, aspects of LH.O's mechanical and fire protection systems could have also been prefabricated to this effect, given their relatively complex designs. The mechanical system includes a DOAP with enthalpy wheel and 3 VAV ACU's with humidifiers and dehumidifiers. A computer model has been created for the system, which could be used to facilitate communications with fabricators. Fire protection includes a 500 GPM split-case fire pump, laser smoke detection, both wet and dry sprinkler systems, and a visual display communication system.

Application Methodology

In conducting research for this technical analysis, the following steps are to be executed:

1) Analyze MEPF schedule and constructability
   a) Interview the CM, Bob Brandt III, to gain further insight about MEPF scheduling and installation
   b) If possible, interview subcontractors about their experiences installing these systems at LH.O and inquire about any past experiences with prefabricated system installation
2) Perform MEPF feasibility study

   a) Contact fabricators, preferably local, that produce these respective systems
   b) Perform a feasibility study, based on the project schedule, availability of prefabrication, lead times and construction logistics
3) Make recommendations and produce a 3D model
   a) Recommend certain MEPF systems to prefabricate, and demonstrate expected scheduling impacts
   b) Produce a model to demonstrate installation & constructability benefits

Preliminary Analysis

In regards to electrical prefabrication, essentially everything can be prefabricated from pre-punched junction boxes and panel ends to custom wire assemblies to lighting assemblies. Regional subcontractors such as Marathon Electrical Contractors provide this service. If the application is properly planned, labor efficiency should increase, non-productive time should be reduced, work environment should be cleaner and safer, and overlapping work areas of trades should be reduced.

HVAC and plumbing prefabrication is anticipated to provide similar benefits to LH.O. Companies such as HiMEC Mechanical fabricate these building features and even specialize in green/sustainable projects. In the case of LH.O, these systems were already designed in 3D models, which could be sent to the fabricator for production. System design would include everything from photovoltaic panels to heat pumps to heat recovery coils.

Fire protection sprinklers, pipes, fire department connections, sensors, and communication systems could likewise be prefabricated. Companies such as GEM Fabrication perform this service and utilize green building practices per USGBC.

Potential Solutions

In determining MEPF systems to prefabricate for LH.O on the bases of scheduling and constructability, foreseeable outcomes include the following:

- Prefabrication of all systems will be found beneficial
- Lead times considerations, party communication issues, transportation issues or other restrictions will render one of the systems impractical for prefabrication
- Only prefabrication of electric panel boxes will be found beneficial

Expected Outcome

It is anticipated that select aspects from each of the MEPF systems which presented the biggest installation and scheduling challenges will be deemed feasible for prefabrication on the LH.O project. This is predicted because of the complexity of various electrical system features and the availability of computer models. Prefabrication can increase labor efficiency, reduce non-productive time, reduce work overlap between trades, and allow a cleaner safer workspace. The project schedule is predicted to be shorter as feasible MEPF prefabrications are implemented, further increasing constructability for those systems.

MEPF Schedule and Constructability Analysis

GC Interview

Based off of a phone call with the project's construction manager, Bob Brandt III of Benchmark Construction, it was determined that electrical prefabrication should be the focus of the analysis. Fire protection and HVAC ductwork were actually prefabricated on the project and will no longer be considered for Analysis III. However, plumbing and electrical prefabrication will be considered, and electrical prefabrication will be the focus.

The fact that fire protection communication systems and ductwork prefabrication were implemented on the project is a good sign that electrical and plumbing prefabrication could be implemented as well. Lead-times for the systems will be investigated more in depth, once their prefabrication is determined feasible in *MEPF Feasibility Study*.

Subcontractor Interviews

Electrical

In a telephone conversation with Sam Sterkenberg, of SP Construction and Design, the electrical system installation methods were established. Site lights and receptacles were run in PVC pipe underneath the slab on grade. Conduit from the remote mounted exterior load bank into the building is run in Rigid Metal Conduit (RMC), and interior Electrical Metal Conduit (EMC) was used for interior feeder conduits.

Sterkenberg mentioned that he didn't think there would be enough lead time to have electrical components pre-fabricated, but this will still be investigated. Feeder EMC runs vertically to the concrete floor above then laterally along the bottom of the concrete floor above. It also runs through metal stud framing. This means that it cannot be installed until after the precast plank in the addition is set and metal stud frames are in. According to project schedule (see Appendix 0.B), this will not occur until February 7, 2012. This time will be used as a delivery deadline when considering prefabrication implementation for electrical components.

Plumbing

The plumbing subcontractor for LH.O was Garden Spot Mechanical, and Dean Eberly was provided as a contact from Benchmark Construction. In a telephone conference with Eberly, it was determined that plumbing system prefabrication was not recommended due to the size of the project, but implementation can still be studied for this analysis. Eberly had been to a project where DWV units were prefabricated, and expressed that a common occurrence is that site conditions do not match drawings. This is inherently problematic but especially for prefabricated units that are bulky. He acknowledged that it is possible to save on prevailing wage expenses, and recommended the Worth Company as a plumbing fabricator.

MEPF Feasibility Study

Context

Originally, Analysis 3 was intended to be an investigation of MEPF prefabrication, but the investigation will be altered to provide a detailed analysis of electrical and plumbing prefabrication. The GC PM indicated during an interview that ductwork and fire-protection communication systems were already prefabricated for the LH.O project, leaving only plumbing and electric to be considered for feasibility. However, electrical prefabrication research will be expanded from just panels to include more system components.

Introduction

The LH.O project was partially financed by state and federal governments, and such financing has requirements that all subcontractors be paid prevailing wage, a rate that is frequently higher than private competitive rates. For example, LH.O received a grant by the Redevelopment Assistance Capital Program (RACP) which requires prevailing wage in construction but not for prefabrication (Brandt, 2012). These union wages can potentially be avoided and/or reduced when various assemblies are pre-fabricated off-site. The catch to this approach is that conditions on the drawings may not necessarily match conditions on site, which can cause constructability concerns. Further, the timing associated with fabrication lead times brings about scheduling considerations. As such, pre-fabrication often requires additional planning and communication which must be considered before the decision is made to implement it. Therefore, the purpose of this analysis is to find whether electrical prefabrication would increase constructability and shorten project schedule for the system.

Detailed Electrical Take-Off

The first step to this analysis involves establishing a detailed take-off for the electrical system. The take-off is done by looking at electrical construction drawings and specifications, including single line diagrams, plans, elevations and panel schedules. This take-off will be sent to fabricators to receive quotes and used to establish a detailed schedule for each of the various system components.

Branch Feeder EMT Conduit

LH.O specifications require that EMT be used in interior, dry locations for switchboard and panelboard branch feeders, lighting and appliance circuitry, homeruns, fire alarm and telecommunications. It is to be galvanized steel conforming to ANSI C 80.3, UL 797 and NEC Article 358. Fittings, couplings and connectors are also galvanized steel. They are compression type when sized less than 1.5" and double screw set type when sized 1.5" and larger. Connectors are to be insulated throat type.

Lengths of branch feeder conduit are taken by drawing lines on the construction drawing plans, connecting various panels and gear as indicated on the panel schedule. Building architecture and structure is considered. The lengths of these lines represent the length of required conduit for construction. Branch feeders account for the following EMT take-offs in Appendix 3.B. While, conduits are not actually fabricated as entire runs, they are used to quantify the amount of bends to be prefabricated and to terminate boxes, switches GFI and etc. with a length of conduit already attached.

Lighting & Receptacle Conduit

Because there is a large portion of .75" conduit for lighting and receptacles (including dimming), a detailed quantity take-off for these conduits is approximated by measuring lengths of electric conduit for individual, repetitive rooms. This number is then extrapolated by multiplying the linear feet per room type by the ratio of total square feet of room type to the square feet of room type sampled. This way, EMT can be more precisely measured than by a standard square foot estimate by building type. The calculations and results of this process are as follows:

The sample space for the office/library area type is the section of architectural points B and C, located on the south end of the building on the lower level. The area of this sample is 1,856 square feet. Here, receptacle conduit accounts for 3,314 linear feet and lighting conduit accounts for 370 linear feet. Vertical drops to receptacles are assumed to be 9 feet from the ceiling and drops to switches are assumed to be 5 feet for this and all other room types. The total amount for this area sample is 469 linear feet.

Total Quantity = (Sample Quantity) x (Total Type Area) / (Sample Area)

= (469 L.F.) x (9,206 S.F.) / (1,856 S.F.)

= 2,326 L.F.

There is only one gallery, but it is selected to represent LH.Os Lobby, Auditorium and miscellaneous surrounding space south of architectural point G on the ground level as well. The gallery is 1,936 square feet, while the total area of these similar rooms is 8,541 square feet. Receptacle conduit accounts for 372 linear feet, and lighting conduit accounts for 696 linear feet. Conduit homeruns from other areas that pass through the room are accounted for in these quantities.

Total Quantity = (Sample Quantity) x (Total Type Area) / (Sample Area)

= (1,068 L.F.) x (8,541 S.F.) / (1,936 S.F.)

= 4,712 L.F.

A process and storage room type is unique in its conduit layout, so no extrapolation is needed. Rather the lighting and receptacle conduit quantities found in this area will be included in the total quantities for the entire building. Here, there is found to be 214 linear feet of conduit serving receptacles and 572 linear feet of conduit serving luminaires and switches. The total area is 2,052 square feet.

Total Quantity = 786 L.F.

The sample space for mechanical area types is Mechanical Room 1, and the other rooms this area represents are the other mechanical rooms, electrical rooms, fire protection and water rooms. The sample area is 920 square feet, while the total representative area of these spaces is 2,318 square feet. In Mech. Room 1, there is 86 linear feet of receptacle conduit and 130 linear feet of lighting conduit.

Total Quantity = (Sample Quantity) x (Total Type Area) / (Sample Area)

= (216 L.F.) x (2,318 S.F.) / (920 S.F.)

= 544 L.F.

The bathroom area covers the men and women's bathrooms on the lower level and ground level, totaling 945 square feet in area. The Lower level bathrooms are used as a sample and have a combined area of 520 square feet. These rooms are found to contain 98 linear feet of conduit serving receptacles and 127 linear feet serving luminaires.

Total Quantity = (Sample Quantity) x (Total Type Area) / (Sample Area)

= (225 L.F.) x (945 S.F.) / (520 S.F.)

= 409 L.F.

The other sample areas did not include vertical conduit running to the roof (serving photovoltaic panels), so roof conduit is accounted for in this area. The middle arc roof was used as a sample to cover the other two arc roofs and flat roof areas. Here, the sample area is approximated to be 3,050 square feet and have 292 linear feet of .75" conduit. Vertical drops are assumed to be 12 feet from the bottom of the arc and 24 feet from the top. The total roof area is 9,894 square feet.

Total Quantity = (Sample Quantity) x (Total Type Area) / (Sample Area)

= (292 L.F.) x (9,894 S.F.) / (3,050 S.F.)

= 947 L.F.

Summing up the conduit quantities for each room type approximates the total amount of .75" EMT homeruns in the building. The number of elbows is approximated by averaging the number of elbows for .75" to 1.25" sized conduits per liner feet from the take-off and extrapolating it. The number of connections is estimated by taking the conduit quantity divided by 20 feet (the assumed length of conduit pieces) and adding two connections per elbow. The grand totals for these calculations are 9,724 linear feet of .75” EMT, 493 elbows, and 1,472 connections, respectively. These quantities are added to the total conduit take-off and sent to fabricators for estimates.

Wire Assemblies

Wire assemblies are estimated by comparing the panel schedule to the conduit run take-offs. For the wire take-off quantities, the lengths of respective conduits are multiplied by the number of wires running through them, adding in 3 feet of wire for every junction for pull out and terminations. This estimate can be seen in Appendix 3.A. Wire pre-fabrications wouldn’t involve terminations being preinstalled, but rather their lengths would be used to make a roll with notches to reduce time spent measuring and cutting in the field. If effectively coordinated this would have the potential to improve constructability, but poor coordination between the shop and field would have the opposite effect.

DWV Unit Estimate

For this estimate, bathroom plenum assemblies on the first and second floor are considered. As seen in Appendix 3.C, the assemblies consist of various sizes of iron pipe, couplings, tees, and sanitary y’s. While the plumbing contractor specified that the plenum was not large enough to accommodate prefabrication for these units, the assembly savings would have been minimal anyway. Prefabrication of DWV units would be considered more preferable for a building with a large number of similar assemblies. Had this idea been implemented, construction issues associated with transporting the units and keeping them from damage would have to be considered.

Summary of Results

Following multiple telephone and e-mail conversations with Chuck Tomasco and Howie Menard of Truland Systems, a company that typically analyzes whether its projects should prefabricate or field build various electric assemblies, it is determined that prefabrication is definitely feasible for the LancasterHistory.org project. Specifically, the entire office area on the south end of the ground level can be prefabricated. Additionally, conduit bends where conduit is greater than 1.5 inches in diameter would be recommended for fabrication. Last, panelboxes could be pre-punched as well to save time in the field.

In order to determine which units would save the most labor time, spreadsheets are provided by Menard for side-by-side comparison of these assemblies using the take-offs quantified. Because the prevailing wage rate is different for the Washington DC area versus that of Lancaster, wage rate is changed to represent an electrical lineman's wage at the time of construction. This cost is $54.99 as described in LH.O specifications, and it includes fringe benefits (health insurance, pension fund, & holidays). Additionally, the labor rate for prefabricated materials is assumed to be $19.84 an hour, which was the mean hourly rate for electricians in Lancaster at the time of bidding. Field labor hours and material costs are taken from RS Means. Because panel pre-punching isn't greatly affected by size, panels are assumed to all be 225A for the purpose of chart simplification. A cost comparison of prefabricated versus field can be found in Appendix 3.A.

Conclusions & Recommendations

It is recommended that electrical assembly prefabrication be implemented on the LancasterHistory.org project, because the schedule would be reduced, and constructability would improve, assuming there is effective communications between parties. As a corollary, General conditions costs will also be reduced. Electrical assemblies in the LH.O office area combined with various receptacle-cable assemblies in stud frames is estimated to save the budget **$10,430.80** (not including general conditions) and save over **91 labor hours** on-site. It is not recommended that DWV units be prefabricated.

Analysis IV – Greater Use of BIM:

Introduction

Opportunity Identification

Building Information Modeling (BIM) can be effective for essentially any aspect of a building's creation when used effectively. In the case of the LancasterHistory.org project, BIM was helpful in the design phase but could have been used more in each of the project's phases to increase project constructability and decrease schedule. Analyzing the BIM application process as it relates to the LancasterHistory.org project will show how a greater use of BIM could have benefitted the various parties involved by facilitating communications.

Background Research

Following the BIM Execution Guide's approach to BIM utilization selection, the following BIM uses are deemed applicable for the LancasterHistory.org project:

Table 7 - Potential LH.O BIM Applications

Building Systems Analysis	Disaster Planning	3D Control and Planning (Digital Layout)
Site Utilization Planning	Construction System Design (Virtual Mockup)	3D Coordination
Space management & tracking	Digital Fabrication	Code Validation
Phase Planning (4D Modeling)	Design Reviews	Facility Energy Analysis
Sustainability (LEED) Evaluation	Cost Estimation	Design Authoring
Engineering Analysis	Record Modeling	

Application Methodology

In conducting research for this technical analysis, the following steps are to be executed:

1) Analyze utilizations of BIM for value
   a) Interview the project manager, Bob Brandt III to better understand detail of existing computer models and extent of BIM implementation
   b) Interview project architect, Pete Cornell, to better understand the following:

   i) Extent of BIMs implementation and application in design
   ii) Communication agreements and techniques between parties
   c) Inspect BIM models for systems included
2) Further apply the BIM Execution Planning Guide
   a) BIM use evaluation
   b) Make recommendations for BIM utilizations to be implemented

Preliminary Analysis

Upon preliminary research, this analysis is feasible. The BIM Execution Planning guide is relevant and can be followed, and design models are available from Centerbrook Architecture which may aide in providing visuals. Also, various AE teachers and graduate students have offered assistance.

Potential Solutions

In analyzing a greater use of BIM on the basis of value, foreseeable outcomes include the following:

- Schedule and constructability benefits associated with a greater use of BIM will render further implementation in LH.O design, construction and operations impractical
- Further BIM implementations for LH.O will be deemed valuable

Expected Outcome

Based upon preliminary analysis and past reports, it is expected that a greater use of BIM in design and in construction will be deemed valuable for LH.O and model turnover will not be valuable. BIM is expected to be valuable in design and construction based on lessons learned at PSU. Model turnover is anticipated to be deemed impractical given the relatively small size of LH.Os infrastructure. However, it is expected that the value of record modeling will be proven for large establishments such as PSU.

BIM Utilization Value Analysis

Interview Bob Brandt III

In this interview, Brandt expressed that BIM implementation by Benchmark Construction was minimal. The ductwork modeled by Benchmark’s BIM employee was used to show contractors the exact layout of systems. Brandt did not think that further implementation would be useful due to the size of the project. BIM would have possibly been utilized more in construction, had a different contract type been used.

Interview project architect, Pete Cornell, to better understand the following:

Extent of BIMs implementation and application in design

BIM was used a great deal in the design process of the building because it was used to enhance the owner's understanding of the architectural design. Various designs were created and changed before the owner decided upon the building that exists today.

Communication agreements and techniques between parties

Due to the contract type, this model was exchanged between Centerbrook, Altieri Sebor Wieber, Gibble Norden Champion Brown, and DM/A, starting with structural. There was a series of meetings, e-mails, and other exchanges occurring on a daily basis.

Inspect for Systems Included

Based upon the models received from Centerbrook Architects, it is apparent that architectural, structural and mechanical modeling had been extensively conducted for the LancasterHistory.org project, but electric conduit modeling had not been implemented. It is apparent that designed models are complete, based upon comparison to construction drawings. It should be noted that based upon the project delivery method, computer models are used simply for design purposes, and the general contractor would not receive the models. The models displayed in this analysis are for educational purposes only, and permission was received by the architect.

Further apply the BIM Execution Planning Guide

Introduction

Before developing a BIM use list it is important to list the goals of the project as they relate to BIM. The projects goals listed in this report are specific to the LancasterHistory.org project (see Appendix 4.A for BIM Goal List). They encompass all stages of the building's creation from planning to design to operation. As a note, the owner does not require BIM for building operation, and Benchmark opted to not use much BIM in the construction process. The goals are then used to determine how BIM should be applied to the project (see Appendix 4.D for Level-1 Process Map).

After listing the projects goals, a chart is created in the form of a BIM Goal List. Each goal is paired with potential BIM applications that are or would be used to facilitate reaching them. Further, the goals are ranked in priority from low to high. This is used to allocate resources later in the BIM planning process. BIM use analysis is later conducted in this section to determine BIM use implementation.

BIM Use Evaluation

Code Validation

Code validation is a process that uses computer software to check model parameters for code compliance. These parameters are project specific. This software is still new to the industry and its use is not as widespread as other BIM utilizations, but it has the potential to become more prevalent.

Validation software can be applied to various types of codes, such as IBC and ADA to reduce the chance of code design errors. It can even be done automatically during building design processes. Further, it saves time by reducing 3D model review by code officials. This means that there is less time spent meeting, on-site, and fixing violations late in the construction phase. This could have greatly benefitted LH.O.

According to Robin Sarratt, LH.O VP, various codes were not met (2012). For instance, some handrails were not included in design or budget that had to be later installed. In addition, a shower was not handicap accessible by the Americans with Disabilities Act (ADA), and it cannot be used. The shower's exterior dimensions were per code but its interiors' were not. Code violations such as these can easily be checked with computer models.

Code validation could have been more extensively used to prevent at least three change orders from occurring on LH.O, being a change order for door and hardware, an areas-of-refuge intercom, and fire dampers in transfer grills. Combined, these changes amounted to $19,438 for the owner, and additional time and resources for the construction manager as well.

Digital Fabrication

Digital fabrication is used in the industry to assist in the fabrication of various construction materials and assemblies, particularly dealing with metal. It serves to better communicate designs to fabricators in order to minimize ambiguities. As a result, less time is spent fabricating, and less waste is created in the process. Furthermore, chances of parts being off are reduced, because a greater quality of information is ensured.

As mentioned in the proposal for *Analysis 3,* prefabrication would have greatly simplified electric panel installation. Assuming implementation of this and prefabrication of other MEPF features, digital fabrication could greatly increase project value. As indicated earlier, LH.O received a grant by the Redevelopment Assistance Capital Program (RACP) which requires prevailing wage in construction but not for prefabrication (Brandt, 2012).

Digital fabrication was used by Benchmark Construction to prefabricate ductwork for the LancasterHistory.org project, but it could have potentially also been used to facilitate prefabrication of the various electrical assemblies described in *Analysis III*. This would allow for time and wastes to be minimized in fabrication due to more effective communication than 2D drawings. Also, this would improve accuracy and reduce lead time. For example, the $10,430.80 cost savings and 91.7 labor hour duration savings associated with prefabricating electrical assemblies would have been made much more tangible. This does not consider general conditions costs associated with a decreased project schedule, which would further increase cost savings.

Phase Planning

This is the combination of a 3D model with the added element of time. It is used to demonstrate the construction sequence and space requirements of a project, allowing for better communication between involved parties. This is important to reduce project cost and schedule duration, because it can give the project team and the owner a better understanding of project milestones and critical activities. It is to be used in the design and construction phases of the project. In addition, special complexities can be better analyzed ahead of time to prevent workspace conflicts. Its required resources include scheduling software, a 3D model and 4D modeling software.

For the LancasterHistory.org project, 4D modeling could have been beneficial, particularly considering that the project is a renovation-addition, and that it has various site and workspace constraints. There are various existing building elements and artifacts that are to be removed and relocated or stored in various locations during the project's construction. Additionally, select trees were to be relocated. Further, this BIM utilization would have been beneficial to project site and earth work activities, which are on the project's critical path. While the site plan created in *Analysis I*, addresses initial schedule delays due to site congestion during excavations, BIM phase planning would have maximized planning for safety, constructability and schedule considerations. For example, if applied to excavations, this could have made the $72,446.64 cost savings and 13 day labor duration savings more solid. Additionally, the flagger would have a better understanding of his daily interactions and objectives.

Three-Dimensional Coordination

Three-dimensional coordination is important because it is used to determine major system conflicts before they happen via clash detection software. This means that the various models developed by involved design parties (Architectural, Structural, MEP), are combined into one file to test for and reduce system conflicts (see figure 5). Further, it allows for a better opportunity for contractors to visualize construction. Consequently, construction productivity is increased and schedule is reduced, not to mention the time savings from reduced RFI's. It is used in the design and construction phases of a project.

While 3D coordination was used by the various design members under Centerbrook, it could have potentially been used to a greater extent, as various clashes are still found within the provided models. In fact, running a test between the mechanical and structural systems with a tolerance of .03 meters, 264 clashes are found. However, most of these clashes are mechanical piping, which is not that much of a problem during construction.

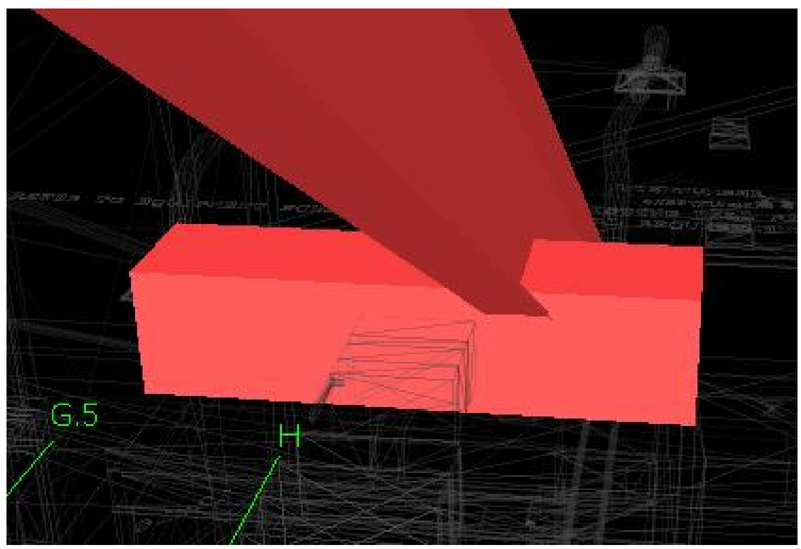

Figure 7 - Steel-Duct Clash #86

Additionally, the owner was not pleased to see how low some ducts extended below a beam in the storage room. In fact, it is preventing the owner from storing as much materials it would have liked. Had the owner seen more extensive model renderings, this could have potentially been avoided, by running the duct through the beam and increasing the beams strength. This can be visualized and accounted for using Navisworks (see Appendix 4.C for a simplistic demonstration).

Sustainability (LEED) Evaluation

LEED Evaluation addresses the sustainability goals of a project by evaluating LEED criteria and processes in all stages of the project's life. It can be used in tandem with Building Systems Analysis via 3D coordination to save time and money by quickly analyzing design changes and bringing about a quality, sustainable design. This process is done by running energy simulations, calculations and by documenting within an integrative environment. This means that the various disciplines and parties involved with in the project can interact early on through completion so any green insights can be accounted for. Overall, the model provides supplementation to the LEED evaluation, to further ensure that the building is green.

Though not explicitly stated by the architect, this BIM utilization was indirectly implemented on the LancasterHistory.org project in the form of various energy analyses (see next section), but it could have been used to a greater extent in order to ensure the greenest building and environment. For example, it could have been further used in site development to create more open spaces, or it could have been used to a greater extent to possibly allow for greater innovation in design (see Appendix 0.C). These areas are more rapidly assessed via BIM, because computer programs can quickly check for specific LEED goals right off of the computer model. This takes a greater period of time to assess without BIM and requires a much greater deal of coordination between involved parties.

Building Systems Analysis

Using Building systems analysis, MEPF and solar aspects of a project can be efficiently reviewed. These components of the building are analyzed to ensure they meet the owner's criteria in the design phase and the design criteria in the construction/commissioning phase of the project. Further, it is used to make sure systems continue to operate properly for the owner in the project's maintenance phase, if the owner requests this service (see *Record Modeling*). Specifically, this BIM process measures how performance compares to design, considering mechanical, architectural, and lighting systems, amongst others. Further, this method can be used to reduce operational costs for the owner. This BIM application requires systems analysis software.

Building systems analysis was performed on the LH.O project in designing an effective mechanical system, addressing energy efficiency, cost, and performance considerations. This process was used in the design phase through the construction phase, during commissioning. Additionally, it was used in a mechanical redesign during construction, concerning the project's mechanical system change discussed in *Analysis II*. For example, data was collected for the open loop geothermal system's well to ensure that the constructed version's performance matched the design model. Lighting fixtures and architectural designs were greatly evaluated using this BIM method. Further implementation of this BIM application is not practical, due to the extensiveness of its actual use for LH.O.

Virtual Mockup

Virtual Mockup is used on a project in its design phase to analyze construction and increase planning, to increase construction productivity and to decrease language barriers between parties. It is a detailed 3D model to the extent of an actual mockup. It only requires 3D modeling software, but it can be used in conjunction with many other BIM applications.

Because of the unusual shape of the roof arcs in the LancasterHistory.org project, this BIM application could be used to communicate enclosure of the building. This is very important to ensure the building's longevity (i.e. so that water damage does not occur). Further, it could be used to greater communicate customized casework on the interior of the building that Brandt mentioned took a significant amount of time to install (2012). For this application to be deemed practical, the project cost savings associated with construction labor duration reduction and general conditions costs less the labor expenses of modeling would have to be greater than the savings associated with other modeling applications.

Site Utilization Planning

Site utilization planning is facilitated with BIM because space and sequencing can be more realistically represented than with just two dimensional drawings. Buildings, labor, materials and equipment can all be realistically simulated in the model, depicting site usage for facilities layout and assembly areas and material deliveries. The BIM application of site utilization planning saves time and more effectively evaluates construction safety concerns. It is great for construction scheduling, especially when adapting to schedule changes it can save time planning. It can be used with phase planning.

This BIM utilization process was not implemented but would be particularly important for the LancasterHistory.org project, given its ambitious schedule and the fact that nearby facilities remain operational. Additionally, were the alternate soil remediation approach described in *Analysis I* implemented, this would have come in very handy. This is because there would be a lot of site congestion issues associated with the additional earth moving activities that require coordination with other tasks. In addition to taking less time planning the activity sequences, the entire process could be potentially expedited due to the greater site awareness made possible by this BIM implementation.

Record Modeling

Record modeling as it relates to BIM involves representing the physical, material, and environmental conditions of a constructed facility with a computer model. This model contains information about the building's architectural, structural and MEP elements at a minimum. However it is more than just combining these elements, because the model has to be altered during the construction phase for the most accurate representation of an as build facility. This model will typically also incorporate any 4D models, fabrication models, mockups, and etcetera into the final product. Most importantly, the model must be designed to incorporate operation, maintenance and asset data into the program, such that the owner can use it to maintain the facility and its components. The model should be created such that it can be updated by the owner as well.

There are many great incentives of record modeling that should be considered for its implementation. First, the computer model would facilitate future modeling and 3d coordination should the building be renovated. It improves documentation of the building from a historical preservation standpoint. Record modeling can aid in the permitting process, it minimizes building turnover information, and it can help foster a stronger relationship with the owner. Finally, the owner would benefit by saving costs over the building's life span.

In regards to the LancasterHistory.org building, record modeling with BIM would be feasible based upon the fact that there are the required models already designed. This would involve greater modeling during construction and a different agreement between the architect and the owner that would include an option for record modeling. However, should it be done, the mentioned benefits would all be there. The incentives of BIM record modeling that are historical preservation, an option for future modeling, and potential to foster better company relationships are all there. In particular, a greater ability to facilitate future renovations is relevant for LH.O as this project marks the building's third (3rd) renovation. The question becomes whether the additional time and resources spent updating the computer models for a project of this size would be practical.

Space Management

Space Management is used on a project to effectively allocate, manage and monitor space usage for a facility, particularly for renovations that are to be occupied during construction. It can be very helpful to track the use of current space and resources as well as plan for future space needs. It requires space mapping and bi-directional model manipulation software.

For the LancasterHistory.org project, this BIM application helped the owner and architect determine how much space was needed for various historical artifacts and exhibits in the design phase. It could have been implemented in the construction phase to better store artifacts from the renovation that were required to be preserved by the owner. Additionally, it could have been used to better plan storage of materials relating to renovation or addition. Further, it could have been used in conjunction with a record model in the maintenance phase by the owner to monitor artifacts and other resources during the facilities operation. This would require an understanding of space tracking software.

BIM Use Analysis

Next, a BIM use analysis chart is created (see Appendix 4.B). This chart determines parties involved in the BIM Process, and it rates each party capability per BIM use. After considering additional resources or competencies required, a decision is made to proceed or not to proceed with the considered BIM applications and relevant parties. It is determined in this report that Phase Planning, 3D Coordination, Building System Analysis, Virtual Mockup, Site Utilization Planning and Space Management are all to be implemented on the LancasterHistory.org project, (It can be noted that LEED Evaluation is not practical for this project because the project size is too small to achieve profit.). Active parties in the BIM process are determined to be the owner, architect, contractor, MEPF engineer, structural engineer and occasional subcontractors (excavation, structural-steel, mechanical & electrical subs.). Given the resources and experience of the LEED certified Architect on the project, LEED Gold Certification can still be achieved.

To better understand the implementation of the BIM Uses, BIM project execution process is designed. In doing so, a process map is established, which defines various processes performed by parties. It also communicates information exchanges between parties. This map would later used to determine member selection criteria, contract structure, BIM deliverable requirements and IT infrastructure. A BIM Overview Map for the LancasterHistory.org project can be found in Appendix 4.D.

Critical Evaluation

BIM was used on this project by the owner, architect, structural engineer and MEP engineer to each of their benefits. It was used minimally by Benchmark given the size of the project and availability greater facilitated, and there would be a greater possibility of more BIM uses to be implemented. For example, had there been an agreement between Centerbrook and Benchmark, 3D and 4D models could have been implemented by the contractor with minimal effort. Additional BIM implementations recommended for LH.O are consolidated in the following section.

Suggested Implementations

Had there been different contractual relationships between LH.O disciplines, the following implementations are recommended based upon the results of *BIM Use Analysis:*

Table 8 - Suggested LH.O BIM Applications

Building Systems Analysis	Disaster Planning	3D Control and Planning (Digital Layout)
Site Utilization Planning	Construction System Design (Virtual Mockup)	3D Coordination
Space management & tracking	Digital Fabrication	Code Validation
Phase Planning (4D Modeling)	Design Reviews	Facility Energy Analysis
Sustainability (LEED) Evaluation	Cost Estimation	Design Authoring
Engineering Analysis	Record Modeling	

It is impossible to quantify the BIM utilizations with added value other than to greater solidify the potential savings in analyses 1 through 3 using site utilization and phase planning, building systems analysis and digital fabrication, respectively. However, it is 100 percent certain that the time spent remodeling by the GC what was already modeled by Centerbrook could have been applied to greater BIM utilizations, doubling its value at no or little additional cost. For example, the prefabrication and installation of Ductwork managed by Benchmark was facilitated by one modeler. Assuming that employee spent three weeks modeling (based upon an interview with an experienced modeler, Leicht, 2013), and assuming a wage of $110 per hour (Cornell, 2013), that BIM application required an initial cost of $13,200. That is already less than the estimated cost savings associated with prefabricating electrical assemblies, which can be prefabricated to a much lesser extent than ductwork for LH.O, and that only takes into consideration materials and labor costs. Because Brandt specifically mentioned in an interview that 4D modeling facilitated installation and reduced installation time, it is safe to assume that prefabrication reduced schedule as well.

Conclusions & Recommendations

Given both the goals and personnel involved in the LancasterHistory.org project, the BIM uses highlighted above are appropriate. Each party creates their own models and brings them to coordination meetings, which are held every Thursday morning. Significant design changes are submitted to relevant personnel as soon as possible, and models are shared online to keep information current. It is suggested that the <u>contractual agreements be modified to include a transfer of model to the general contractor</u>. This way, schedule would potentially be decreased and constructability would show great improvements with minimal modeling required by the general contractor modeler(s).

Reflection:

Course Reflection

The Senior Thesis Capstone project made me feel like everything I learned as an Architectural Engineering student at The Pennsylvania State University is useful in my goal to become a Project Manager in the real world. In addition, to applying my math, science and engineering skills to real world scenarios, it really improved my communication skills. In doing so, I was able to broaden my knowledge about construction management to know more about how the design teams such as mechanical and structural engineers operate. Overall, I believe the techniques, skills and use of modern technology I experienced in this program has provided the foundation for a successful career in the industry.

Specifically, a great deal was learned about:

- How geotechnical report interpretation is crucial for a project to remain on schedule and on budget
- The importance of life cycle costing in a mechanical system evaluation
- The level of detail required in take-offs for prefabrication to be implemented
- The extent that BIM can be applied in construction to facilitate communications between parties

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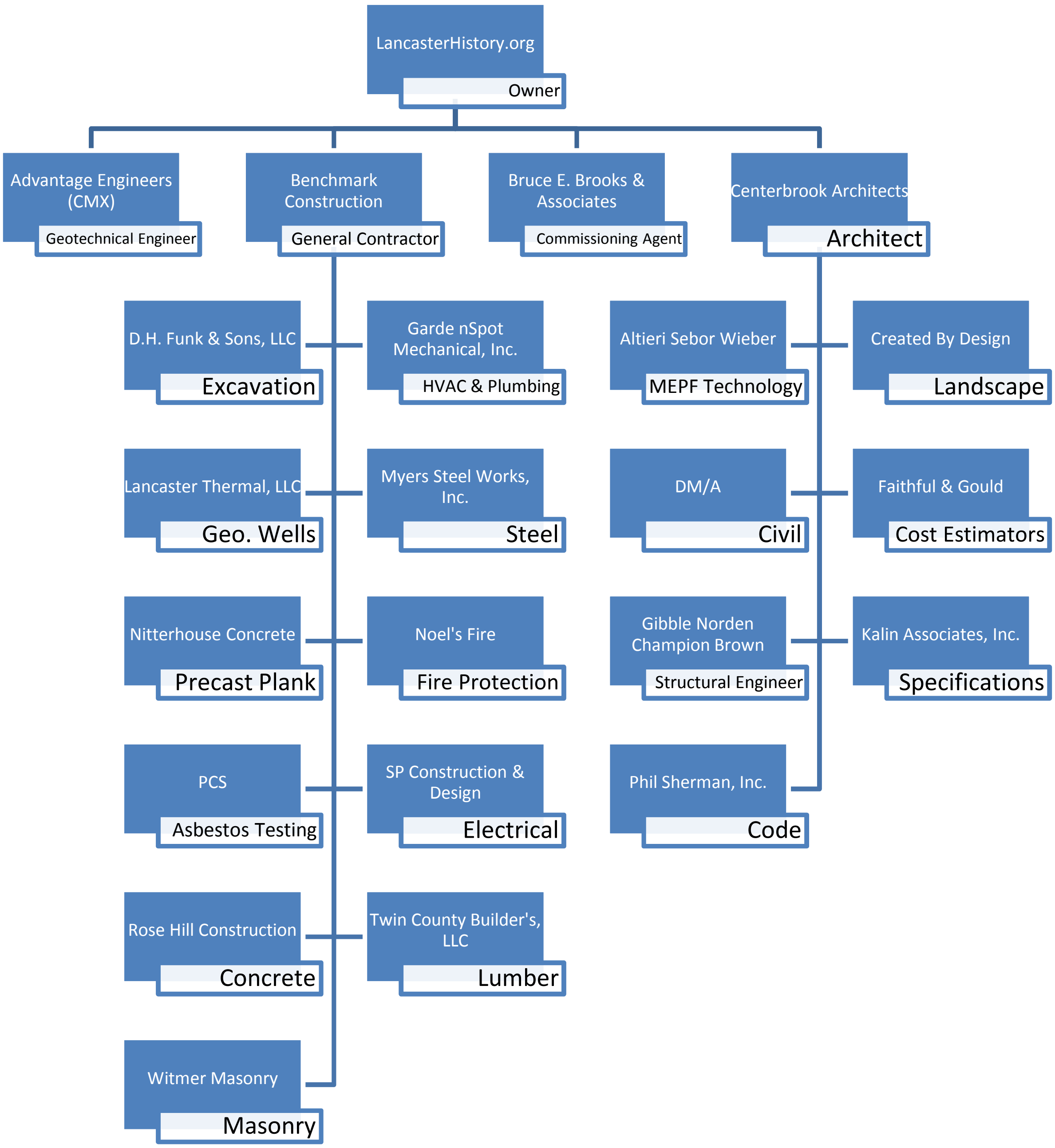
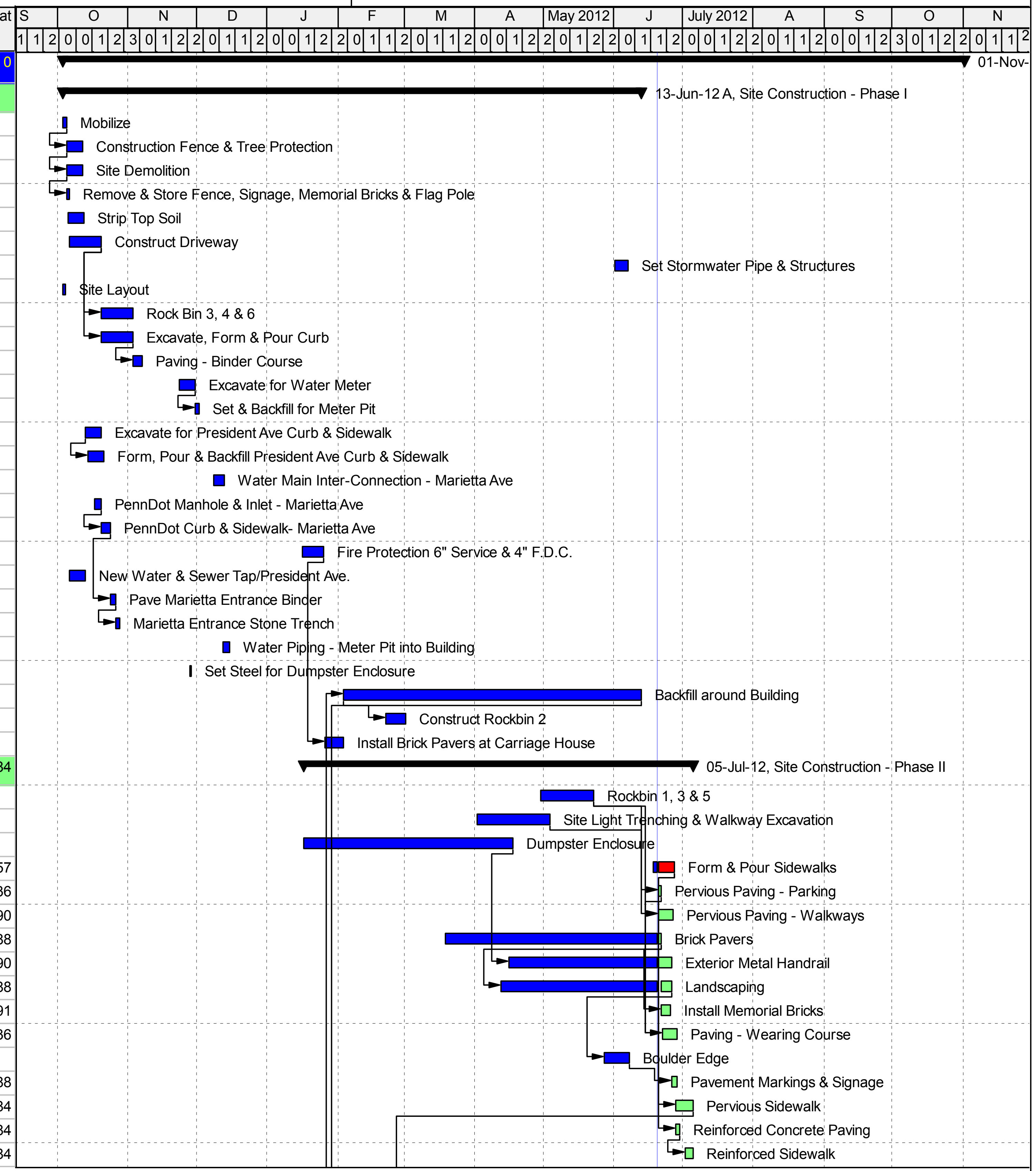
Appendix 0.A – Project Delivery System:


LancasterHistory.org
Owner
Advantage Engineers (CMX)
Geotechnical Engineer
Benchmark Construction
General Contractor
Bruce E. Brooks & Associates
Commissioning Agent
Centerbrook Architects
Architect
D.H. Funk & Sons, LLC
Excavation
Garde nSpot Mechanical, Inc.
HVAC & Plumbing
Altieri Sebor Wieber
MEPF Technology
Created By Design
Landscape
Lancaster Thermal, LLC
Geo. Wells
Myers Steel Works, Inc.
Steel
DM/A
Civil
Faithful & Gould
Cost Estimators
Nitterhouse Concrete
Precast Plank
Noel's Fire
Fire Protection
Gibble Norden Champion Brown
Structural Engineer
Kalin Associates, Inc.
Specifications
PCS
Asbestos Testing
SP Construction & Design
Electrical
Phil Sherman, Inc.
Code
Rose Hill Construction
Concrete
Twin County Builder's, LLC
Lumber
Witmer Masonry
Masonry

Appendix 0.B - Construction Schedule as Implemented:

LancasterHistory.org | Update 1 | 17-Sep-12 16:50

Activity ID	Activity Name	Original Duration	Early Start	Early Finish	Late Start	Late Finish	Activity % Complete	Total Float
LancasterHistory.org		277	20-Jun-12	01-Nov-12	30-Mar-12	01-Nov-12		0
Site Construction - Phase I		171	20-Jun-12	20-Jun-12	05-Sep-12	01-Nov-12		
A1000	Mobilize	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1010	Construction Fence & Tree Protection	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1020	Site Demolition	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1030	Remove & Store Fence, Signage, Memorial Brick	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1040	Strip Top Soil	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1050	Construct Driveway	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1060	Set Stormwater Pipe & Structures	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1070	Site Layout	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1080	Rock Bin 3, 4 & 6	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1110	Excavate, Form & Pour Curb	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1150	Paving - Binder Course	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1160	Excavate for Water Meter	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1170	Set & Backfill for Meter Pit	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1200	Excavate for President Ave Curb & Sidewalk	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1210	Form, Pour & Backfill President Ave Curb & Sidew	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1220	Water Main Inter-Connection - Marietta Ave	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1230	PennDot Manhole & Inlet - Marietta Ave	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1240	PennDot Curb & Sidewalk- Marietta Ave	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1120	Fire Protection 6" Service & 4" F.D.C.	8	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1130	New Water & Sewer Tap/President Ave.	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1140	Pave Marietta Entrance Binder	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2450	Marietta Entrance Stone Trench	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2460	Water Piping - Meter Pit into Building	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1420	Set Steel for Dumpster Enclosure	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1190	Backfill around Building	5	20-Jun-12	20-Jun-12	05-Sep-12	05-Sep-12	100%	
A1250	Construct Rockbin 2	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1270	Install Brick Pavers at Carriage House	7	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
Site Construction - Phase II		100	20-Jun-12	05-Jul-12	30-Mar-12	01-Nov-12		84
A1100	Rockbin 1, 3 & 5	5	20-Jun-12	20-Jun-12	10-Aug-12	10-Aug-12	100%	
A1180	Site Light Trenching & Walkway Excavation	15	20-Jun-12	20-Jun-12	25-Oct-12	25-Oct-12	100%	
A1400	Dumpster Enclosure	3	20-Jun-12	20-Jun-12	25-Oct-12	25-Oct-12	100%	
A1260	Form & Pour Sidewalks	15	20-Jun-12	27-Jun-12	30-Mar-12	09-Apr-12	60%	-57
A1290	Pervious Paving - Parking	2	20-Jun-12	21-Jun-12	10-Aug-12	13-Aug-12	0%	36
A1300	Pervious Paving - Walkways	5	20-Jun-12	26-Jun-12	25-Oct-12	01-Nov-12	0%	90
A1330	Brick Pavers	8	20-Jun-12	21-Jun-12	23-Oct-12	25-Oct-12	80%	88
A2370	Exterior Metal Handrail	8	20-Jun-12	26-Jun-12	25-Oct-12	01-Nov-12	40%	90
A1370	Landscaping	5	21-Jun-12	26-Jun-12	25-Oct-12	30-Oct-12	40%	88
A1410	Install Memorial Bricks	2	21-Jun-12	25-Jun-12	30-Oct-12	01-Nov-12	0%	91
A1280	Paving - Wearing Course	5	22-Jun-12	28-Jun-12	14-Aug-12	20-Aug-12	0%	36
A1360	Boulder Edge	2	26-Jun-12	26-Jun-12	30-Oct-12	30-Oct-12	100%	
A1380	Pavement Markings & Signage	2	26-Jun-12	28-Jun-12	30-Oct-12	01-Nov-12	0%	88
A1310	Pervious Sidewalk	5	28-Jun-12	05-Jul-12	25-Oct-12	01-Nov-12	0%	84
A1340	Reinforced Concrete Paving	2	28-Jun-12	29-Jun-12	25-Oct-12	29-Oct-12	0%	84
A1350	Reinforced Sidewalk	3	02-Jul-12	05-Jul-12	29-Oct-12	01-Nov-12	0%	84



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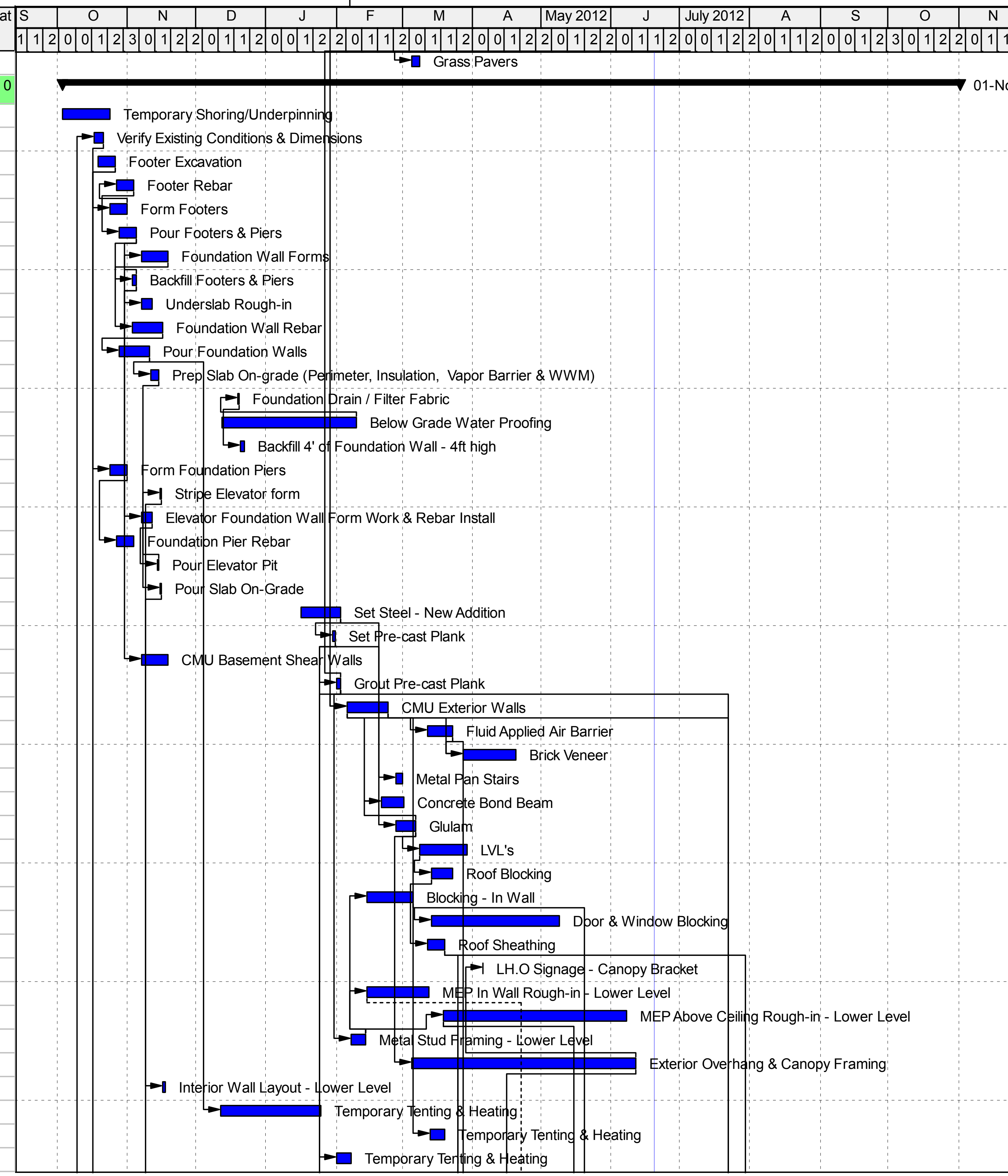
Activity ID	Activity Name	Original Duration	Early Start	Early Finish	Late Start	Late Finish	Activity % Complete	Total Float
A1320	Grass Pavers	2	05-Jul-12	05-Jul-12	01-Nov-12	01-Nov-12	100%	
Building Construction		277	20-Jun-12	01-Nov-12	20-Jun-12	01-Nov-12		0
A1430	Temporary Shoring/Underpinning	15	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1450	Verify Existing Conditions & Dimensions	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1470	Footer Excavation	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1480	Footer Rebar	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1490	Form Footers	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1500	Pour Footers & Piers	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1510	Foundation Wall Forms	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1520	Backfill Footers & Piers	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1540	Underslab Rough-in	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1550	Foundation Wall Rebar	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1560	Pour Foundation Walls	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1580	Prep Slab On-grade (Perimeter, Insulation, Vapoı	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1590	Foundation Drain / Filter Fabric	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1600	Below Grade Water Proofing	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1610	Backfill 4' of Foundation Wall - 4ft high	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1630	Form Foundation Piers	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1640	Stripe Elevator form	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1650	Elevator Foundation Wall Form Work & Rebar Ins	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1660	Foundation Pier Rebar	6	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1670	Pour Elevator Pit	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1700	Pour Slab On-Grade	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1440	Set Steel - New Addition	10	20-Jun-12	20-Jun-12	20-Jun-12	20-Jun-12	100%	
A1620	Set Pre-cast Plank	2	20-Jun-12	20-Jun-12	21-Jun-12	21-Jun-12	100%	
A1690	CMU Basement Shear Walls	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1710	Grout Pre-cast Plank	2	20-Jun-12	20-Jun-12	21-Jun-12	21-Jun-12	100%	
A1720	CMU Exterior Walls	20	20-Jun-12	20-Jun-12	05-Sep-12	05-Sep-12	100%	
A1730	Fluid Applied Air Barrier	20	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1750	Brick Veneer	25	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1810	Metal Pan Stairs	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1820	Concrete Bond Beam	8	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1830	Glulam	5	20-Jun-12	20-Jun-12	20-Jun-12	20-Jun-12	100%	
A1840	LVL's	15	20-Jun-12	20-Jun-12	20-Jun-12	20-Jun-12	100%	
A1850	Roof Blocking	15	20-Jun-12	20-Jun-12	20-Jun-12	20-Jun-12	100%	
A1860	Blocking - In Wall	15	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1870	Door & Window Blocking	25	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1890	Roof Sheathing	15	20-Jun-12	20-Jun-12	20-Jun-12	20-Jun-12	100%	
A1950	LH.O Signage - Canopy Bracket	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2290	MEP In Wall Rough-in - Lower Level	20	20-Jun-12	20-Jun-12	21-Jun-12	21-Jun-12	100%	
A2300	MEP Above Ceiling Rough-in - Lower Level	25	20-Jun-12	20-Jun-12	18-Oct-12	18-Oct-12	100%	
A2380	Metal Stud Framing - Lower Level	5	20-Jun-12	20-Jun-12	21-Jun-12	21-Jun-12	100%	
A2420	Exterior Overhang & Canopy Framing	15	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2470	Interior Wall Layout - Lower Level	2	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1570	Temporary Tenting & Heating	8	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1680	Temporary Tenting & Heating	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1780	Temporary Tenting & Heating	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	



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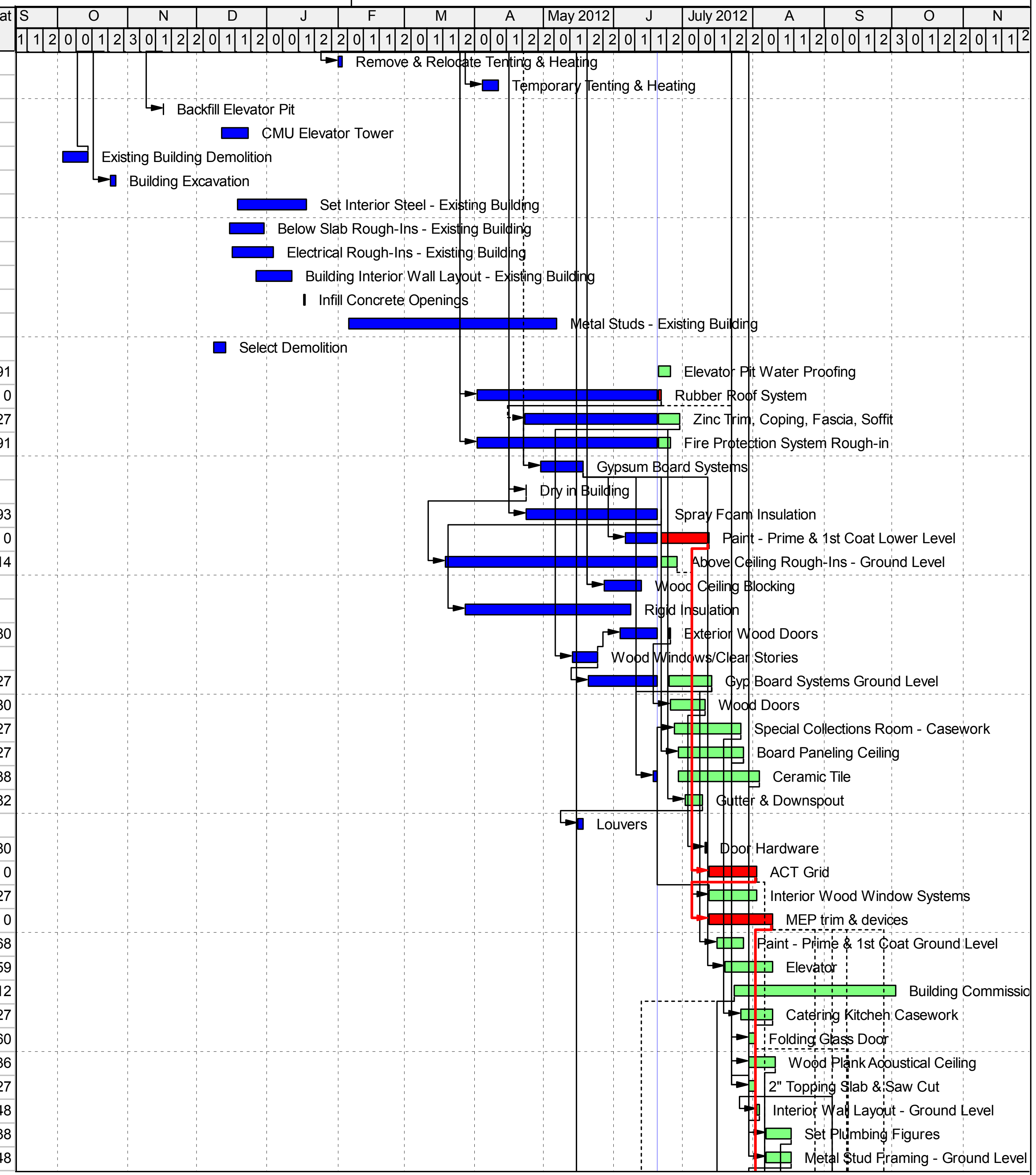
Activity ID	Activity Name	Original Duration	Early Start	Early Finish	Late Start	Late Finish	Activity % Complete	Total Float
A1940	Remove & Relocate Tenting & Heating	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1960	Temporary Tenting & Heating	5	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1930	Backfill Elevator Pit	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2020	CMU Elevator Tower	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1790	Existing Building Demolition	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2030	Building Excavation	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2330	Set Interior Steel - Existing Building	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2430	Below Slab Rough-Ins - Existing Building	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2440	Electrical Rough-Ins - Existing Building	10	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2510	Building Interior Wall Layout - Existing Building	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2520	Infill Concrete Openings	1	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2540	Metal Studs - Existing Building	3	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A2550	Select Demolition	4	20-Jun-12	20-Jun-12	01-Nov-12	01-Nov-12	100%	
A1740	Elevator Pit Water Proofing	4	20-Jun-12	25-Jun-12	26-Oct-12	01-Nov-12	0%	91
A1990	Rubber Roof System	15	20-Jun-12	21-Jun-12	20-Jun-12	21-Jun-12	90%	0
A2000	Zinc Trim, Coping, Fascia, Soffit	20	20-Jun-12	29-Jun-12	27-Jul-12	08-Aug-12	60%	27
A2340	Fire Protection System Rough-in	20	20-Jun-12	25-Jun-12	26-Oct-12	01-Nov-12	80%	91
A2160	Gypsum Board Systems	15	21-Jun-12	21-Jun-12	21-Jun-12	21-Jun-12	100%	
A2040	Dry in Building	1	21-Jun-12	21-Jun-12	12-Jul-12	12-Jul-12	100%	
A1970	Spray Foam Insulation	10	21-Jun-12	21-Jun-12	01-Nov-12	01-Nov-12	95%	93
A2250	Paint - Prime & 1st Coat Lower Level	20	21-Jun-12	12-Jul-12	21-Jun-12	12-Jul-12	30%	0
A2410	Above Ceiling Rough-Ins - Ground Level	25	21-Jun-12	28-Jun-12	12-Jul-12	19-Jul-12	80%	14
A1880	Wood Ceiling Blocking	10	21-Jun-12	21-Jun-12	01-Nov-12	01-Nov-12	100%	
A1980	Rigid Insulation	2	21-Jun-12	21-Jun-12	01-Nov-12	01-Nov-12	100%	
A2110	Exterior Wood Doors	4	25-Jun-12	25-Jun-12	16-Oct-12	17-Oct-12	80%	80
A2500	Wood Windows/Clear Stories	20	25-Jun-12	25-Jun-12	01-Aug-12	01-Aug-12	100%	
A2570	Gyp Board Systems Ground Level	20	25-Jun-12	13-Jul-12	01-Aug-12	21-Aug-12	30%	27
A2050	Wood Doors	10	25-Jun-12	10-Jul-12	17-Oct-12	31-Oct-12	0%	80
A2140	Special Collections Room - Casework	20	27-Jun-12	26-Jul-12	06-Aug-12	04-Sep-12	0%	27
A1900	Board Paneling Ceiling	20	29-Jun-12	27-Jul-12	07-Aug-12	05-Sep-12	0%	27
A2170	Ceramic Tile	25	29-Jun-12	03-Aug-12	22-Aug-12	27-Sep-12	0%	38
A2010	Gutter & Downspout	5	02-Jul-12	09-Jul-12	25-Oct-12	01-Nov-12	0%	82
A2150	Louvers	3	09-Jul-12	09-Jul-12	01-Nov-12	01-Nov-12	100%	
A2130	Door Hardware	1	10-Jul-12	11-Jul-12	31-Oct-12	01-Nov-12	0%	80
A2180	ACT Grid	15	12-Jul-12	02-Aug-12	12-Jul-12	02-Aug-12	0%	0
A2070	Interior Wood Window Systems	15	12-Jul-12	02-Aug-12	20-Aug-12	11-Sep-12	0%	27
A2560	MEP trim & devices	20	12-Jul-12	09-Aug-12	12-Jul-12	09-Aug-12	0%	0
A2580	Paint - Prime & 1st Coat Ground Level	10	16-Jul-12	27-Jul-12	18-Oct-12	01-Nov-12	0%	68
A2320	Elevator	15	19-Jul-12	09-Aug-12	11-Oct-12	01-Nov-12	0%	59
A1910	Building Commissioning	50	23-Jul-12	02-Oct-12	08-Aug-12	18-Oct-12	0%	12
A2100	Catering Kitchen Casework	10	26-Jul-12	09-Aug-12	04-Sep-12	18-Sep-12	0%	27
A2080	Folding Glass Door	3	30-Jul-12	01-Aug-12	22-Oct-12	25-Oct-12	0%	60
A2240	Wood Plank Acoustical Ceiling	10	30-Jul-12	10-Aug-12	18-Sep-12	02-Oct-12	0%	36
A2490	2" Topping Slab & Saw Cut	3	30-Jul-12	01-Aug-12	05-Sep-12	10-Sep-12	0%	27
A2480	Interior Wall Layout - Ground Level	2	02-Aug-12	03-Aug-12	09-Oct-12	11-Oct-12	0%	48
A2360	Set Plumbing Figures	10	06-Aug-12	17-Aug-12	27-Sep-12	11-Oct-12	0%	38
A2390	Metal Stud Framing - Ground Level	10	06-Aug-12	17-Aug-12	11-Oct-12	25-Oct-12	0%	48



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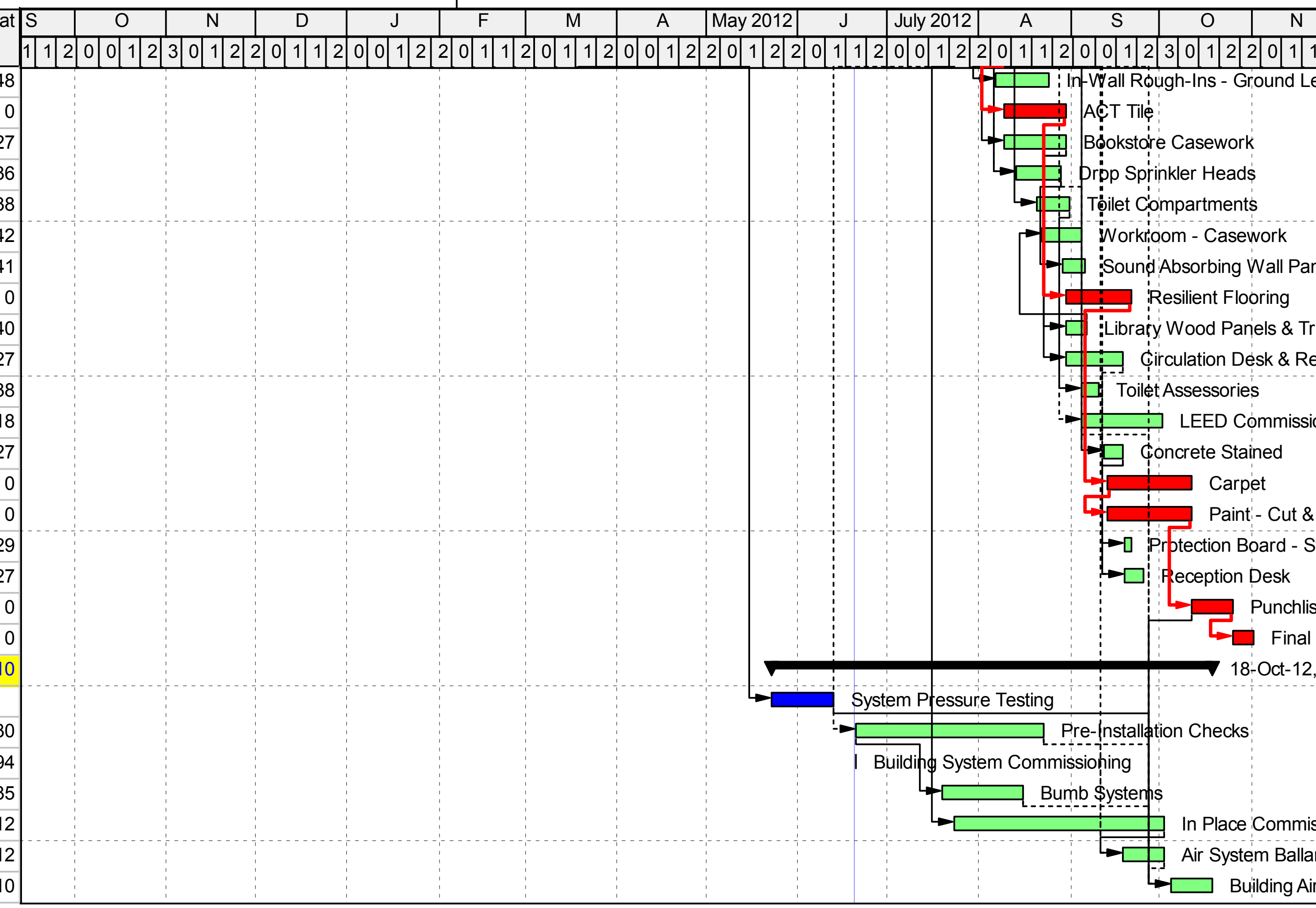
Activity ID	Activity Name	Original Duration	Early Start	Early Finish	Late Start	Late Finish	Activity % Complete	Total Float
A2400	In-Wall Rough-Ins - Ground Level	15	06-Aug-12	24-Aug-12	11-Oct-12	01-Nov-12	0%	48
A2190	ACT Tile	15	09-Aug-12	30-Aug-12	09-Aug-12	30-Aug-12	0%	0
A2090	Bookstore Casework	15	09-Aug-12	30-Aug-12	18-Sep-12	09-Oct-12	0%	27
A2350	Drop Sprinkler Heads	12	13-Aug-12	28-Aug-12	02-Oct-12	18-Oct-12	0%	36
A2270	Toilet Compartments	10	20-Aug-12	31-Aug-12	11-Oct-12	25-Oct-12	0%	38
A2230	Workroom - Casework	8	22-Aug-12	04-Sep-12	22-Oct-12	01-Nov-12	0%	42
A2260	Sound Absorbing Wall Panel	5	29-Aug-12	05-Sep-12	25-Oct-12	01-Nov-12	0%	41
A2210	Resilient Flooring	15	30-Aug-12	21-Sep-12	30-Aug-12	21-Sep-12	0%	0
A1460	Library Wood Panels & Trim	4	30-Aug-12	06-Sep-12	26-Oct-12	01-Nov-12	0%	40
A2310	Circulation Desk & Reading Room Casework	12	30-Aug-12	18-Sep-12	09-Oct-12	25-Oct-12	0%	27
A2280	Toilet Assessories	5	04-Sep-12	10-Sep-12	25-Oct-12	01-Nov-12	0%	38
A1800	LEED Commissioning	20	04-Sep-12	01-Oct-12	27-Sep-12	25-Oct-12	0%	18
A2220	Concrete Stained	5	12-Sep-12	18-Sep-12	18-Oct-12	25-Oct-12	0%	27
A2200	Carpet	20	13-Sep-12	11-Oct-12	13-Sep-12	11-Oct-12	0%	0
A1920	Paint - Cut & Roll Final Coat	20	13-Sep-12	11-Oct-12	13-Sep-12	11-Oct-12	0%	0
A2060	Protection Board - Stained Concrete Floor	3	19-Sep-12	21-Sep-12	29-Oct-12	01-Nov-12	0%	29
A2120	Reception Desk	5	19-Sep-12	25-Sep-12	25-Oct-12	01-Nov-12	0%	27
A1760	Punchlist	10	11-Oct-12	25-Oct-12	11-Oct-12	25-Oct-12	0%	0
A1770	Final Inspections	5	25-Oct-12	01-Nov-12	25-Oct-12	01-Nov-12	0%	0
Building Commissioning		98	20-Jun-12	18-Oct-12	01-Aug-12	01-Nov-12		10
A25	System Pressure Testing	45	20-Jun-12	20-Jun-12	18-Oct-12	18-Oct-12	100%	
A26	Pre-Installation Checks	45	20-Jun-12	22-Aug-12	01-Aug-12	04-Oct-12	0%	30
A26	Building System Commissioning	1	20-Jun-12	20-Jun-12	31-Oct-12	01-Nov-12	0%	94
A26	Bumb Systems	20	19-Jul-12	15-Aug-12	06-Sep-12	04-Oct-12	0%	35
A26	In Place Commissioning	50	23-Jul-12	02-Oct-12	08-Aug-12	18-Oct-12	0%	12
A26	Air System Ballancing	10	18-Sep-12	02-Oct-12	04-Oct-12	18-Oct-12	0%	12
A26	Building Air Blowdown	10	04-Oct-12	18-Oct-12	18-Oct-12	01-Nov-12	0%	10



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Appendix 0.C – LEED Checklist:

LEED 2009 for New Construction and Major Renovations

Project Checklist

Lancaster History.org - Addition and Renovations 09/25/2012

Sustainable Sites — Possible Points: 26

Y	?	N			
13				Sustainable Sites	26
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
		x	Credit 2	Development Density and Community Connectivity	5
		x	Credit 3	Brownfield Redevelopment	1
6			Credit 4.1	Alternative Transportation—Public Transportation Access	6
		x	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
3			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
		x	Credit 4.4	Alternative Transportation—Parking Capacity	2
		x	Credit 5.1	Site Development—Protect or Restore Habitat	1
		x	Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
1			Credit 6.2	Stormwater Design—Quality Control	1
		x	Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
		x	Credit 8	Light Pollution Reduction	1

Water Efficiency — Possible Points: 10

Y	?	N			
6				Water Efficiency	10
Y			Prereq 1	Water Use Reduction—20% Reduction	
4			Credit 1	Water Efficient Landscaping	2 to 4
		x	Credit 2	Innovative Wastewater Technologies	2
2			Credit 3	Water Use Reduction	2 to 4

Energy and Atmosphere — Possible Points: 35

Y	?	N			
24				Energy and Atmosphere	35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
13			Credit 1	Optimize Energy Performance	1 to 19
2			Credit 2	On-Site Renewable Energy	1 to 7
2			Credit 3	Enhanced Commissioning	2
2			Credit 4	Enhanced Refrigerant Management	2
3			Credit 5	Measurement and Verification	3
2			Credit 6	Green Power	2

Materials and Resources — Possible Points: 14

Y	?	N			
9				Materials and Resources	14
Y			Prereq 1	Storage and Collection of Recyclables	
2			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
		x	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
2			Credit 2	Construction Waste Management	1 to 2
		x	Credit 3	Materials Reuse	1 to 2

Materials and Resources, Continued

Y	?	N			
2			Credit 4	Recycled Content	1 to 2
2			Credit 5	Regional Materials	1 to 2
		x	Credit 6	Rapidly Renewable Materials	1
1			Credit 7	Certified Wood	1

Indoor Environmental Quality — Possible Points: 15

Y	?	N			
12				Indoor Environmental Quality	15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
1			Credit 1	Outdoor Air Delivery Monitoring	1
		x	Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
1			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
1			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
1			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
1			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
1			Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
1			Credit 6.2	Controllability of Systems—Thermal Comfort	1
1			Credit 7.1	Thermal Comfort—Design	1
1			Credit 7.2	Thermal Comfort—Verification	1
		x	Credit 8.1	Daylight and Views—Daylight	1
		x	Credit 8.2	Daylight and Views—Views	1

Innovation and Design Process — Possible Points: 6

Y	?	N			
2				Innovation and Design Process	6
1			Credit 1.1	Innovation in Design: Specific Title	1
		x	Credit 1.2	Innovation in Design: Specific Title	1
		x	Credit 1.3	Innovation in Design: Specific Title	1
		x	Credit 1.4	Innovation in Design: Specific Title	1
		x	Credit 1.5	Innovation in Design: Specific Title	1
1			Credit 2	LEED Accredited Professional	1

Regional Priority Credits — Possible Points: 4

Y	?	N			
3				Regional Priority Credits	4
1			Credit 1.1	Regional Priority: Specific Credit	1
1			Credit 1.2	Regional Priority: Specific Credit	1
		x	Credit 1.3	Regional Priority: Specific Credit	1
1			Credit 1.4	Regional Priority: Specific Credit	1

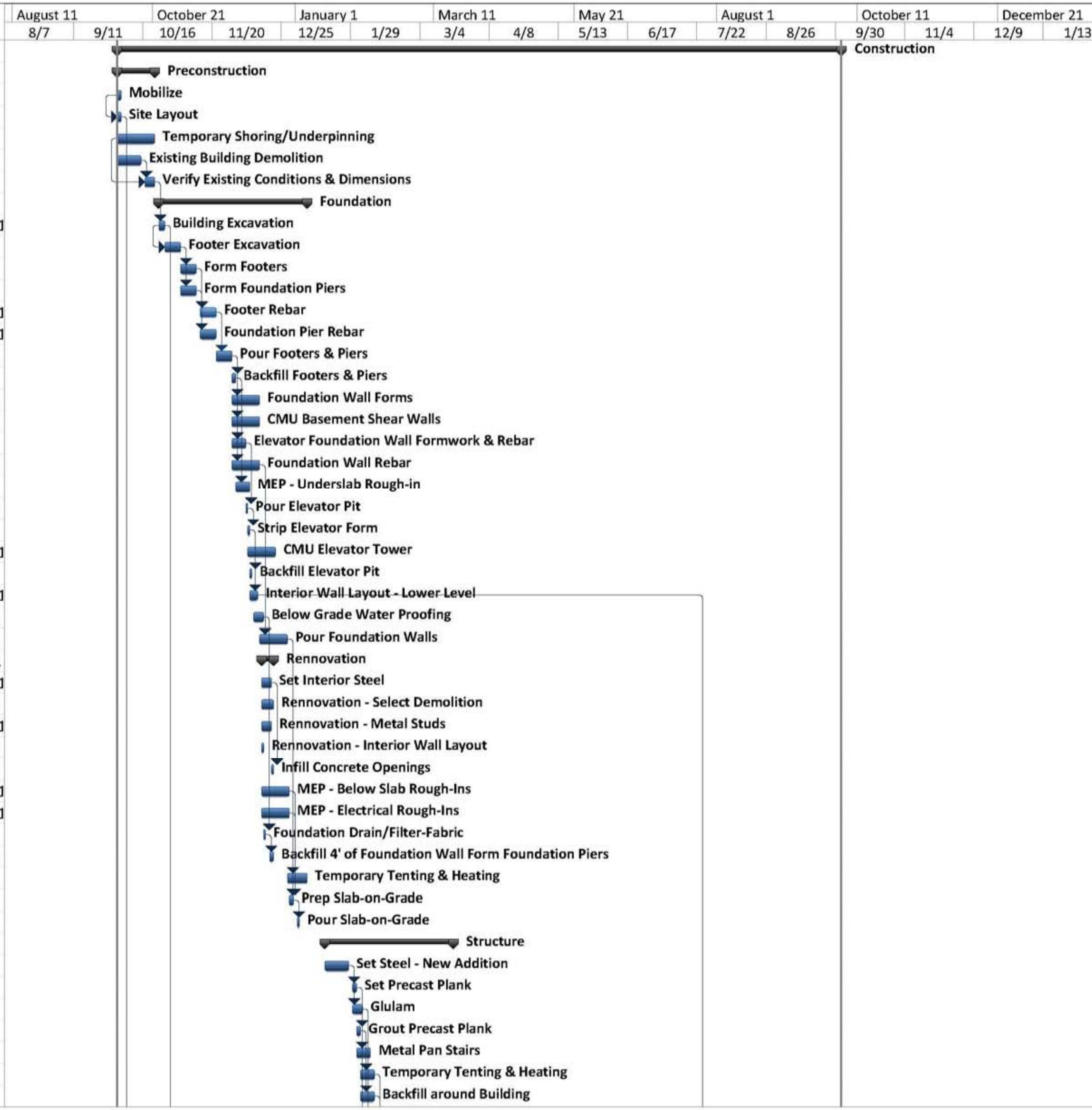
Total — Possible Points: 110

Y	?	N		Possible Points
69			Total	110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

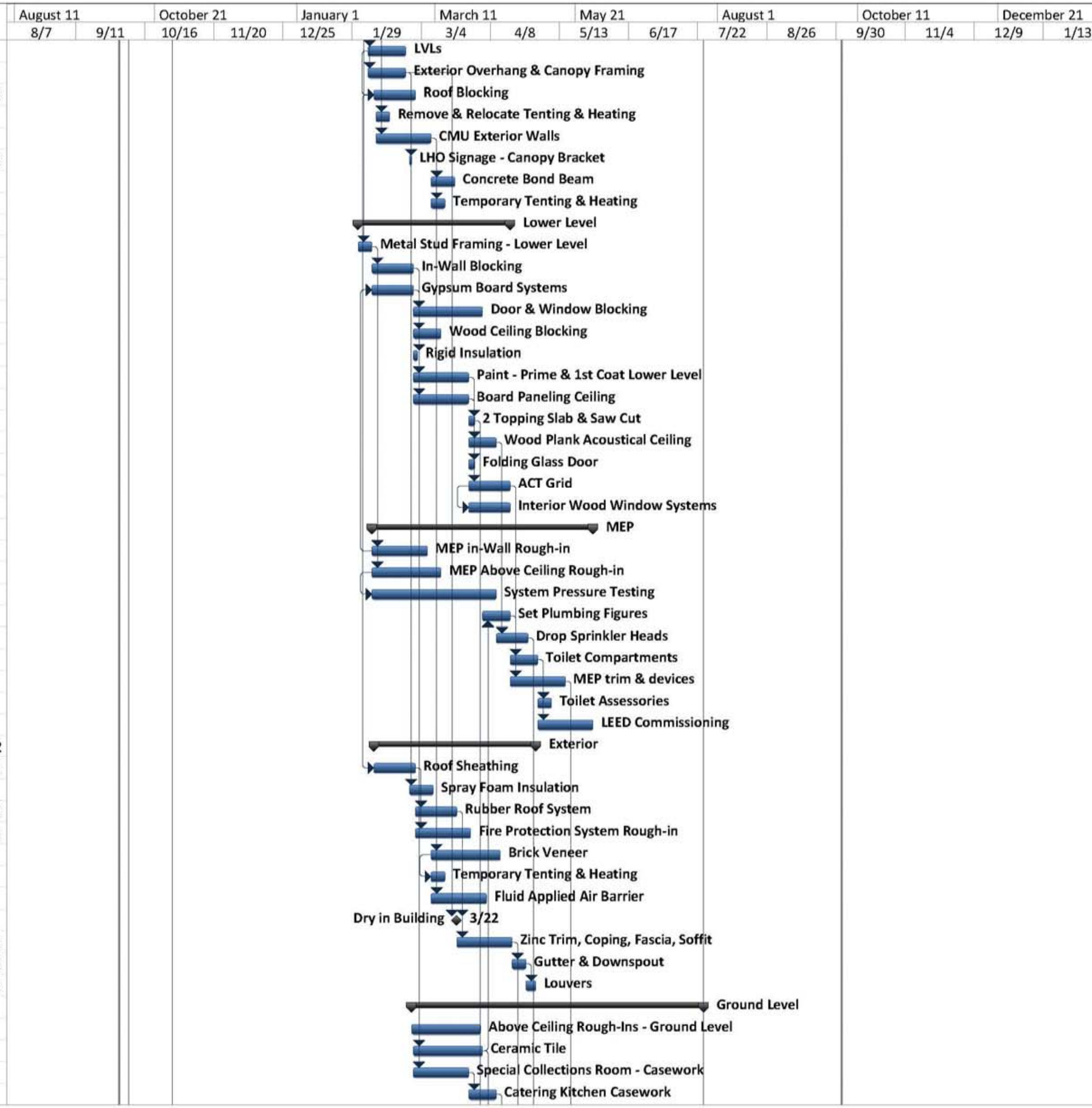
Appendix 1.A – Alternate Construction Schedule:

	Name	Duration	Start	Finish
3	**Construction**	**262 days**	**Mon 10/3/11**	**Tue 10/2/12**
4	**Preconstruction**	**15 days**	**Mon 10/3/11**	**Fri 10/21/11**
5	Mobilize	2 days	Mon 10/3/11	Tue 10/4/11
6	Site Layout	2 days	Mon 10/3/11	Tue 10/4/11
7	Temporary Shoring/Underpinr	15 days	Mon 10/3/11	Fri 10/21/11
8	Existing Building Demolition	10 days	Mon 10/3/11	Fri 10/14/11
9	Verify Existing Conditions & Di	5 days	Mon 10/17/11	Fri 10/21/11
0	**Foundation**	**55 days**	**Mon 10/24/1:**	**Fri 1/6/12**
4	Building Excavation	3 days	Mon 10/24/11	Wed 10/26/11
1	Footer Excavation	6 days	Thu 10/27/11	Thu 11/3/11
2	Form Footers	6 days	Fri 11/4/11	Fri 11/11/11
3	Form Foundation Piers	6 days	Fri 11/4/11	Fri 11/11/11
5	Footer Rebar	6 days	Mon 11/14/11	Mon 11/21/11
6	Foundation Pier Rebar	6 days	Mon 11/14/11	Mon 11/21/11
7	Pour Footers & Piers	6 days	Tue 11/22/11	Tue 11/29/11
8	Backfill Footers & Piers	2 days	Wed 11/30/11	Thu 12/1/11
9	Foundation Wall Forms	10 days	Wed 11/30/11	Tue 12/13/11
0	CMU Basement Shear Walls	10 days	Wed 11/30/11	Tue 12/13/11
1	Elevator Foundation Wall Forn	5 days	Wed 11/30/11	Tue 12/6/11
2	Foundation Wall Rebar	10 days	Wed 11/30/11	Tue 12/13/11
8	MEP - Underslab Rough-in	5 days	Fri 12/2/11	Thu 12/8/11
3	Pour Elevator Pit	1 day	Wed 12/7/11	Wed 12/7/11
4	Strip Elevator Form	1 day	Thu 12/8/11	Thu 12/8/11
3	CMU Elevator Tower	10 days	Thu 12/8/11	Wed 12/21/11
5	Backfill Elevator Pit	1 day	Fri 12/9/11	Fri 12/9/11
6	Interior Wall Layout - Lower Le	2 days	Fri 12/9/11	Mon 12/12/11
5	Below Grade Water Proofing	5 days	Sun 12/11/11	Thu 12/15/11
7	Pour Foundation Walls	10 days	Wed 12/14/11	Tue 12/27/11
9	**Rennovation**	**4 days**	**Thu 12/15/11**	**Tue 12/20/11**
0	Set Interior Steel	3 days	Thu 12/15/11	Mon 12/19/11
2	Rennovation - Select Demol	4 days	Thu 12/15/11	Tue 12/20/11
3	Rennovation - Metal Studs	3 days	Thu 12/15/11	Mon 12/19/11
4	Rennovation - Interior Wall	1 day	Thu 12/15/11	Thu 12/15/11
1	Infill Concrete Openings	1 day	Tue 12/20/11	Tue 12/20/11
6	MEP - Below Slab Rough-Ins	10 days	Thu 12/15/11	Wed 12/28/11
7	MEP - Electrical Rough-Ins	10 days	Thu 12/15/11	Wed 12/28/11
8	Foundation Drain/Filter-Fabric	1 day	Fri 12/16/11	Fri 12/16/11
9	Backfill 4' of Foundation Wall I	2 days	Mon 12/19/11	Tue 12/20/11
0	Temporary Tenting & Heating	8 days	Wed 12/28/11	Fri 1/6/12
1	Prep Slab-on-Grade	2 days	Thu 12/29/11	Fri 12/30/11
2	Pour Slab-on-Grade	1 day	Mon 1/2/12	Mon 1/2/12
4	**Structure**	**47 days**	**Mon 1/16/12**	**Tue 3/20/12**
5	Set Steel - New Addition	10 days	Mon 1/16/12	Fri 1/27/12
6	Set Precast Plank	2 days	Mon 1/30/12	Tue 1/31/12
00	Glulam	5 days	Mon 1/30/12	Fri 2/3/12
7	Grout Precast Plank	2 days	Wed 2/1/12	Thu 2/2/12
01	Metal Pan Stairs	5 days	Wed 2/1/12	Tue 2/7/12
8	Temporary Tenting & Heating	5 days	Fri 2/3/12	Thu 2/9/12
04	Backfill around Building	5 days	Fri 2/3/12	Thu 2/9/12



Page 1

	Name	Duration	Start	Finish
02	LVLs	15 days	Mon 2/6/12	Fri 2/24/12
03	Exterior Overhang & Canopy F	15 days	Mon 2/6/12	Fri 2/24/12
06	Roof Blocking	15 days	Thu 2/9/12	Wed 2/29/12
9	Remove & Relocate Tenting &	5 days	Fri 2/10/12	Thu 2/16/12
05	CMU Exterior Walls	20 days	Fri 2/10/12	Thu 3/8/12
07	LHO Signage - Canopy Bracket	1 day	Mon 2/27/12	Mon 2/27/12
08	Concrete Bond Beam	8 days	Fri 3/9/12	Tue 3/20/12
09	Temporary Tenting & Heating	5 days	Fri 3/9/12	Thu 3/15/12
22	**Lower Level**	**55 days**	**Wed 2/1/12**	**Tue 4/17/12**
23	Metal Stud Framing - Lower Le	5 days	Wed 2/1/12	Tue 2/7/12
24	In-Wall Blocking	15 days	Wed 2/8/12	Tue 2/28/12
27	Gypsum Board Systems	15 days	Wed 2/8/12	Tue 2/28/12
25	Door & Window Blocking	25 days	Wed 2/29/12	Tue 4/3/12
26	Wood Ceiling Blocking	10 days	Wed 2/29/12	Tue 3/13/12
28	Rigid Insulation	2 days	Wed 2/29/12	Thu 3/1/12
29	Paint - Prime & 1st Coat Lowe	20 days	Wed 2/29/12	Tue 3/27/12
30	Board Paneling Ceiling	20 days	Wed 2/29/12	Tue 3/27/12
31	2 Topping Slab & Saw Cut	3 days	Wed 3/28/12	Fri 3/30/12
32	Wood Plank Acoustical Ceiling	10 days	Wed 3/28/12	Tue 4/10/12
33	Folding Glass Door	3 days	Wed 3/28/12	Fri 3/30/12
34	ACT Grid	15 days	Wed 3/28/12	Tue 4/17/12
35	Interior Wood Window Systen	15 days	Wed 3/28/12	Tue 4/17/12
4	**MEP**	**80 days**	**Wed 2/8/12**	**Tue 5/29/12**
5	MEP in-Wall Rough-in	20 days	Wed 2/8/12	Tue 3/6/12
6	MEP Above Ceiling Rough-in	25 days	Wed 2/8/12	Tue 3/13/12
3	System Pressure Testing	45 days	Wed 2/8/12	Tue 4/10/12
7	Set Plumbing Figures	10 days	Wed 4/4/12	Tue 4/17/12
8	Drop Sprinkler Heads	12 days	Wed 4/11/12	Thu 4/26/12
9	Toilet Compartments	10 days	Wed 4/18/12	Tue 5/1/12
1	MEP trim & devices	20 days	Wed 4/18/12	Tue 5/15/12
0	Toilet Assessories	5 days	Wed 5/2/12	Tue 5/8/12
2	LEED Commissioning	20 days	Wed 5/2/12	Tue 5/29/12
10	**Exterior**	**58 days**	**Thu 2/9/12**	**Mon 4/30/12**
12	Roof Sheathing	15 days	Thu 2/9/12	Wed 2/29/12
13	Spray Foam Insulation	10 days	Mon 2/27/12	Fri 3/9/12
16	Rubber Roof System	15 days	Thu 3/1/12	Wed 3/21/12
20	Fire Protection System Rough-	20 days	Thu 3/1/12	Wed 3/28/12
14	Brick Veneer	25 days	Fri 3/9/12	Thu 4/12/12
15	Temporary Tenting & Heating	5 days	Fri 3/9/12	Thu 3/15/12
21	Fluid Applied Air Barrier	20 days	Fri 3/9/12	Thu 4/5/12
11	Dry in Building	0 days	Thu 3/22/12	Thu 3/22/12
17	Zinc Trim, Coping, Fascia, Soffi	20 days	Thu 3/22/12	Wed 4/18/12
18	Gutter & Downspout	5 days	Thu 4/19/12	Wed 4/25/12
19	Louvers	3 days	Thu 4/26/12	Mon 4/30/12
36	**Ground Level**	**106 days**	**Tue 2/28/12**	**Tue 7/24/12**
37	Above Ceiling Rough-Ins - Grou	25 days	Tue 2/28/12	Mon 4/2/12
38	Ceramic Tile	25 days	Wed 2/29/12	Tue 4/3/12
43	Special Collections Room - Cas	20 days	Wed 2/29/12	Tue 3/27/12
44	Catering Kitchen Casework	10 days	Wed 3/28/12	Tue 4/10/12



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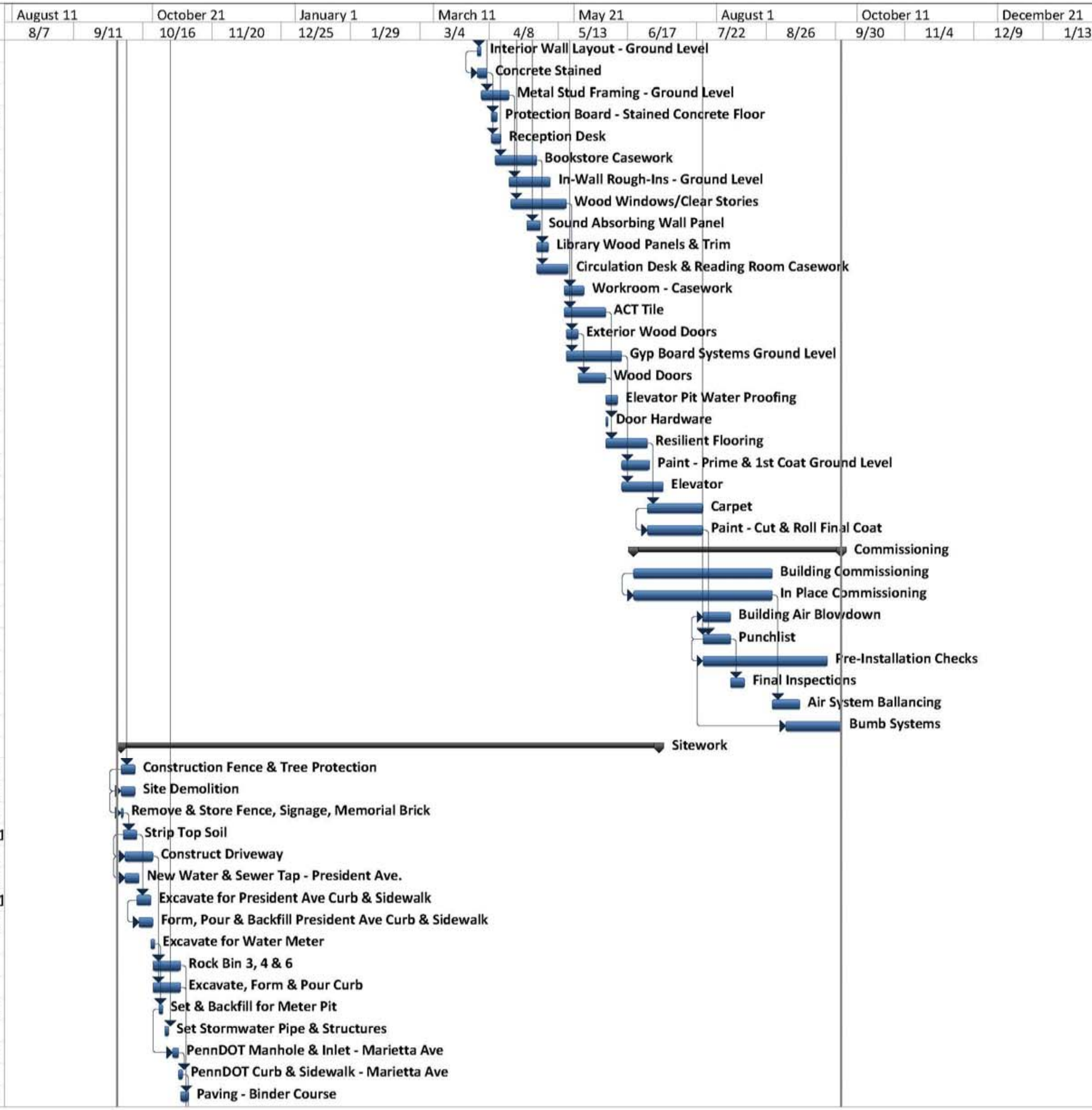
	Name	Duration	Start	Finish
39	Interior Wall Layout - Ground	2 days	Mon 4/2/12	Tue 4/3/12
40	Concrete Stained	5 days	Mon 4/2/12	Fri 4/6/12
49	Metal Stud Framing - Ground I	10 days	Wed 4/4/12	Tue 4/17/12
41	Protection Board - Stained Cor	3 days	Mon 4/9/12	Wed 4/11/12
42	Reception Desk	5 days	Mon 4/9/12	Fri 4/13/12
46	Bookstore Casework	15 days	Wed 4/11/12	Tue 5/1/12
50	In-Wall Rough-Ins - Ground Le	15 days	Wed 4/18/12	Tue 5/8/12
51	Wood Windows/Clear Stories	20 days	Thu 4/19/12	Wed 5/16/12
55	Sound Absorbing Wall Panel	5 days	Fri 4/27/12	Thu 5/3/12
47	Library Wood Panels & Trim	4 days	Wed 5/2/12	Mon 5/7/12
48	Circulation Desk & Reading Ro	12 days	Wed 5/2/12	Thu 5/17/12
59	Workroom - Casework	8 days	Wed 5/16/12	Fri 5/25/12
60	ACT Tile	15 days	Wed 5/16/12	Tue 6/5/12
62	Exterior Wood Doors	4 days	Thu 5/17/12	Tue 5/22/12
56	Gyp Board Systems Ground Le	20 days	Thu 5/17/12	Wed 6/13/12
53	Wood Doors	10 days	Wed 5/23/12	Tue 6/5/12
45	Elevator Pit Water Proofing	4 days	Wed 6/6/12	Mon 6/11/12
54	Door Hardware	1 day	Wed 6/6/12	Wed 6/6/12
61	Resilient Flooring	15 days	Wed 6/6/12	Tue 6/26/12
57	Paint - Prime & 1st Coat Grour	10 days	Thu 6/14/12	Wed 6/27/12
58	Elevator	15 days	Thu 6/14/12	Wed 7/4/12
52	Carpet	20 days	Wed 6/27/12	Tue 7/24/12
63	Paint - Cut & Roll Final Coat	20 days	Wed 6/27/12	Tue 7/24/12
64	**Commissioning**	**75 days**	**Wed 6/20/12**	**Tue 10/2/12**
65	Building Commissioning	50 days	Wed 6/20/12	Tue 8/28/12
66	In Place Commissioning	50 days	Wed 6/20/12	Tue 8/28/12
68	Building Air Blowdown	10 days	Wed 7/25/12	Tue 8/7/12
69	Punchlist	10 days	Wed 7/25/12	Tue 8/7/12
71	Pre-Installation Checks	45 days	Wed 7/25/12	Tue 9/25/12
70	Final Inspections	5 days	Wed 8/8/12	Tue 8/14/12
67	Air System Ballancing	10 days	Wed 8/29/12	Tue 9/11/12
72	Bumb Systems	20 days	Wed 9/5/12	Tue 10/2/12
1	**Sitework**	**194 days**	**Wed 10/5/11**	**Mon 7/2/12**
2	Construction Fence & Tree Prote	5 days	Wed 10/5/11	Tue 10/11/11
3	Site Demolition	5 days	Wed 10/5/11	Tue 10/11/11
4	Remove & Store Fence, Signage,	1 day	Wed 10/5/11	Wed 10/5/11
5	Strip Top Soil	5 days	Thu 10/6/11	Wed 10/12/11
8	Construct Driveway	10 days	Fri 10/7/11	Thu 10/20/11
9	New Water & Sewer Tap - Presid	5 days	Fri 10/7/11	Thu 10/13/11
6	Excavate for President Ave Curb	5 days	Thu 10/13/11	Wed 10/19/11
7	Form, Pour & Backfill President A	5 days	Fri 10/14/11	Thu 10/20/11
14	Excavate for Water Meter	2 days	Thu 10/20/11	Fri 10/21/11
11	Rock Bin 3, 4 & 6	10 days	Fri 10/21/11	Thu 11/3/11
12	Excavate, Form & Pour Curb	10 days	Fri 10/21/11	Thu 11/3/11
15	Set & Backfill for Meter Pit	2 days	Mon 10/24/11	Tue 10/25/11
10	Set Stormwater Pipe & Structure	2 days	Thu 10/27/11	Fri 10/28/11
17	PennDOT Manhole & Inlet - Mari	3 days	Mon 10/31/11	Wed 11/2/11
18	PennDOT Curb & Sidewalk - Mari	2 days	Thu 11/3/11	Fri 11/4/11
13	Paving - Binder Course	2 days	Fri 11/4/11	Mon 11/7/11



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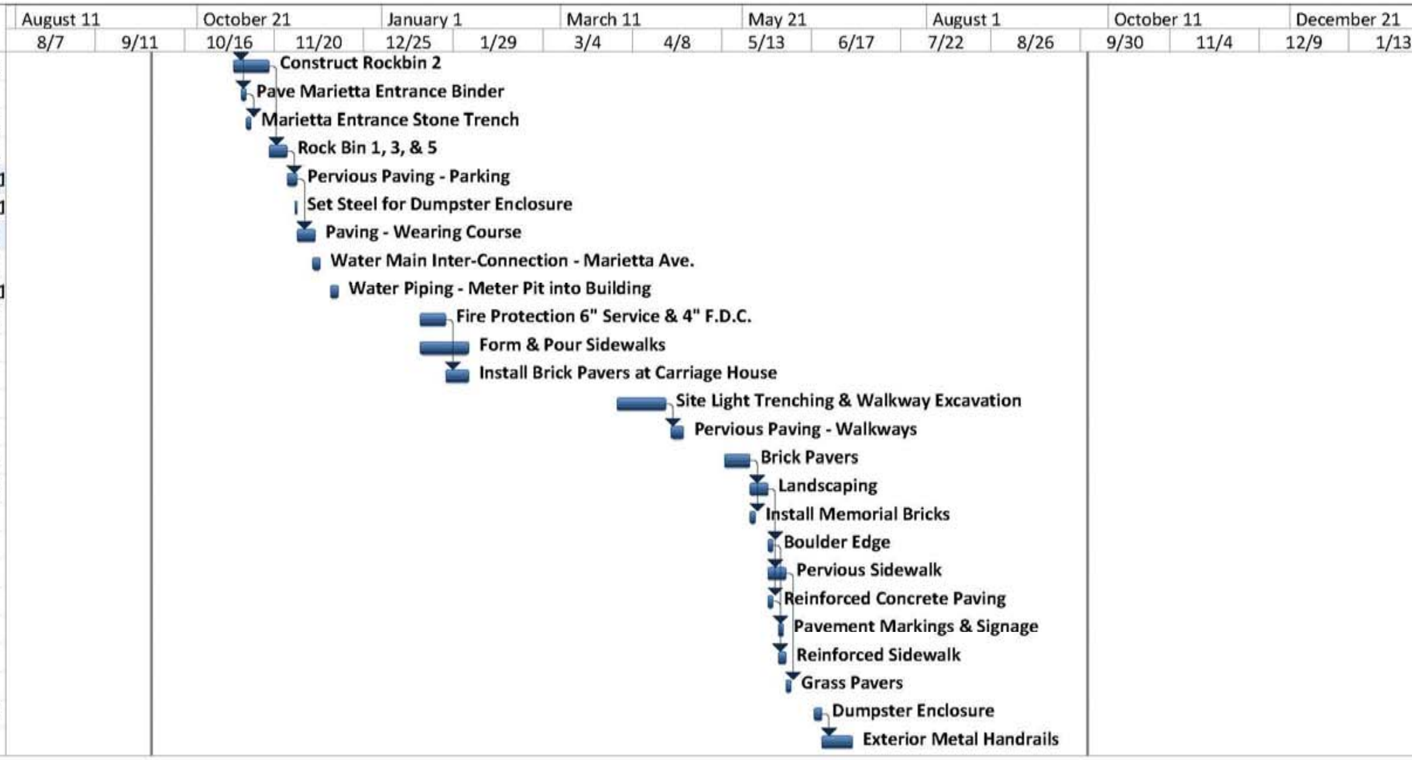
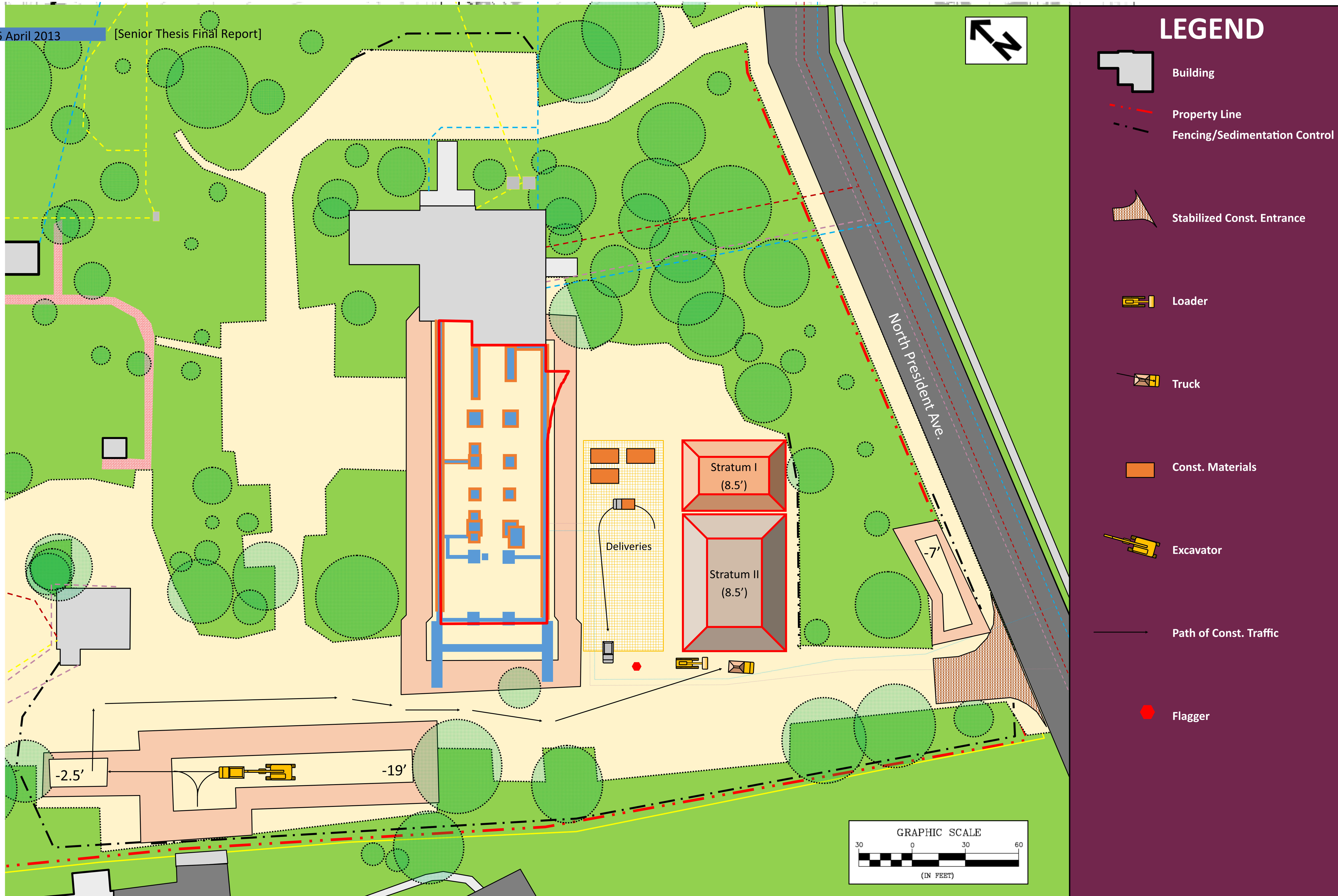
	Name	Duration	Start	Finish
4	Construct Rockbin 2	10 days	Fri 11/4/11	Thu 11/17/11
0	Pave Marietta Entrance Binder	2 days	Mon 11/7/11	Tue 11/8/11
1	Marietta Entrance Stone Trench	2 days	Wed 11/9/11	Thu 11/10/11
6	Rock Bin 1, 3, & 5	5 days	Fri 11/18/11	Thu 11/24/11
0	Pervious Paving - Parking	2 days	Fri 11/25/11	Mon 11/28/11
3	Set Steel for Dumpster Enclosure	1 day	Mon 11/28/11	Mon 11/28/11
6	Paving - Wearing Course	5 days	Tue 11/29/11	Mon 12/5/11
6	Water Main Inter-Connection - M	3 days	Mon 12/5/11	Wed 12/7/11
2	Water Piping - Meter Pit into Bui	3 days	Mon 12/12/11	Wed 12/14/11
9	Fire Protection 6" Service & 4" F.	8 days	Mon 1/16/12	Wed 1/25/12
9	Form & Pour Sidewalks	15 days	Mon 1/16/12	Fri 2/3/12
5	Install Brick Pavers at Carriage H	7 days	Thu 1/26/12	Fri 2/3/12
7	Site Light Trenching & Walkway E	15 days	Mon 4/2/12	Fri 4/20/12
1	Pervious Paving - Walkways	5 days	Mon 4/23/12	Fri 4/27/12
2	Brick Pavers	8 days	Mon 5/14/12	Wed 5/23/12
4	Landscaping	5 days	Thu 5/24/12	Wed 5/30/12
5	Install Memorial Bricks	2 days	Thu 5/24/12	Fri 5/25/12
7	Boulder Edge	2 days	Thu 5/31/12	Fri 6/1/12
9	Pervious Sidewalk	5 days	Thu 5/31/12	Wed 6/6/12
0	Reinforced Concrete Paving	2 days	Thu 5/31/12	Fri 6/1/12
8	Pavement Markings & Signage	2 days	Mon 6/4/12	Tue 6/5/12
1	Reinforced Sidewalk	3 days	Mon 6/4/12	Wed 6/6/12
2	Grass Pavers	2 days	Thu 6/7/12	Fri 6/8/12
8	Dumpster Enclosure	3 days	Mon 6/18/12	Wed 6/20/12
3	Exterior Metal Handrails	8 days	Thu 6/21/12	Mon 7/2/12



Appendix 1.B – Site Plan for Rock Bins 3, 4 & 6:


LEGEND
Building
Property Line
Fencing/Sedimentation Control
Stabilized Const. Entrance
Loader
Truck
Const. Materials
Excavator
Path of Const. Traffic
Flagger
North President Ave.
Stratum I
(8.5')
Stratum II
(8.5')
Deliveries
-7'
-2.5'
-19'
GRAPHIC SCALE
30 0 30 60
(IN FEET)

Appendix 1.C – Earth Moving Estimates:

Earth Moving Estimate - As Planned							Duration		
Cost Code	*Item Description*	*Qty.*	*Unit*	*Price $/Unit*	*Grand Total*	*Area Total*	*Hours/Unit*	*Total Hours*	*Area Total (days)*
1	Building (inc. footers) - Excavate to Grade	6,124	CY	$ 5.00	$ 30,620.00	$ 175,866.00	0.0041667	26	34
2	Load & Haul - Off Site	5,765	CY	$ 20.00	$ 115,300.00		0.0333333	192	
3	Load & Haul - On Site	1,584	CY	$ 8.00	$ 12,672.00		0.0033333	5	
4	Place & Compact Soil	1,584	CY	$ 8.00	$ 12,672.00		0.0252525	40	
5	2A Stone Delivered	177	CY	$ 18.00	$ 3,186.00		0.0338066	6	
6	Place & Compact Stone	177	CY	$ 8.00	$ 1,416.00		0.0142929	3	
7	Rock Bins 3, 6, and 4 - Excavate to Grade	2,429	CY	$ 5.00	$ 12,145.00	$ 66,703.00	0.0041667	10	13
8	Load & Haul - Off Site	309	CY	$ 20.00	$ 6,180.00		0.0333333	10	
9	Load & Haul - On Site	2,606	CY	$ 8.00	$ 20,848.00		0.0033333	9	
10	Place & Compact Soil	2,606	CY	$ 8.00	$ 20,848.00		0.0252525	66	
11	2A Stone Delivered	257	CY	$ 18.00	$ 4,626.00		0.0338066	9	
12	Place & Compact Stone	257	CY	$ 8.00	$ 2,056.00		0.0142929	4	
13	Rock Bin 2 - Excavate to Grade	1,101	CY	$ 5.00	$ 5,505.00	$ 37,049.00	0.0041667	5	8
14	Load & Haul - Off Site	405	CY	$ 20.00	$ 8,100.00		0.0333333	13	
15	Load & Haul - On Site	916	CY	$ 8.00	$ 7,328.00		0.0033333	3	
16	Place & Compact Soil	916	CY	$ 8.00	$ 7,328.00		0.0252525	23	
17	2A Stone Delivered	338	CY	$ 18.00	$ 6,084.00		0.0338066	11	
18	Place & Compact Stone	338	CY	$ 8.00	$ 2,704.00		0.0142929	5	
19	Rock Bins 1 and 5 - Excavate to Grade	1,120	CY	$ 5.00	$ 5,600.00	$ 46,046.00	0.0041667	5	10
20	Load & Haul - Off Site	738	CY	$ 20.00	$ 14,760.00		0.0333333	25	
21	Load & Haul - On Site	606	CY	$ 8.00	$ 4,848.00		0.0033333	2	
22	Place & Compact Soil	606	CY	$ 8.00	$ 4,848.00		0.0252525	15	
23	2A Stone Delivered	615	CY	$ 18.00	$ 11,070.00		0.0338066	21	
24	Place & Compact Stone	615	CY	$ 8.00	$ 4,920.00		0.0142929	9	
25	Driveway - Excavate to Grade	367	CY	$ 5.00	$ 1,835.00	$ 9,889.00	0.0041667	2	2
26	Load & Haul - Off Site	39	CY	$ 20.00	$ 780.00		0.0333333	1	
27	Load & Haul - On Site	401	CY	$ 8.00	$ 3,208.00		0.0033333	1	
28	Place & Compact Soil	401	CY	$ 8.00	$ 3,208.00		0.0252525	10	
29	2A Stone Delivered	33	CY	$ 18.00	$ 594.00		0.0338066	1	
30	Place & Compact Stone	33	CY	$ 8.00	$ 264.00		0.0142929	0	

	Grand Total	*Duration Total (days)*
Subtotal	**$ 335,553.00**	**66**
Tax (6%)	**$ 20,133.18**	
Overhead & Profit (10%)	**$ 33,555.30**	
Earth Moving Grand Total	**$ 389,241.48**	

Earth Moving Estimate - As Performed							Duration		
Cost Code	***Item Description***	***Qty.***	***Unit***	***Price $/Unit***	***Grand Total***	***Area Total***	***Hours/Unit***	***Total Hours***	***Area Total (days)***
1	Building (inc. footers) - Excavate to Grade	6,124	CY	$ 5.00	$ 30,620.00	$ 175,382.00	0.0041667	26	34
2	Load & Haul - Off Site	5,580	CY	$ 20.00	$ 111,600.00		0.0333333	186	
3	Load & Haul - On Site	849	CY	$ 8.00	$ 6,792.00		0.0033333	3	
4	Place & Compact Soil	849	CY	$ 8.00	$ 6,792.00		0.0252525	21	
5	2A Stone Delivered	753	CY	$ 18.00	$ 13,554.00		0.0338066	25	
6	Place & Compact Stone	753	CY	$ 8.00	$ 6,024.00		0.0142929	11	
7	Rock Bins 3, 6, and 4 - Excavate to Grade	2,919	CY	$ 5.00	$ 14,595.00	$ 71,113.00	0.0041667	12	14
8	Load & Haul - Off Site	799	CY	$ 20.00	$ 15,980.00		0.0333333	27	
9	Load & Haul - On Site	2,116	CY	$ 8.00	$ 16,928.00		0.0033333	7	
10	Place & Compact Soil	2,116	CY	$ 8.00	$ 16,928.00		0.0252525	53	
11	2A Stone Delivered	257	CY	$ 18.00	$ 4,626.00		0.0338066	9	
12	Place & Compact Stone	257	CY	$ 8.00	$ 2,056.00		0.0142929	4	
13	Rock Bin 2 - Excavate to Grade	1,473	CY	$ 5.00	$ 7,365.00	$ 73,027.00	0.0041667	6	15
14	Load & Haul - Off Site	1,496	CY	$ 20.00	$ 29,920.00		0.0333333	50	
15	2A Stone Delivered	1731	CY	$ 18.00	$ 31,158.00		0.0338066	59	
16	Place & Compact Stone	573	CY	$ 8.00	$ 4,584.00		0.0142929	8	
17	Rock Bins 1 and 5 - Excavate to Grade	1,120	CY	$ 5.00	$ 5,600.00	$ 46,046.00	0.0041667	5	10
18	Load & Haul - Off Site	738	CY	$ 20.00	$ 14,760.00		0.0333333	25	
19	Load & Haul - On Site	606	CY	$ 8.00	$ 4,848.00		0.0033333	2	
20	Place & Compact Soil	606	CY	$ 8.00	$ 4,848.00		0.0252525	15	
21	2A Stone Delivered	615	CY	$ 18.00	$ 11,070.00		0.0338066	21	
22	Place & Compact Stone	615	CY	$ 8.00	$ 4,920.00		0.0142929	9	
23	Driveway - Excavate to Grade	917	CY	$ 5.00	$ 4,585.00	$ 32,439.00	0.0041667	4	7
24	Load & Haul - Off Site	589	CY	$ 20.00	$ 11,780.00		0.0333333	20	
25	Load & Haul - On Site	951	CY	$ 8.00	$ 7,608.00		0.0033333	3	
26	Place & Compact Soil	951	CY	$ 8.00	$ 7,608.00		0.0252525	24	
27	2A Stone Delivered	33	CY	$ 18.00	$ 594.00		0.0338066	1	
28	Place & Compact Stone	33	CY	$ 8.00	$ 264.00		0.0142929	0	

	Grand Total
Subtotal	**$ 398,007.00**
Tax (6%)	**$ 23,880.42**
Overhead & Profit (10%)	**$ 39,800.70**
Earth Moving Grand Total	**$ 461,688.12**

Duration Total (days)
79

Appendix 1.D – Earth Moving Quantity Calculations:

Building Footprint

Equation 4 - Building Excavation to Grade from Existing Building to South Facade

$$A = W \times L = [61' + 2(2')](137' + 2') = 9{,}055\ ft^2$$

$$V = A \times D = (9{,}055\ ft^2)(10.5')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 3{,}460\ yd^3$$

Equation 5 - Building Excavation to Grade to the West of Existing Building

$$A = W \times L = (15' + 2') \times (29') = 493\ ft^2$$

$$V = A \times D = (493\ ft^2)(9')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 163\ yd^3$$

Equation 6 - Building Excavation to Grade between Retaining Walls

$$A = W \times L = [66.8' + 2(2')](16' + 2') = 1{,}275\ ft^2$$

$$V = A \times D = (1{,}275\ ft^2)(9')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 423\ yd^3$$

Equation 7 - Slope to Grade on Building East Side

$$V = L \times \left[{(D)^2}/{Slope}\right] = (159.6')\left[{(9.9')^2}/{1.5}\right]\left({1\ ft^3}/{27\ yd^3}\right) = 430\ yd^3$$

Equation 8 - Slope to Grade on Building South Side

$$V = L \times \left[{(D)^2}/{Slope}\right] = (66.8')\left[{(8.9')^2}/{1.5}\right]\left({1\ ft^3}/{27\ yd^3}\right) = 145\ yd^3$$

Equation 9 - Slope to Grade on Building West Side

$$V = L \times \left[{(D)^2}/{Slope}\right] = (188.6')\left[{(10.8')^2}/{1.5}\right]\left({1\ ft^3}/{27\ yd^3}\right) = 605\ yd^3$$

Equation 10 - Total Excavation to Grade Amount for Building Footprint

$$V_{total} = \sum V_{building} + \sum V_{slope} =$$
$$(3{,}460\ yd^3 + 163\ yd^3 + 423\ yd^3) + (430\ yd^3 + 145\ yd^3 + +605 + 40\ yd^3) =$$
$$5{,}266\ yd^3$$

Rock Bins

Equation 11 - Excavation to Grade in Rock Bin 3

$$V = L \times W \times D = [(30' \times 36' \times 19') + (19' \times 100' \times 19')]\left(\frac{1\ ft^3}{27\ yd^3}\right) = 2{,}097\ yd^3$$

Equation 12 - Excavation to Grade in Rock Bin 4

$$V = L \times W \times D = (63' \times 20' \times 2.5')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 115\ yd^3$$

Equation 13 - Excavation to Grade in Rock Bin 6

$$V = L \times W \times D = \left[(60' \times 15' \times 7') + \frac{1}{2}(10' \times 30' \times 7')\right]\left(\frac{1\ ft^3}{27\ yd^3}\right) = 272\ yd^3$$

Equation 14 - Excavation to Grade in Rock Bin 5

$$V = L \times W \times D = (60' \times 38' \times 3.5')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 296\ yd^3$$

Equation 15 - Excavation to Grade in Rock Bin 1

$$V = L \times W \times D = (120' \times 53' \times 3.5')\left(\frac{1\ ft^3}{27\ yd^3}\right) = 824\ yd^3$$

Equation 16 - Excavation to Grade in Rock Bin 2

$$V = L \times W \times D = (101.6' \times 39' \times 7.5')\left(1\,ft^3 / 27\,yd^3\right) = 1{,}101\,yd^3$$

Equation 17 - Total Excavation to Grade Amount for Rock Bins

$$V_{rock\ bins} = \sum V = 2{,}097\,yd^3 + 115\,yd^3 + 272\,yd^3 + 296\,yd^3 + 824\,yd^3 + 1{,}101\,yd^3 =$$

$$= 4{,}705\,yd^3$$

Assume: 15% additional volume for rock bin slope

$$V_{total} = 1.15(4{,}705\,yd^3) = 5{,}411\,yd^3$$

Pervious Paving

Equation 18 - Excavation to Grade in Driveway to the East of the Addition

$$V = A \times D = (2{,}475' \times 4')\left(1\,ft^3 / 27\,yd^3\right) = 367\,yd^3$$

Appendix 1.E – Foundation Wall Structural Calculations:

Foundation Wall Structural Calcs.

STEM

Soil bearing pressure

$$\sigma_H = \gamma_e H = 120\,pcf\,(11.75') = 1.41\ klf$$

Maximum shear force

$$V_{max} = \frac{2}{3}\left(\frac{\sigma_H H}{2}\right) = \frac{2}{3}\left(\frac{1{,}410\,psf \cdot 11.75'}{2}\right) = 5.522\ kips$$

$$M_{max} = \frac{\sigma_H H^2}{9\sqrt{3}} = \frac{1{,}410\,psf\,(11.75')^2}{9\sqrt{3}} = 12.488\ ft\text{-}kips$$

$$d = 16'' - 2'' - \frac{.5''}{2} = 13.75''$$

reduced shear capacity

$$\phi V_n = \phi 2\sqrt{f'_c}\,bd = 0.75(2)\sqrt{3\,ksi}\,(12'')(13.75'') = 13{,}557.16$$

$$\phi V_n = 13.6\,k \geq V_{max} = 5.5\,k \quad \checkmark$$

depth of the compression block of conc. ⊥ bending

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(.207\ in^2/ft)(60\,ksi)}{0.85\,(4\,ksi)(12'')} = 0.3044''$$

depth of neutral axis

$$c = \frac{a}{\beta_1} = \frac{0.3044''}{0.85} = 0.385''$$

strain of steel

$$\varepsilon_1 = \frac{0.003}{c}(d-c) = \frac{0.003}{0.385''}(13.75'' - 0.385'') = 0.10414$$

$$0.10414 \geq 0.005 \quad \therefore \phi = 0.9$$

reduced moment capacity

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$$= 0.9\,(0.207\ in^2/ft.)(60\ ksi)\left(13.75'' - \frac{0.3044''}{2}\right)$$

$$= 12.67'\,kips$$

$$\phi M_n = 12.67'\,kips \geq M_u = 12.49'\,kips \quad \checkmark$$

steel to conc. ratio

$$\rho = \frac{A_s}{bd} = \frac{0.207\ in^2/ft}{(12'')(13.75'')}$$

$$= 0.00125 \geq 0.0012 \quad \checkmark$$

$$\rho = \frac{A_s}{bd} = \frac{0.200\ in^2/ft}{(12'')(16'')}$$

$$= 0.00208 \geq 0.002 \quad \checkmark$$

TOE

$$d = 12'' - 3'' - \frac{.625''}{2} = 8.688''$$

max mom. on toe

$$M_u = \frac{(\text{Soil Bearing Capacity})(1'5'')^2}{2} = \frac{2.5\,ksf\,(1.41\bar{6}')^2}{2}$$

$$= 2.509'k$$

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.413\ in^2/ft)(60\ ksi)}{0.85\,(4\ ksi)(12'')}$$

$$= 0.6074''$$

$$c = \frac{a}{\beta_1} = \frac{0.6074''}{0.85}$$

$$= 0.7145''$$

$$\varepsilon_1 = \frac{0.003}{c}(d-c) = \frac{0.003}{0.7145''}(8.688'' - 0.7145'')$$

$$= 0.03348$$

$$0.03348 \geq 0.005 \therefore \phi = 0.9$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.9(60ksi)(.413 in^2/ft)\left(8.69'' - \frac{0.6078''}{2}\right)$$

$$= 15.582'k$$

$$\phi M_n = 15.582'k \geq M_u = 2.509'k \checkmark$$

$$\rho = \frac{A_s}{bh} = \frac{0.413 in^2/ft}{(12'')(12'')}$$

$$= 0.002868 \geq 0.0018 \checkmark$$

$$\rho = \frac{A_s}{bh} = \frac{0.372 in^2/ft}{(12'')(12'')}$$

$$= 0.002583 \geq 0.0018 \checkmark$$

Foundation Wall Redesign

STEM

Soil bearing pressure

$$\sigma_H = \gamma_e H = 105\,pcf\,(11.75') = 1.23\text{ klf}$$

maximum shear force

$$V_{max} = \frac{2}{3}\left(\frac{\sigma_H H}{2}\right) = \frac{2}{3}\left(\frac{1{,}230\,psf \cdot 11.75'}{2}\right)$$

$$= 4.83\text{ kips}$$

$$M_{max} = \frac{\sigma_H H^2}{9\sqrt{3}} = \frac{1{,}230\,psf\,(11.75')^2}{9\sqrt{3}}$$

$$= 10{,}893\text{ ft-kips}$$

$$d = 16'' - 2'' - \frac{.5''}{2} = 13.75''$$

reduced shear capacity

$$\phi V_n = \phi\, 2\sqrt{f'_c}\, bd = 0.75\,(2)\sqrt{3\,ksi}\,(12'')(13.75'') = 13{,}557.16$$

$$\phi V_n = 13.6\,k \geq V_{max} = 4.83\,k \quad \checkmark$$

depth of the compression block of concrete under loading

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(.200\,in^2/ft)(60\,ksi)}{0.85\,(4\,ksi)(12'')}$$

$$= 0.2941''$$

depth of neutral axis

$$c = \frac{a}{\beta_1} = \frac{0.2941''}{0.85}$$

$$= 0.3460''$$

strain

$$\varepsilon_1 = \frac{0.003}{c}(d - c) = \frac{0.003}{0.346''}(13.75'' - 0.346'')$$

$$= 0.1162$$

$$0.1162 \geq 0.005 \quad \therefore \phi = 0.9$$

reduced nominal capacity

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$$= 0.9\,(0.200 \text{ in}^2/\text{ft.})(60 \text{ ksi})\left(13.75'' - \frac{0.1764''}{2}\right)$$

$$= 12.32' \text{ kips}$$

$$\phi M_n = 12.32' \text{ kips} \geq M_u = 10.89' \text{ kips} \quad \checkmark$$

steel to conc. ratio

$$\rho = \frac{A_s}{bd} = \frac{0.200 \text{ in}^2/\text{ft}}{(12'')(13.75'')}$$

$$= 0.00121 \geq 0.0012 \quad \checkmark$$

$$\rho = \frac{A_s}{bd} = \frac{0.200 \text{ in}^2/\text{ft}}{(12'')(16'')}$$

$$= 0.00208 \geq 0.002 \quad \checkmark$$

TOE

$$d = 12'' - 3'' - \frac{.5''}{2} = 8.75''$$

max mom. on toe

$$M_u = \frac{(\text{Soil Bearing Capacity})(1'5'')^2}{2} = \frac{2.5 \text{ ksf}\,(1.41\overline{6}')^2}{2}$$

$$= 2.509' k$$

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.267 \text{ in}^2/\text{ft})(60 \text{ ksi})}{0.85\,(4 \text{ ksi})(12'')}$$

$$= 0.3926$$

$$c = \frac{a}{\beta_1} = \frac{0.3926}{0.85}$$

$$= 0.4619$$

$$\varepsilon_1 = \frac{0.003}{c}(d-c) = \frac{0.003}{0.4619}(8.75" - 0.4619")$$

$$= 0.0538$$

$$0.0538 \geq 0.005 \therefore \phi = 0.9$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.9(60ksi)(0.267 in^2/ft)\left(8.75" - \frac{0.3926}{2}\right)$$

$$= 10.277 \text{ k}$$

$$\phi M_n = 10.277k \geq M_u = 2.509'k \checkmark$$

$$\rho = \frac{A_s}{bh} = \frac{0.267 in^2/ft}{(12")(12")}$$

$$= 0.00185 \geq 0.0018 \checkmark$$

Rebar Weight Savings

- 4' base, less 2(3" cover) ⇒ 3.5' rebar
- 3.5' $\left(\frac{300' \text{ strip ftg.}}{\text{every } 9" \text{ o.c.}}\right)$ ⇒ 1,400' total horizontal rbr. in strip ftg.
- #5 : 1,400' (1.043 lb/ft)
  ⇒ 1,460.2 lbs
- #4 : 1,400' (935.2 lb/ft)
  ⇒ 935.2 lbs
- TOTAL MAT'L SAVINGS = 525 lbs rebar

Appendix 1.F – Change Order Requests:

BENCHMARK Construction Company, Inc.™

December 9, 2011

Mr. E. Russell Learned, AIA
CENTERBROOK ARCHITECTS AND PLANNERS, LLP
67 Main Street
PO Box 955
Centerbrook, CT 06409-0955

Re: LancasterHistory.org
Project No.: 1-2011-040
Change Order Request No.: 11 – Unsuitable Soils

Dear Mr. Learned:

Benchmark Construction Company, Inc. is submitting this Change Order Request No. 11 for the remediation of the unsuitable soils.

- Parking Lot – Benchmark Construction Company, Inc. remediated 550 cubic yards of unsuitable soil as directed by ECS, the owner's third party testing agency. Benchmark Construction Company, Inc. excavated below plan bottom to a depth of roughly 6' and backfilled with suitable soils excavated from site.
- Rock Bin 3 – Benchmark Construction Company, Inc. remediated 490 cubic yards of unsuitable soils in rock bin 3 replacing them with 2A stone and providing 750 square yards of Geotextile fabric at plan bottom of the rock bin to bridge the unsuitable soil condition.
- Driveway Elbow – Benchmark Construction Company, Inc. remediated 36 cubic yards of unsuitable soil and replaced it with 2A stone compaction only above plan bottom and completed full remediation of 210 cubic yards below plan bottom including 1,000 square yards of Geotextile fabric.
- Spoils Stockpile –Benchmark Construction Company, Inc. loaded and hauled 2,240 cubic yards of spoils off site that was determined to be unsuitable for appropriate compaction and backfill.
- Marietta Entrance Driveway – Benchmark Construction Company, Inc. was directed to remediate unsuitable soils below plan bottom. Full remediation of 40 cubic yards of soil was removed from the entryway and 250 square yards of Geotextile fabric was used to bridge the unsuitable gap.

All work to be completed for a total lump sum added to the contract value equal to **ONE HUNDRED TWENTY THREE THOUSAND THREE HUNDRED NINETEEN DOLLARS ($123,319.00).** Please see our attached spreadsheet for a breakdown of the costs.

Total Change Order Request No. 11 .... $123,319.00
Total Change in Days to Schedule 0

If you have any questions regarding this change order request please feel free to contact me at your earliest convenience.

Sincerely,

Robert A. Brandt III
Project Manager

RAB III /dlm

BENCHMARK CONSTRUCTION COMPANY, INC.
4121 Oregon Pike, P.O. Box 806, Brownstown, PA 17508 Tel: 717.626.9559 Fax: 717.626.9315 www.benchmarkgc.com

DH FUNK & SONS LLC

Parking Lot Undercut	Dirt Cut & Place/Compact	550	cy	@	$21.00	cy	$11,550.00
	Load & Haul Dirt	550	cy	@	$20.00	cy	$11,000.00
Rock Bin #3	2A Stone place/Compact only	490	cy	@	$50.00	cy	$24,500.00
	Mirafi HP 565 Geotextile	750	sy	@	$5.00	sy	$3,750.00
Elbow	2A Stone place/Compact only	36	cy	@	$25.00	cy	$900.00
	Full Remediation w/2A stone	210	cy	@	$50.00	cy	$10,500.00
	Mirafi HP 565 Geotextile	1000	sy	@	$5.00	sy	$5,000.00
Haul Spoils	Load & Haul (160 lds)	2240	cy	@	$20.00	cy	$44,800.00
Marietta Entrance	Full Remediation w/2A stone	40	cy	@	$50.00	cy	$2,000.00
	Mirafi HP 565 Geotextile	250	sy	@	$5.00	sy	$1,250.00

SUB-TOTAL		$115,250.00
Insurance	1%	$1,153.00
Bond	1%	$1,153.00
5% BCCI Fee		$5,762.50
TOTAL		$123,318.50

Full Remediation w/2A stone	$50.00 cy
Excavate	$5/cy
Load & Haul	$20/cy
2A Stone Delivered	$17/cy
Place & Compact	$8cy
Dirt Cut & Place/Compact	$21.00 cy
Excavate	$5/cy
Load & Haul - On Site	$8/cy
Place & Compact	$8/cy
Load & Haul Dirt	$20.00 cy
Load	$7.5/cy
Haul	$12.5/cy
2A Stone place/Compact only	$25.00 cy
Delivered	$18/cy
Compact	$7/cy
Mirafi HP 565 Geotextile	$5.00 sy
Material	$3.40/cy
Labor	$1.60/cy

BENCHMARK Construction Company, Inc.™

July 6, 2012

Mr. E. Russell Learned, AIA
CENTERBROOK ARCHITECTS AND PLANNERS, LLP
67 Main Street
PO Box 955
Centerbrook, CT 06409-0955

Re: LancasterHistory.org
Project No.: 1-2011-040
Change Order Request No.: 22B Building Backfill & Retaining Wall Backfill

Dear Mr. Learned:

Benchmark Construction Company, Inc. is submitting this Change Order Request No. 22B for the placing and compacting of 412 cubic yards of 2A stone for the remaining building backfill, and for the placing and compacting of 164 cubic yards of 2A stone for the retaining wall backfill. In addition Benchmark Construction Company, Inc. was able to reclaim the existing blacktop to use for the remaining retaining wall backfill. Benchmark Construction Company, Inc. is requesting additional compensation for the site inspection of rock bin 1 by Advantage Engineers to determine if the Stratham II soil was acceptable to be used at the location of plan bottom in an effort to eliminate having to over excavate and incur more unsuitable soil costs.

All work to be completed for a total lump sum added to the contract value equal to **EIGHTEEN THOUSAND THREE HUNDRED SIXTY SEVEN DOLLARS ($18,367.00).** Please see our attached spreadsheet for a breakdown of the costs.

**All material tickets are available upon request.*

Total Change Order Request No. 22B $18,367.00
Total Change in Days to Schedule 0

If you have any questions regarding this change order request please feel free to contact me at your earliest convenience.

Sincerely,

Robert A. Brandt III
Project Manager

RAB III /dlm

Enclosure(s): Spread Sheet of Estimated Costs
D.H. Funk Spread Sheet
D.H. Funk Proposed Change Order
Atvantage Engineering Invoice

Cc: Peter Cornell, Centerbrook Architects

BENCHMARK Construction Company, Inc.™

March 28, 2012

Mr. E. Russell Learned, AIA
CENTERBROOK ARCHITECTS AND PLANNERS, LLP
67 Main Street
PO Box 955
Centerbrook, CT 06409-0955

Re: LancasterHistory.org
Project No.: 1-2011-040
Change Order Request No.: 37 – Unsuitable Soils / Rock Bin 2

Dear Mr. Learned:

Benchmark Construction Company, Inc. is submitting this Change Order Request No. 37 for the remediation of the unsuitable soils within rock bin 2. Benchmark Construction Company, Inc. remediated 1,296 cubic yards of unsuitable soil to plan bottom within rock bin 2. At the direction of ECS, D.H. Funk & Sons, LLC excavated approximately 200 cubic yards of unsuitable soil (roughly 16" below plan bottom) to fully engage the Stratham II soils as part of the requirements of the plans and specifications. In addition D.H. Funk & Sons, LLC added 235 cubic yards by placing and compacting 2A stone above existing grade to allow for the parking above rock bin 2 per the plans and specifications.

All work to be completed for a total lump sum added to the contract value equal to **SIXTY SEVEN THOUSAND ONE HUNDRED FOURTEEN DOLLARS ($67,114.00).** Please see our attached spreadsheet for a breakdown of the costs.

**All material tickets are available upon request*

Total Change Order Request No. 37 .... $67,114.00
Total Change in Days to Schedule 0

If you have any questions regarding this change order request please feel free to contact me at your earliest convenience.

Sincerely,

Robert A. Brandt III
Project Manager

RAB III /dlm
Enclosure(s): D.H. Funk Spread Sheet

Cc: Peter Cornell, Centerbrook Architects
Robin Sarratt, LHO
Tom Ryan, LHO
Ken Huber, Building Committee Chair
Robert A. Brandt, Jr., BCCI
Ted Miller, BCCI

B E N C H M A R K C O N S T R U C T I O N C O M P A N Y , I N C .

4121 Oregon Pike, P.O. Box 806, Brownstown, PA 17508 Tel: 717.626.9559 Fax: 717.626.9315 www.benchmarkgc.com

Appendix 2.A – Direct Comparison Mech. System Estimates:

Geothermal Estimate

Cost Code	Item Description	Qty.	Unit	Mat. $/Unit	Mat. Total	Labor $/Unit	Labor Total	Equip. $/Unit	Equip. Total	Grand Total
1	Boiler, High Efficiency Natural Gas, 909 MBU	1	EA	$ 21,300.00	$ 21,300.00	$ 5,600.00	$ 5,600.00	$ -	$ -	$ 26,900.00
2	Heat Exchanger, Plate type, Liquid-to-Liquid, 800 GPM	2	EA	$ 59,500.00	$ 119,000.00	$ 2,550.00	$ 5,100.00	$ -	$ -	$ 124,100.00
3	Boreholes, 250' deep, 8" max diameter	4	EA	$ 8,349.00	$ 33,396.00	$ 6,171.00	$ 24,684.00	$ 7,260.00	$ 29,040.00	$ 87,120.00
4	3" HDPE Pipe, DR 11	1913	L.F.	$ 1.87	$ 3,577.31	$ -	$ -	$ -	$ -	$ 3,577.31
5	3" HDPE 90 degree elbow	12	L.F.	$ 13.02	$ 156.24	$ -	$ -	$ -	$ -	$ 156.24
6	HDPE Welding Labor (every 40')	72	EA	$ -	$ -	$ 13.85	$ 997.20	$ -	$ -	$ 997.20
7	Grout Boreholes, Normal weight concrete, 2 KSI	4	EA	$ 161.04	$ 644.16	$ 70.40	$ 281.60	$ 22.65	$ 90.60	$ 1,016.36
8	Well Head Assemblies	4	EA	$ 191.58	$ 766.32	$ 22.46	$ 89.84	$ -	$ -	$ 856.16
9	Isolation Valve	12	EA	$ 185.00	$ 2,220.00	$ 101.00	$ 1,212.00	$ -	$ -	$ 3,432.00
10	Core Drilling, 6" diameter	4	EA	$ 0.81	$ 3.24	$ 46.00	$ 184.00	$ 7.85	$ 31.40	$ 218.64
11	Flow Measuring Station	1	EA	$ 335.00	$ 335.00	$ 35.00	$ 35.00	$ -	$ -	$ 370.00
12	Trench Excavation, 8' deep, 1.5 CY excavator	445	BCY	$ -	$ -	$ 1.18	$ 525.10	$ 1.98	$ 881.10	$ 1,406.20
13	Hydraulic Shoring, 4' wide, semi-stable soil	4800	SF Wall	$ 0.15	$ 720.00	$ 0.25	$ 1,200.00	$ -	$ -	$ 1,920.00
14	Backfill, 2 CY loader	400	CY	$ -	$ -	$ 0.92	$ 368.00	$ 1.00	$ 400.00	$ 768.00
					Mat. Total		**Labor Total**		**Equip. Total**	**Grand Total**
				Subtotal	$ 182,118.27		$ 40,276.74		$ 30,443.10	$ 252,838.11
				Tax (6%)	$ 10,927.10				$ 1,826.59	$ 15,170.29
				Geothermal Grand Total	**$ 193,045.37**		**$ 40,276.74**		**$ 32,269.69**	**$ 268,008.40**

Alternate 2: Mechanical Estimate

Cost Code	Item Description	Qty.	Unit	Mat. $/Unit	Mat. Total	Labor $/Unit	Labor Total	Equip. $/Unit	Equip. Total	Grand Total
1	Boiler, High Efficiency Natural Gas, 1,060 MBU	1	EA	$ 21,300.00	$ 21,300.00	$ 5,600.00	$ 5,600.00	$ -	$ -	$ 26,900.00
2	Closed Circuit Cooling Tower, 112 tons	1	EA	$ 64,000.00	$ 64,000.00	$ 2,670.00	$ 2,670.00	$ -	$ -	$ 66,670.00
3	4" Pipe (Refrigerent)	50	L.F.	$ 125.00	$ 6,250.00	$ 34.00	$ 1,700.00	$ -	$ -	$ 7,950.00
4	4" 90 degre elbow (Refrigerent)	8	EA	$ 125.00	$ 1,000.00	$ 34.00	$ 272.00	$ -	$ -	$ 1,272.00
5	3" Pipe (Overflow)	2	L.F.	$ 70.00	$ 140.00	$ 26.00	$ 52.00	$ -	$ -	$ 192.00
6	2" Pipe (Drain)	6	L.F.	$ 32.50	$ 195.00	$ 15.00	$ 90.00	$ -	$ -	$ 285.00
7	1-1/2" Pipe (Make-up)	1	L.F.	$ 21.00	$ 21.00	$ 12.00	$ 12.00	$ -	$ -	$ 33.00
8	1/2" Pipe (Vent)	1	L.F.	$ 5.55	$ 5.55	$ 9.30	$ 9.30	$ -	$ -	$ 14.85
9	Control Panel, 460 volt, 3 phase, 60 Hz w/ NEMA Enclosure & 5-hp starter	1	EA	$ 10,500.00	$ 10,500.00	$ -	$ -	$ 4,575.00	$ 4,575.00	$ 15,075.00
10	Pneumatic Control	1	EA	$ 5,000.00	$ 5,000.00	$ 1,825.00	$ 1,825.00	$ -	$ -	$ 6,825.00
11	Wall/Floor Penetrations	2	EA	$ 0.81	$ 1.62	$ 46.00	$ 92.00	$ 7.85	$ 15.70	$ 109.32
12	Equipment Pad, 10'X10'X12'', 3 ksi	1	EA	$ 427.28	$ 427.28	$ 425.43	$ 425.43	$ 7.54	$ 7.54	$ 860.25
13	12"X12" Steel I Beam Mount, A992	22	L.F.	$ 15.59	$ 342.98	$ 5.52	$ 121.44	$ 2.90	$ 63.80	$ 528.22
					Mat. Total		**Labor Total**		**Equip. Total**	**Grand Total**
				Subtotal	$ 109,183.43		$ 12,869.17		$ 4,662.04	$ 126,714.64
				Tax (6%)	$ 6,551.01				$ 279.72	$ 7,602.88
				Alternate 2: Mechanical Grand Total	**$ 115,734.44**		**$ 12,869.17**		**$ 4,941.76**	**$ 134,317.52**

Appendix 2.B – Direct Comparison Mech. System Durations:

Geothermal Durations							
Item No.	*Activity Description*	*Qty.*	*Unit*	*Hours/Unit*	*Total Hours*	*Crew Size*	*Total Duration (Hours)*
1	Boiler, High efficiency Natural Gas, 909 MBU	1	EA	103	103	4	26
2	Heat Exchanger, Plate type, Liquid-to-Liquid, 800 GPM	2	EA	48	96	3	32
3	Boreholes, 250' deep, 8" max diameter	4	EA	4.34	17	2	9
4	3" HDPE pipe, DR 11	1913	L.F.	0.00833	16	1	16
5	3" HDPE 90 degree elbow	12	L.F.	0.25	3	1	3
6	HDPE Welding Labor (every 40')	72	EA	0.32	23	4	6
7	Grout Boreholes, Normal weight concrete, 2 ksi	4	EA	1.87792	8	2	4
8	Well Head Assemblies	4	EA	19	76	1	76
9	Isolation Valve	12	EA	1.778	21	1	21
10	Core Drilling, 6" diameter	4	EA	1.143	5	1	5
11	Flow Measuring Station	1	EA	0.615	1	1	1
12	Trench Excavation, 8' deep, 1.5 CY excavator	445	BCY	0.053	24	2	12
13	Hydraulic Shoring, 4' wide, semi-stable soil	4800	SF Wall	0.007	34	2	17
14	Backfill, 2 CY loader	400	CY	0.02	8	2	4
				Total Geothermal Install Time	**28.2 Days**		

Alternate 2: Mechanical Durations							
Item No.	*Activity Description*	*Qty.*	*Unit*	*Hours/Unit*	*Total Hours*	*Crew Size*	*Total Duration (Hours)*
1	Boiler, High Efficiency Natural Gas, 1,060 MBU	1	EA	94.118	94	4	24
2	Closed Circuit Cooling Tower, 112 tons	1	EA	51.429	51	2	26
3	4" Pipe (Refrigerent)	50	L.F.	0.348	17	2	9
4	4" 90 degre elbow (Refrigerent)	8	EA	1.231	10	1	10
5	3" Pipe (Overflow)	2	L.F.	0.32	1	1	1
6	2" Pipe (Drain)	6	L.F.	0.291	2	1	2
7	1-1/2" Pipe (Make-up)	1	L.F.	0.235	0	1	0
8	1/2" Pipe (Vent)	1	L.F.	19	19	1	19
9	Control Panel, 460 volt, 3 phase, 60 Hz w/ NEMA Enclosure &	1	EA	12	12	1	12
10	Pneumatic Control	1	EA	35.821	36	1	36
11	Wall/Floor Penetrations	2	EA	1.143	2	1	2
12	Equipment Pad, 10'X10'X12'', 3 ksi	1	EA	9.6	10	2	5
13	12"X12" Steel I Beam Mount, A992	22	L.F.	0.093	2	2	1
				Total Alternate 2 Install Time	**18.0 Days**		

Appendix 2.C – Future Annual Energy Costs:

YEAR		RATES			Closed Circuit Cooling Tower					Geothermal				
					Electricity		Natural Gas			Electricity		Natural Gas		
		inflation	*electricity interest*	*natural gas interest*	*future cost*	*present value*	*future cost*	*present value*	*TOTAL*	*Future cost*	*present value*	*future cost*	*present*	*TOTAL*
0	2012	0.993	0.96	0.98	$ 1,811.95	$ 1,727.30	$ 8,278.62	$ 8,056.26	$ 9,783.55	$ 1,904.73	$ 1,815.74	$ 1,052.10	$ 1,023.84	$ 2,839.58
1	2013	0.971	0.93	0.95	$ 1,811.95	$ 1,636.25	$ 8,278.62	$ 7,636.61	$ 9,272.86	$ 1,904.73	$ 1,720.03	$ 1,052.10	$ 970.51	$ 2,690.54
2	2014	0.943	0.91	0.91	$ 1,811.95	$ 1,554.89	$ 8,278.62	$ 7,104.13	$ 8,659.02	$ 1,904.73	$ 1,634.51	$ 1,052.10	$ 902.84	$ 2,537.34
3	2015	0.915	0.91	0.9	$ 1,811.95	$ 1,508.72	$ 8,278.62	$ 6,817.44	$ 8,326.16	$ 1,904.73	$ 1,585.97	$ 1,052.10	$ 866.40	$ 2,452.38
4	2016	0.888	0.9	0.9	$ 1,811.95	$ 1,448.11	$ 8,278.62	$ 6,616.27	$ 8,064.38	$ 1,904.73	$ 1,522.26	$ 1,052.10	$ 840.84	$ 2,363.10
5	2017	0.863	0.9	0.91	$ 1,811.95	$ 1,407.34	$ 8,278.62	$ 6,501.45	$ 7,908.79	$ 1,904.73	$ 1,479.40	$ 1,052.10	$ 826.25	$ 2,305.65
6	2018	0.837	0.9	0.92	$ 1,811.95	$ 1,364.94	$ 8,278.62	$ 6,374.87	$ 7,739.81	$ 1,904.73	$ 1,434.83	$ 1,052.10	$ 810.16	$ 2,244.99
7	2019	0.813	0.91	0.93	$ 1,811.95	$ 1,340.53	$ 8,278.62	$ 6,259.38	$ 7,599.92	$ 1,904.73	$ 1,409.18	$ 1,052.10	$ 795.48	$ 2,204.66
8	2020	0.789	0.92	0.94	$ 1,811.95	$ 1,315.26	$ 8,278.62	$ 6,139.92	$ 7,455.18	$ 1,904.73	$ 1,382.61	$ 1,052.10	$ 780.30	$ 2,162.91
9	2021	0.766	0.93	0.95	$ 1,811.95	$ 1,290.80	$ 8,278.62	$ 6,024.35	$ 7,315.15	$ 1,904.73	$ 1,356.89	$ 1,052.10	$ 765.61	$ 2,122.50
10	2022	0.744	0.94	0.97	$ 1,811.95	$ 1,267.21	$ 8,278.62	$ 5,974.51	$ 7,241.72	$ 1,904.73	$ 1,332.09	$ 1,052.10	$ 759.28	$ 2,091.37
11	2023	0.722	0.94	0.98	$ 1,811.95	$ 1,229.73	$ 8,278.62	$ 5,857.62	$ 7,087.35	$ 1,904.73	$ 1,292.70	$ 1,052.10	$ 744.42	$ 2,037.13
12	2024	0.701	0.94	0.99	$ 1,811.95	$ 1,193.97	$ 8,278.62	$ 5,745.28	$ 6,939.25	$ 1,904.73	$ 1,255.10	$ 1,052.10	$ 730.15	$ 1,985.25
13	2025	0.681	0.94	1	$ 1,811.95	$ 1,159.90	$ 8,278.62	$ 5,637.74	$ 6,797.64	$ 1,904.73	$ 1,219.29	$ 1,052.10	$ 716.48	$ 1,935.77
14	2026	0.661	0.94	1.01	$ 1,811.95	$ 1,125.84	$ 8,278.62	$ 5,526.89	$ 6,652.73	$ 1,904.73	$ 1,183.48	$ 1,052.10	$ 702.39	$ 1,885.88
15	2027	0.642	0.94	1.02	$ 1,811.95	$ 1,093.48	$ 8,278.62	$ 5,421.17	$ 6,514.65	$ 1,904.73	$ 1,149.47	$ 1,052.10	$ 688.96	$ 1,838.42
16	2028	0.623	0.94	1.03	$ 1,811.95	$ 1,061.11	$ 8,278.62	$ 5,312.31	$ 6,373.42	$ 1,904.73	$ 1,115.45	$ 1,052.10	$ 675.12	$ 1,790.57
17	2029	0.605	0.93	1.04	$ 1,811.95	$ 1,019.49	$ 8,278.62	$ 5,208.91	$ 6,228.40	$ 1,904.73	$ 1,071.70	$ 1,052.10	$ 661.98	$ 1,733.68
18	2030	0.587	0.93	1.05	$ 1,811.95	$ 989.16	$ 8,278.62	$ 5,102.53	$ 6,091.69	$ 1,904.73	$ 1,039.81	$ 1,052.10	$ 648.46	$ 1,688.27
19	2031	0.57	0.93	1.06	$ 1,811.95	$ 960.51	$ 8,278.62	$ 5,001.94	$ 5,962.46	$ 1,904.73	$ 1,009.70	$ 1,052.10	$ 635.68	$ 1,645.38
20	2032	0.554	0.94	1.07	$ 1,811.95	$ 943.59	$ 8,278.62	$ 4,907.40	$ 5,850.99	$ 1,904.73	$ 991.91	$ 1,052.10	$ 623.66	$ 1,615.57

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

------- Monthly Energy Consumption -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Geothermal System													
Electric													
On-Pk Cons. (kWh)	35,138	32,237	22,760	11,076	3,196	7,333	12,270	6,087	2,395	13,765	20,389	31,499	198,145
On-Pk Demand (kW)	60	60	46	35	63	67	87	73	56	36	43	54	87
Gas													
On-Pk Cons. (therms)	1,078	1,336	0	0	0	0	0	0	0	0	0	90	2,505
On-Pk Demand (therms/hr)	3	4	0	0	0	0	0	0	0	0	0	1	4

Energy Consumption		
Building	26,031	Btu/(ft2-year)
Source	64,400	Btu/(ft2-year)
Floor Area	35,600	ft2

Environmental Impact Analysis	
CO_2	2,496,747 lbm/year
SO_2	19,425 gm/year
NOX	3,733 gm/year

Project Name: LancasterHistory
Dataset Name: Complex T Shape 4.trc

TRACE® 700 v6.2.9 calculated at 04:23 PM on 04/06/2013
Alternative - 1 Monthly Energy Consumption report Page 1 of 2

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

------- Monthly Energy Consumption -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternate Mechanical System 2													
Electric													
On-Pk Cons. (kWh)	30,067	27,380	20,032	9,974	2,806	5,866	9,446	4,900	1,791	11,738	18,068	27,631	169,699
On-Pk Demand (kW)	52	52	42	35	55	60	63	57	49	32	38	46	63
Gas													
On-Pk Cons. (therms)	4,186	3,814	2,666	1,251	23	0	0	0	49	1,471	2,424	3,827	19,711
On-Pk Demand (therms/hr)	7	7	6	4	2	0	0	0	1	4	5	6	7
Water													
Cons. (1000gal)	0	0	0	0	7	27	44	22	1	0	0	0	101

Energy Consumption

Building	71,638	Btu/(ft2-year)
Source	107,096	Btu/(ft2-year)
Floor Area	35,600	ft2

Environmental Impact Analysis

CO_2	2,138,312 lbm/year
SO_2	16,636 gm/year
NOX	3,197 gm/year

Project Name: LancasterHistory
Dataset Name: Complex T Shape 4.trc

TRACE® 700 v6.2.9 calculated at 04:23 PM on 04/06/2013
Alternative - 2 Monthly Energy Consumption report Page 2 of 2

Appendix 2.D – Closed Circuit Cooling Tower Quote:

THE MORIN COMPANY LLC
3907 Hartzdale Drive Suite 702
Camp Hill, PA 17011 United States

To: Pennsylvania State University	From: Andy Tesoriero
Attn: Eric Buckwalter	Phone #: 717/232-3685 X13102
Fax #: e-mail	Cell #: 240-417-2219
Date: 03-28-13	Total Pages:

Re: Heat Pump Loop – Closed Circuit Cooling Tower

We are pleased to offer the following equipment for your consideration –

Closed Circuit Cooling Tower

One (1) Baltimore Aircoil Company Model FXV-0809B-28D-L closed circuit cooling tower with the CTI certified capacity to cool 234 GPM of 30% Propylene Glycol from 100°F to 85°F at 78°F entering wet bulb temperature. The unit will be furnished with the following:

- Evertough construction consisting of G-235 Galvanized steel construction further protected with the Baltibond Corrosion Protection System and a TriArmor cold water basin with a 5-year leak free / corrosion free, cold water basin warranty. Evertough materials of construction include a comprehensive parts warranty on the entire cooling tower.
- 15-hp TEAO inverter duty fan motor rated for (460V/3-Phase/60Hz)
- 5-hp TEFC pump motor rated for (460V/3-Phase/60Hz)
- Galvanized steel single circuit coil with 4" inlet and outlet connections, beveled for welding.
- *Electric pan heater with thermostat and low water cut-out
- Mechanical float water make-up.
- Extended lubrication lines.
- Mechanical vibration cut-out switch with local reset.
- *External service platform with handrail, ladder and safety cage.
- *Internal access ladder
- 5 year parts warranty on the cooling tower.

Shipping weight: 9,724 lbs. plus accessories; 6,692 lbs heaviest piece.
*Ships loose for field installation

BUDGET PRICE: ***$64,000.00*** ***FOB factory, freight included to first destination***

Cooling Tower Control Panel

The cooling tower shall be furnished with an electronic control panel for remote mounting. The panel shall be suitable for 460 volts, 3 phase, 60 Hz power supply and shall be complete with:

- NEMA 3R enclosure
- Main disconnect switch
- 120V fused control transformer
- Power and control wiring terminal strips
- Basin heater contactor with branch fuse
- 5-hp pump motor starter
- 0-10 VDC Controller for VFD with temperature sensor for remote mounting
- One (1) 15-hp, 460V/3ph/60Hz variable frequency drive including bypass, manufacturer's start-up and warranty.

BUDGET PRICE: ***$10,500.00*** ***FOB factory, freight included to first destination***

Unless otherwise indicated price does not include vibration isolation, starters, variable frequency drives, power factor correction capacitors, disconnects, wiring, piping, valves, off loading, rigging, support steel, installation, operating controls, heat trace, insulation, commissioning, field performance test, labor warranty, Pennsylvania Steel Act premiums, or taxes.

Quoted price is valid 60 days from date of this proposal.

Sincerely,

Andrew Tesoriero
THE MORIN COMPANY, LLC

Appendix 2.E – Closed Circuit Cooling Tower Selection Program:

Baltimore Aircoil Company, Inc.

Closed Circuit Cooling Tower Selection Program

Version:	7.0.6 NA
Product data correct as of:	March 20, 2013

Project Name:	Penn State University
Selection Name:	
Project State/Province:	Pennyslvania
Project Country:	United States
Date:	March 28, 2013

Wet Operation Selection Parameters

Product Line:	Series FXV
Coil Type:	Standard Coil

Design Conditions

Flow Rate:	234.00 USGPM
Heat Rejection:	1,684,126 BTUH
Fluid:	PG, 30% by Vol.
Fluid Freeze Point:	8.00 °F
Entering Fluid Temp.:	100.00 °F
Leaving Fluid Temp.:	85.00 °F
Wet Bulb Temp.:	78.00 °F

Selection Requirements

Max. Fluid Pressure Drop:	25.00 psi
Number of Units:	1 to 9
Reserve Capability:	-2% minimum
Max. Total Fan Motor Power:	999.00 HP
Max. Total Pump Motor Power:	999.00 HP
Max. Length (for all units):	9,999 ft.
Max. Width:	9,999 ft.
Max. Height:	9,999 ft.

Model Accessories

Intake Option:	None
Internal Option:	None
Discharge Option:	None
Fan Type:	Standard Fan

User-Chosen Selection

Thermal performance for this selection is certified by the Cooling Technology Institute (CTI).

Qty	Model	Total Fan Motor (HP)	Total Pump Motor (HP)	Pressure Drop (psi)	Reserve Capability (%)
1	FXV-0809B-28D-L	15.00	5.00	4.56	4.54

This selection assumes an open and unobstructed installation; no external static pressure unless specified above; and, unless specified above, no accessories which may affect airflow through the unit, such as capacity control dampers, solid bottom panels, discharge hood, and sound attenuation. If one or more of these assumptions do not apply to this project, please use the program to compute the applicable performance derate or contact your local BAC sales representative.

Baltimore Aircoil Company, Inc.

Closed Circuit Cooling Tower Selection Program

Version:	7.0.6 NA
Product data correct as of:	March 20, 2013

Project Name:	Penn State University
Selection Name:	
Project State/Province:	Pennyslvania
Project Country:	United States
Date:	March 28, 2013

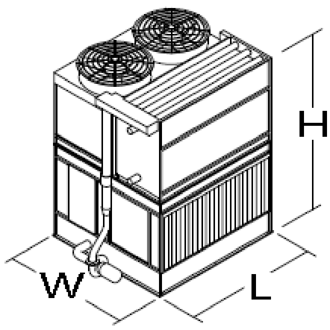
Model Information

Product Line:	Series FXV
Model:	FXV-0809B-28D-L
Number of Units:	1
Fan Type:	Standard Fan
Fan Motor:	Full Speed, 15.00 BHP
Coil Type:	Standard Coil
Coil Finning:	None
Total Standard Fan Power:	15.00 HP/Unit
Total Pump Motor Power:	5.00 HP/Unit
Intake Option:	None
Internal Option:	None
Discharge Option:	None

Design Conditions

Fluid:	PG, 30% by Vol.
Fluid Freeze Point:	8.00 °F
Flow Rate:	234.00 USGPM
Entering Fluid Temp.:	100.00 °F
Leaving Fluid Temp.:	85.00 °F
Wet Bulb Temp.:	78.00 °F
Fluid Pressure Drop:	4.56 psi
Reserve Capability:	4.05%

Thermal performance at design conditions and standard total fan motor power is certified by the Cooling Technology Institute (CTI).



Engineering Data, per Unit

Unit Length:	9' + 1' 6.00" (Pump) = 10' 6.00" (Total)
Unit Width:	8' 5.75"
Unit Height:	17' 11.00"

Approximate Shipping Weight:	9,705 pounds
Heaviest Section:	6,673 pounds
Approximate Operating Weight:	14,711 pounds
Approximate Remote Sump Operating Weight:	13,544 pounds

Air Flow:	50,700	CFM
Spray Water Flow:	500	USGPM
Coil Volume:	153	U.S. gallons
Minimum Distance Required:		
From Solid Wall:	4.5	ft
From 50% Open Wall:	3	ft

Coil Connections:	(1) 4" Coil Inlet and Outlet, Based on 234.00 USGPM Flow per Unit
Remote Sump Connections:	(1) 8"

Note: These unit dimensions do not account for any accessories. Please contact your local BAC sales representative for dimensions of units with accessories.

Baltimore Aircoil Company, Inc.

Closed Circuit Cooling Tower Selection Program

Version:	7.0.6 NA
Product data correct as of:	March 20, 2013

Project Name:	Penn State University
Selection Name:	
Project State/Province:	Pennyslvania
Project Country:	United States
Date:	March 28, 2013

Model Information

Product Line:	Series FXV
Model:	FXV-0809B-28D-L
Number of Units:	1
Fan Type:	Standard Fan
Fan Motor:	Full Speed, 15.00 BHP
Coil Type:	Standard Coil
Coil Finning:	None
Total Standard Fan Power:	15.00 HP/Unit
Total Pump Motor Power:	5.00 HP/Unit
Intake Option:	None
Internal Option:	None
Discharge Option:	None

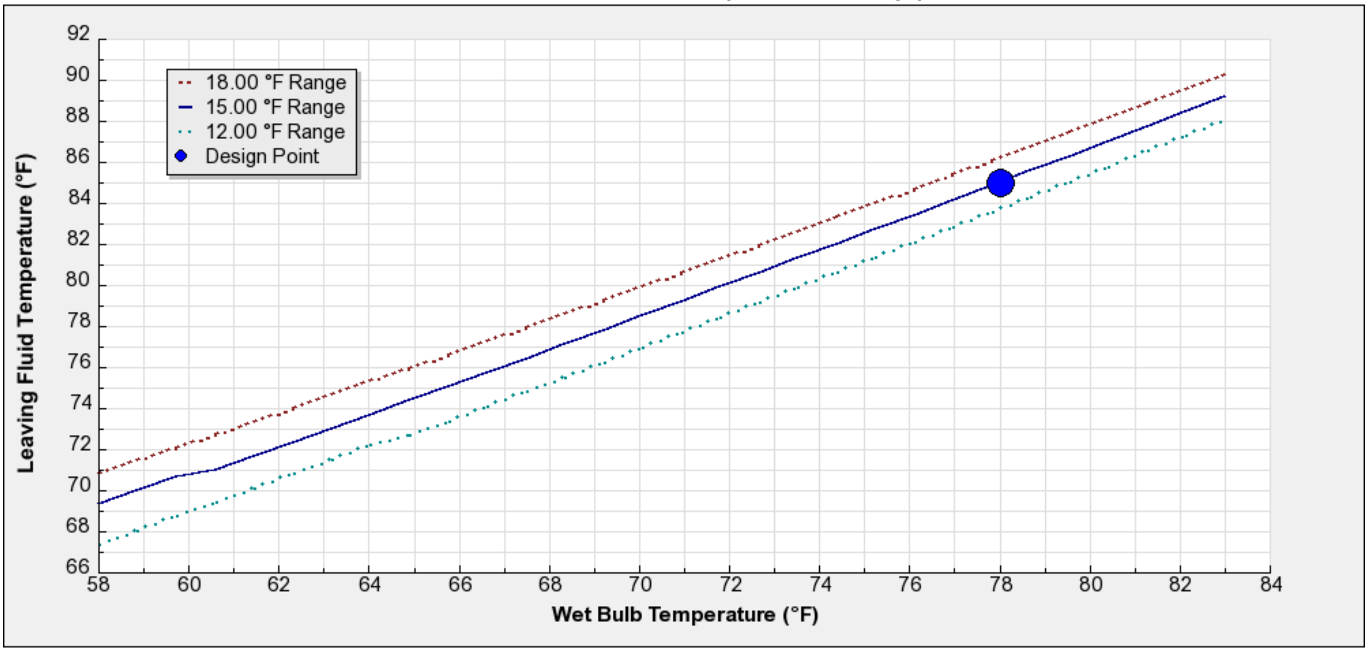
Design Conditions

Fluid:	PG, 30% by Vol.
Fluid Freeze Point:	8.00 °F
Flow Rate:	234.00 USGPM
Entering Fluid Temp.:	100.00 °F
Leaving Fluid Temp.:	85.00 °F
Wet Bulb Temp.:	78.00 °F
Fluid Pressure Drop:	4.56 psi
Reserve Capability:	4.05%

Design Conditions @ Standard Total Fan Motor Power per Unit (15.00 HP)

Thermal performance at design conditions and standard total fan motor power is certified by the Cooling Technology Institute (CTI).

Predicted Performance
Fan Motor Alternative = Full Speed, 15.00 BHP
Flow Rate = 234.00 USGPM (100.00% of Design)



These performance curves are based on constant fan power.

Baltimore Aircoil Company, Inc.

Closed Circuit Cooling Tower Selection Program

Version: 7.0.6 NA
Product data correct as of: March 20, 2013

Project Name: Penn State University
Selection Name:
Project State/Province: Pennyslvania
Project Country: United States
Date: March 28, 2013

Model Information

Product Line:	Series FXV	Coil Type:	Standard Coil
Model:	FXV-0809B-28D-L	Coil Finning:	None
Number of Units:	1	Total Standard Fan Power:	15.00 HP/Unit
Fan Type:	Standard Fan	Total Pump Motor Power:	5.00 HP/Unit
Fan Motor:	Full Speed, 15.00 BHP/Unit		
Intake Option:	None		
Internal Option:	None		
Discharge Option:	None		

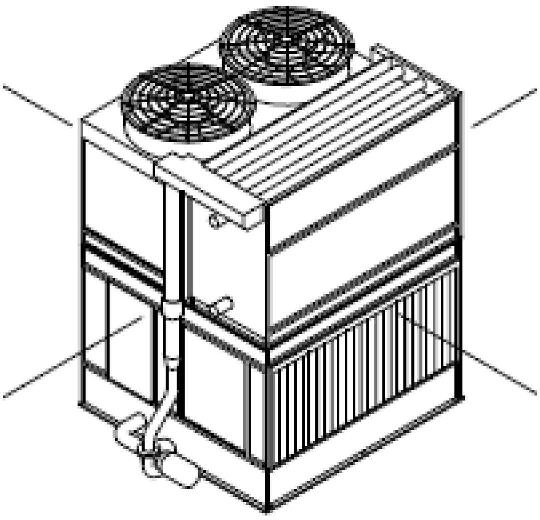
Octave band and A-weighted sound pressure levels (Lp) are expressed in decibels (dB) reference 0.0002 microbar. Sound power levels (Lw) are expressed in decibels (dB) reference one picowatt. Octave band 1 has a center frequency of 63 Hertz.

Top Lp
Sound Pressure (dB)

Octave Band	Distance 5 ft.	50 ft.
1	80	68
2	87	75
3	87	74
4	85	73
5	84	71
6	79	64
7	73	59
8	66	53
A-wgtd	**88**	**75**

Back Lp
Sound Pressure (dB)

Octave Band	Distance 5 ft.	50 ft.
1	73	67
2	79	69
3	77	66
4	71	64
5	66	59
6	56	51
7	48	44
8	40	35
A-wgtd	**73**	**65**



End Lp
Sound Pressure (dB)

Octave Band	Distance 5 ft.	50 ft.
1	76	69
2	79	68
3	78	66
4	71	63
5	66	59
6	56	51
7	48	44
8	41	35
A-wgtd	**73**	**64**

Connection End Lp
Sound Pressure (dB)

Octave Band	Distance 5 ft.	50 ft.
1	76	69
2	79	68
3	78	66
4	71	63
5	66	59
6	56	51
7	48	44
8	41	35
A-wgtd	**73**	**64**

Air Inlet Lp
Sound Pressure (dB)

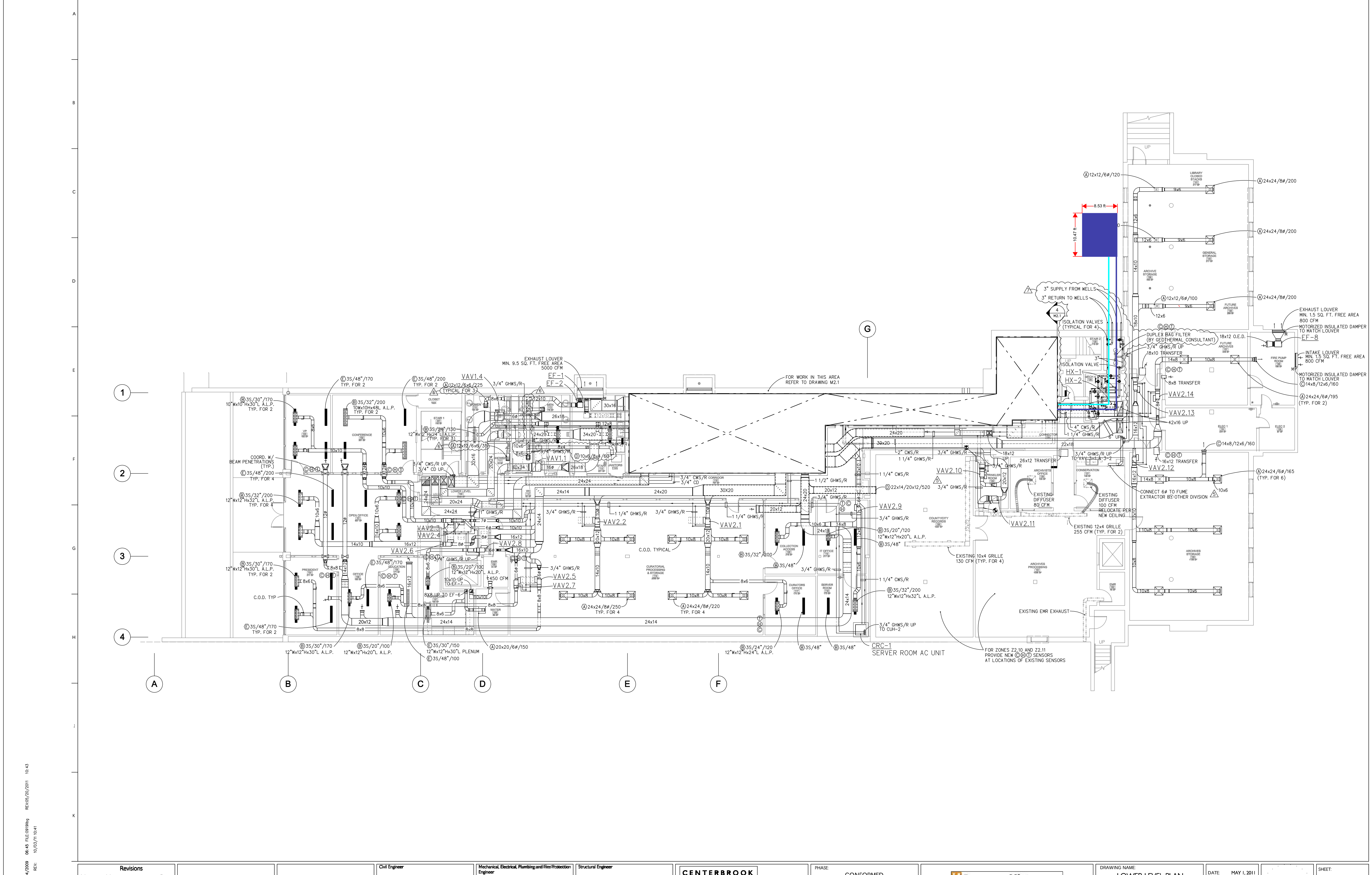
Octave Band	Distance 5 ft.	50 ft.
1	80	69
2	86	71
3	85	64
4	81	64
5	77	60
6	68	52
7	58	44
8	53	38
A-wgtd	**82**	**65**

Sound Power (dB)

Octave Band	Center Frequency (Hertz)	Lw
1	63	100
2	125	103
3	250	101
4	500	100
5	1000	97
6	2000	90
7	4000	85
8	8000	78

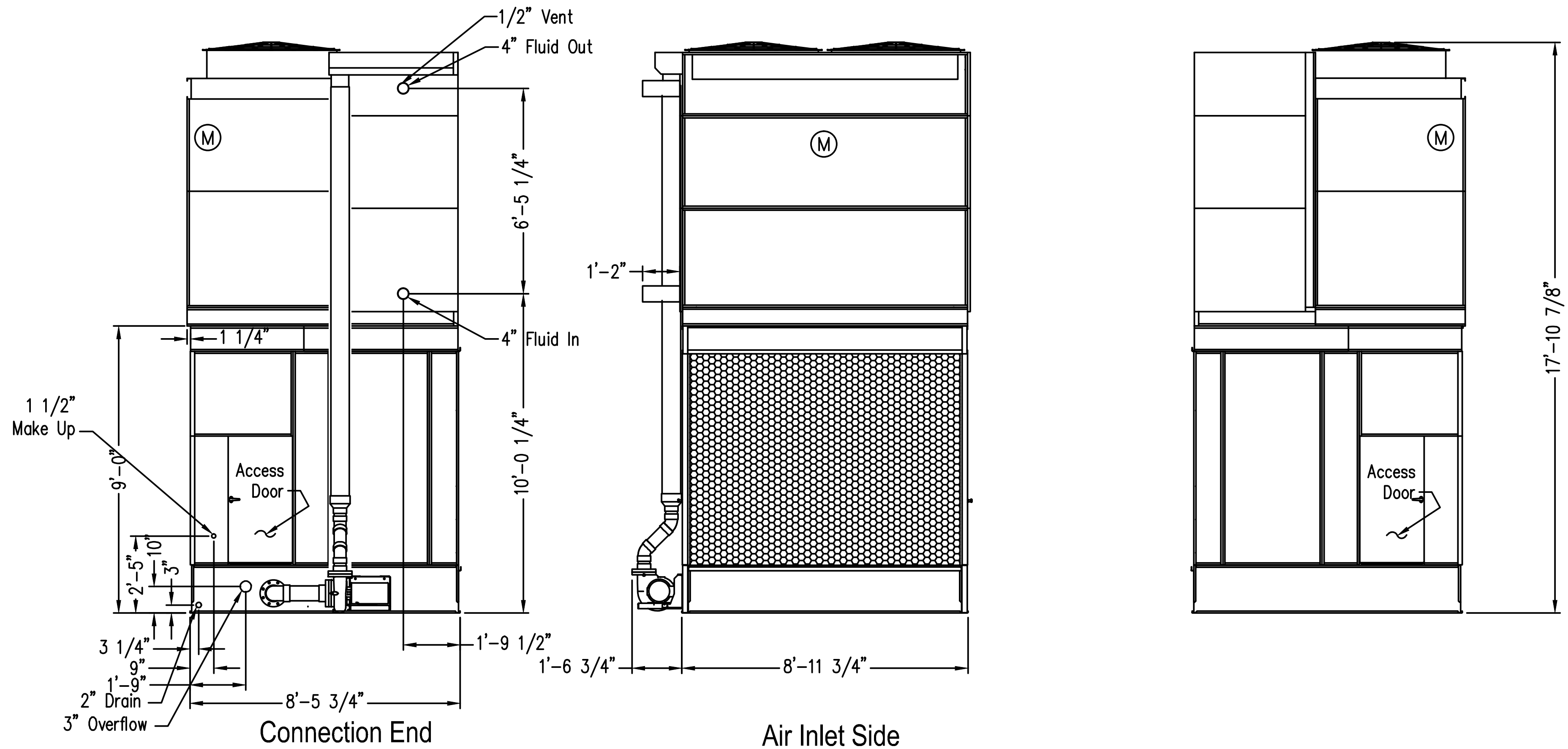
Note: The use of frequency inverters (variable frequency drives) can increase sound levels.

Appendix 2.F – Closed Circuit Cooling Tower Dimensions:


EXHAUST LOUVER
MIN. 9.5 SQ. FT. FREE AREA
5000 CFM
FOR WORK IN THIS AREA
REFER TO DRAWING M2.1
3" SUPPLY FROM WELLS
3" RETURN TO WELLS
ISOLATION VALVES
(TYPICAL FOR 4)
DUPLEX BAG FILTER
(BY GEOTHERMAL CONSULTANT)
CRC-1
SERVER ROOM AC UNIT
FOR ZONES Z2.10 AND Z2.11
PROVIDE NEW SENSORS
AT LOCATIONS OF EXISTING SENSORS
EXISTING EMR EXHAUST
Revisions
DAVID MILLER/ASSOCIATES, INC. (DMA)
GIBBLE NORDEN CHAMPION BROWN
CENTERBROOK
CONFORMED CONSTRUCTION SET
LancasterHistory.org
230 NORTH PRESIDENT AVENUE, LANCASTER, PA 17603
LOWER LEVEL PLAN

Data Version 1.07
DWG Version 1.1

Notes
1) All dimensions are in feet and inches. Weights are in pounds.
2) Dimensions showing location of coil and spray water connections are approximate and should not be used for prefabrication of connecting piping.
3) The area above the discharge of the fan must be unobstructed.
4) For weight loading and support requirements refer to the suggested steel support drawing.
5) Do not support piping from unit connections. All necessary piping supports to be supplied by others.
6) Weights include all the options and accessories.
7) All unit piping conections 3" and smaller are MPT unless otherwise noted.
8) Coil is provided with a 1/2" threaded vent located on the upper outlet pipe stub.
9) All Coil conections are beveled for weld unless otherwise noted.



Model Number	Shipping Weight	Operating Weight	Heaviest Section
FXV-0809B-28D-L	9724	14729	6692

Right Hand

ORDER NO: **5537_FXV-0809B-28D-L**

DATE: **3/28/2013**

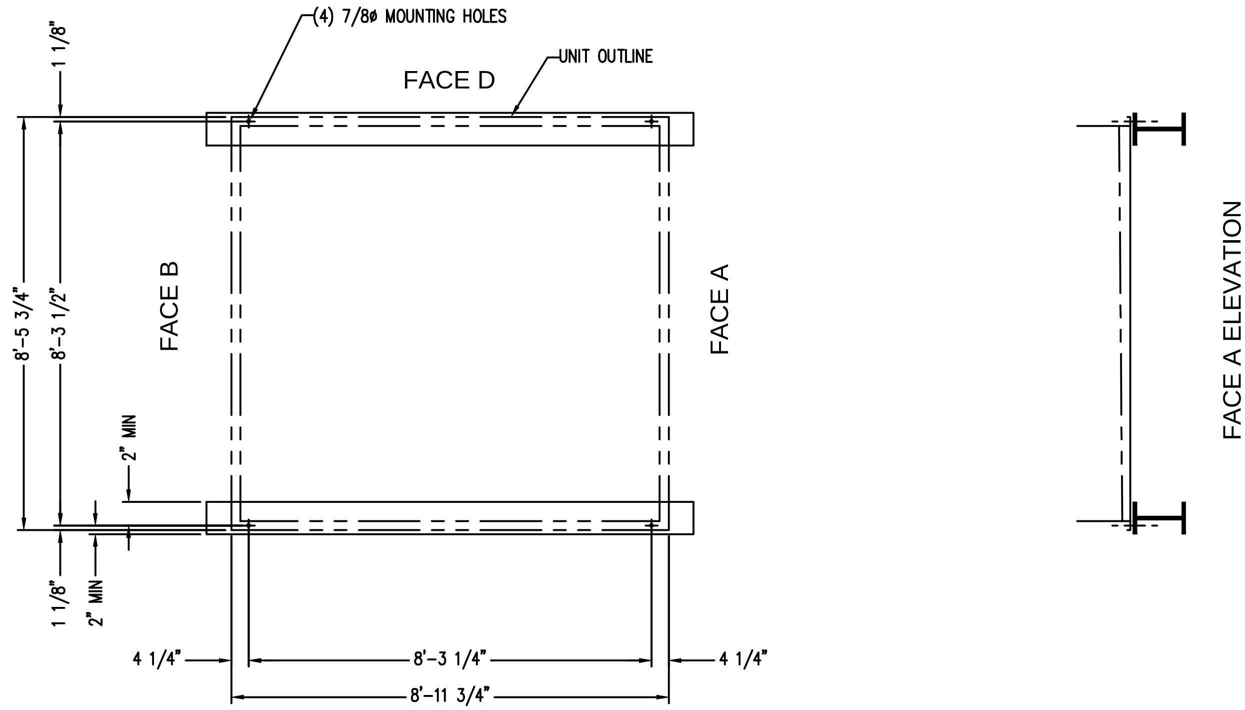
BALTIMORE AIRCOIL COMPANY

8.5 X 9 Unit Print

DRAWING NUMBER:
UP-5537_FXV-0809B-28D-L

Data Version 1.07
DWG Version 1.01

Notes
1) Supporting steelwork and anchor bolts to be designed and furnished by others.
2) All supporting steel must be level at top.
3) Beams should be selected in accordance with accepted structural practice, maximum deflection of beam under unit to be 1/360 of span, not to exceed 1/2 inch.
4) Supporting steel will be greater than or equal to the length of the basin.
5) Alternatively the unit may be supported on columns at the four corners of the unit. Consult your BAC Representative for details.
6) If vibration isolation rails are used between unit and supporting steel, be certain to allow for the length of the vibration rails when determining length of supporting steel. Vibration rail length and mounting hole locations may differ from those of the unit. Refer to vibration isolator drawings for this data.
7) Do not use this drawing to size point vibration isolators. See your BAC Representative for details.
8) All Dimensions are in feet and inches. All weights are in pounds.
9) Weights include all of the options and accessories.



FACE C (AIR INLET)
PLAN VIEW

PLAN "A" STEEL

Model Number	Shipping Weight	Operating Weight
FXV-0809B-28D-L	9724	14729

ORDER NO: **5537_FXV-0809B-28D-L**

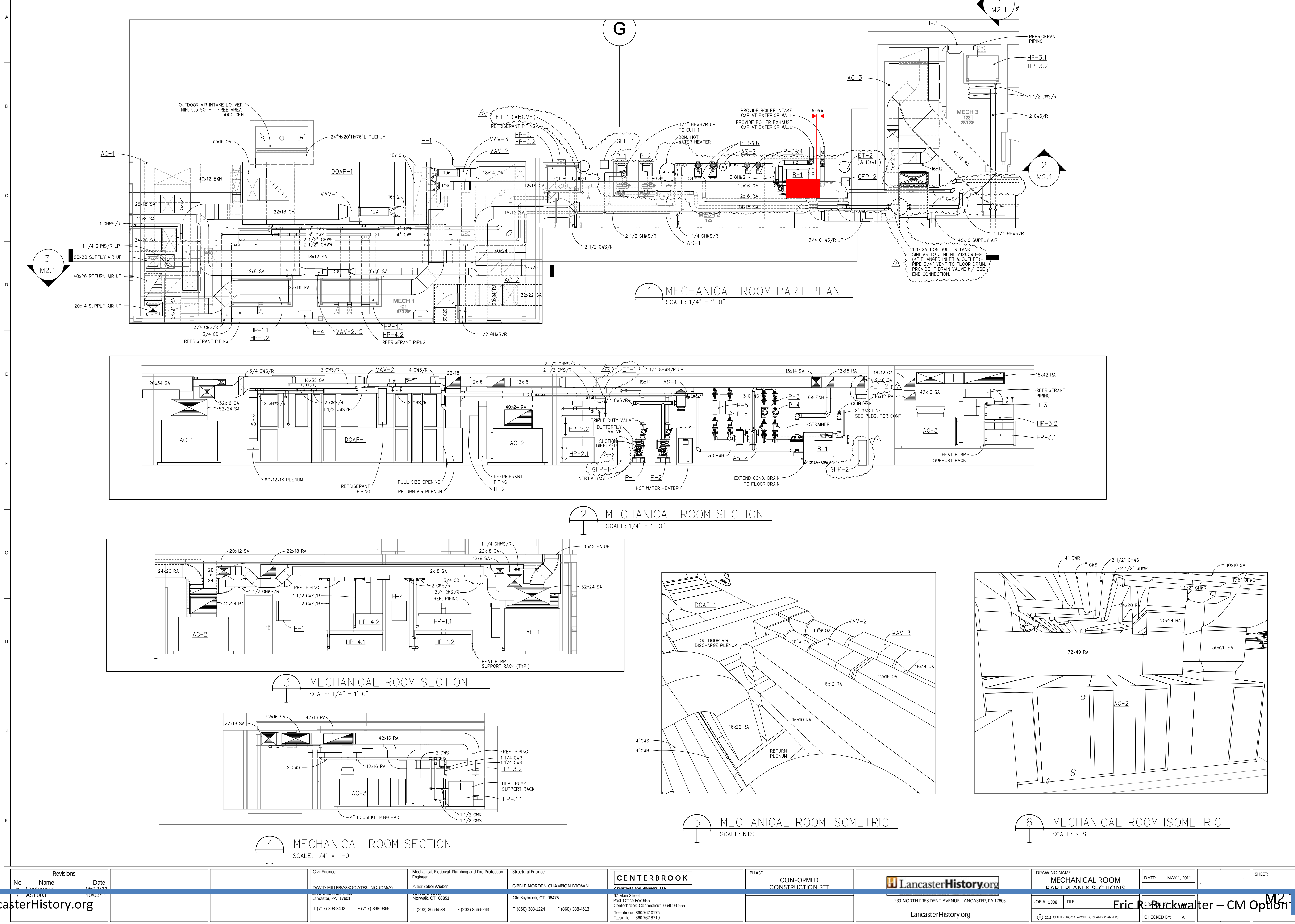
DATE: **3/28/2013**

BALTIMORE AIRCOIL COMPANY

Single Cell Unit Support

DRAWING NUMBER: **SS-5537_FXV-0809B-28D-L**

Appendix 2.G – Boiler Dimensions:



MECHANICAL ROOM PART PLAN
SCALE: 1/4" = 1'-0"
MECHANICAL ROOM SECTION
SCALE: 1/4" = 1'-0"
MECHANICAL ROOM SECTION
SCALE: 1/4" = 1'-0"
MECHANICAL ROOM SECTION
SCALE: 1/4" = 1'-0"
MECHANICAL ROOM ISOMETRIC
SCALE: NTS
MECHANICAL ROOM ISOMETRIC
SCALE: NTS
PROVIDE BOILER INTAKE CAP AT EXTERIOR WALL
PROVIDE BOILER EXHAUST CAP AT EXTERIOR WALL
5.05 in
CENTERBROOK
CONFORMED CONSTRUCTION SET
LancasterHistory.org
230 NORTH PRESIDENT AVENUE, LANCASTER, PA 17603
MECHANICAL ROOM PART PLAN & SECTIONS
DATE: MAY 1, 2011

AERCO

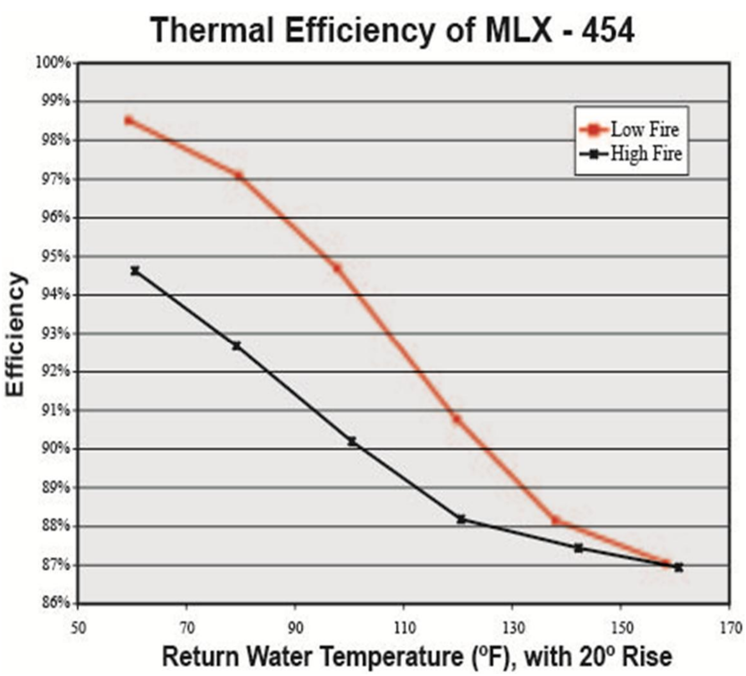
MODEL MLX
TECHNICAL DATA SHEET

AERCO MODULEX BOILERS

A breakthrough in high-efficiency design, AERCO's condensing and fully modulating Modulex boilers support 300,000 to 1 million BTU/hr. hydronic heating systems while delivering a greater degree of operating reliability for customer peace of mind. To achieve the greatest possible fuel savings, each boiler combines independent, 151,500 BTU/hr. thermal modules (see back) that operate to deliver superior turndown and a range of non-cycling operation not readily achieved by competitive equipment or controls. In addition to minimizing redundant capacity needed for any project, these quiet and lightweight boilers can support low NOX and low gas pressure applications and a variety of venting materials. Each unit enclosure offers multiple supply/return piping and venting locations for installation flexibility and allows for multiple units to be easily co-located for greater than 1 million BTU/hr. applications. Combustion view ports and easy access to all operating components further simplify minimal maintenance requirements. In addition to controlling the boiler according to a constant set point, indoor/outdoor reset or 0-10V signal, one or more units can be integrated via Modbus communications protocol to a facility-wide Energy Management or Building Automation System.

THERMAL EFFICIENCY

AERCO is currently developing comprehensive efficiency curves for the complete line of Modulex boilers using a new, rigorous testing protocol which will be witnessed and reviewed by an independent organization. Until comprehensive, independently confirmed curves are available, the figure below provides boundary data for MLX-454 efficiency. Please note: Low Fire represents 45,500 BTU/hr. input – the lowest firing rate of every Modulex unit. Full Fire represents 454,000 BTU/hr. or 100% capacity of the MLX-454.



FEATURES

- Condensing Boiler
- Natural Gas or Propane
- Unmatched Turndown
- 6:1 to 23:1 Depending Upon Unit
- Whisper Quiet Operation <50 dBa
- Low NOx Emission <14ppm
- Direct or Conventional Vent with PVC, CPVC or AL29-4C Materials
- Small, Doorway-Size Footprint
- Flexible Piping and Venting Connections
- Equipped with Sealed Combustion
- Superior Reliability
- Minimal Maintenance
- Easy Open Access for Service
- Supports Integration to BAS System

*Consult AERCO website or Engineering Manual for complete warranty details.

RATINGS

Model Number	Min Input	Max Input	Max Output*	Net IBR Rating
MLX-303	45,500	303,000	260,000-279,000	237,000
MLX-454	45,500	454,500	390,000-418,000	355,000
MLX-606	45,500	606,000	521,000-558,000	474,000
MLX-757	45,500	757,500	651,000-696,000	592,000
MLX-909	45,500	909,000	781,000-835,000	710,000
MLX-1060	45,500	1,060,500	912,000-975,000	829,000

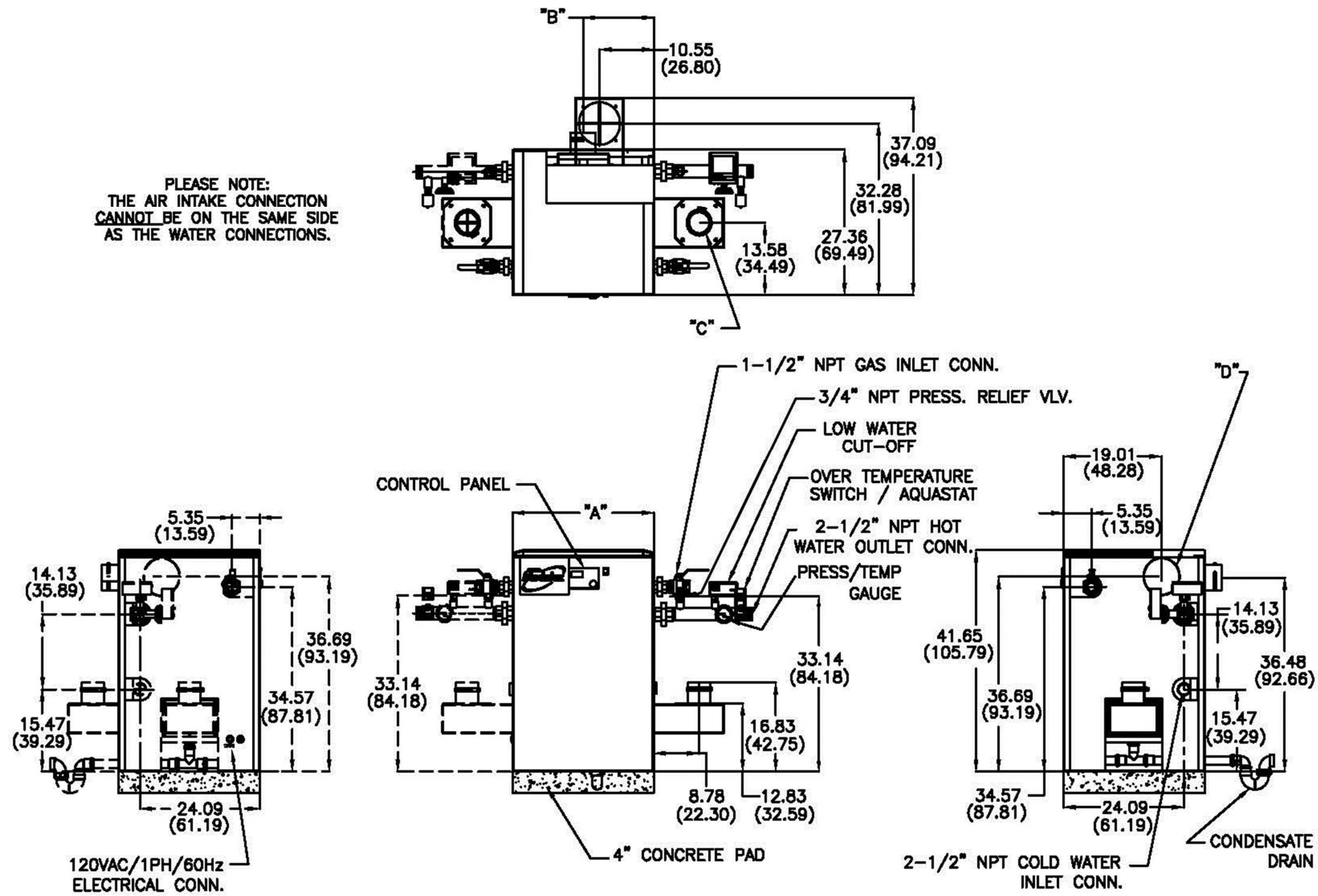
*Depending on Return Water Temperature

DIMENSIONS

Model Number	Height	Width	Depth	Weight
MLX-303	42ò	28ò	27ò	405 lbs.
MLX-454	42ò	28ò	27ò	484 lbs.
MLX-606	42ò	33ò	27ò	575 lbs.
MLX-757	42ò	38ò	27ò	673 lbs.
MLX-909	42ò	44ò	27ò	764 lbs.
MLX-1060	42ò	49ò	27ò	869 lbs.

SPECIFICATIONS

	MLX-303	MLX-454	MLX-606	MLX-757	MLX-909	MLX-1060
Boiler Category	IV	IV	IV	IV	IV	IV
Gas Connections (NPT)	1.5ò	1.5ò	1.5ò	1.5ò	1.5ò	1.5ò
Max. Gas Pressure	14ò	14ò	14ò	14ò	14ò	14ò
Min. Gas Pressure	4ò	4ò	4ò	4ò	4ò	4ò
Max. Allowed Working Pressure	92 psi	92 psi	92 psi	92 psi	92 psi	92 psi
Electrical Req: 120V 15AMP max.	1.2 FLA	1.8 FLA	2.4 FLA	3.0 FLA	3.6 FLA	4.2 FLA
Water Connections (NPT)	2 1/2ò	2 1/2ò	2 1/2ò	2 1/2ò	2 1/2ò	2 1/2ò
Min. Water Flow (GPM)	11	17	22	28	34	39
Max. Water Flow (GPM)	28	42	55	70	84	98
Water Pressure Drop @ Max. Flow (Ft. of Hd)	7.8	9.3	9.4	10.0	10.1	10.2
Water Volume: Gallons	2.7	3.8	4.9	5.9	6.9	8.0
Water Volume: Liters	10.4	14.4	18.4	22.3	26.3	30.2
Thermal Modules	2	3	4	5	6	7
Turndown or Operating Range	6:1	10:1	13:1	16:1	20:1	23:1
Vent Size	4ò	4ò	4	6ò	6ò	6ò
Vent Materials (as per local code)	Can support PVC, CPVC or AL29-4C venting materials.					
Type of Gas	Natural Gas or Propane					
Temperature Control Range	Units deliver 50°-180°F supply; Min. 35°F inlet water required.					
Maximum Noise Level	All units deliver <50 dBa when operating at or below full fire.					
NOx Emissions Certification	Certified by SCAQMD and TCEQ; All units deliver <14 ppm NOx.					
Standard Listings and Approvals	CSA, ASME, CSD-1, MEA					
Water Quality	Ph operating range 6.5 to 8.0 and Glycol (if used) MUST be compatible Cast Aluminum heat exchangers.					



MATERIALS OF CONSTRUCTION
HEAT EXCHANGER: SAND CAST ALUMINUM ALLOY EN AC-AlSi10g(a), F Temper
HEAT EXCHANGER DESIGN STANDARDS
MAX. WORKING PRESS. (PSIG): 92 MAXIMUM TEMP. (°F): 200 TEST PRESS. (PSIG): 138
ASME B & PV CODE SECTION IV STAMP H

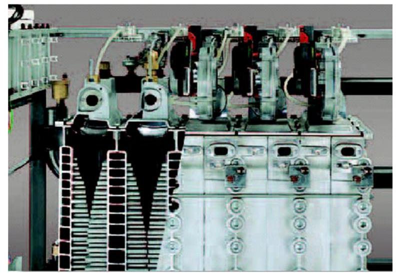
DIMENSION	MODULEX MODEL					
	MLX-303	MLX-454	MLX-606	MLX-757	MLX-909	MLX-1060
OVERALL WIDTH "A"	27.36 (69.49)	27.36 (69.49)	32.83 (83.39)	38.11 (96.80)	43.39 (110.21)	48.66 (123.60)
REAR AIR INTAKE LOCATION "B"	13.68 (34.75)	13.68 (34.75)	16.42 (41.71)	19.06 (48.41)	21.70 (55.12)	24.33 (61.80)
EXHAUST DIAMETER "C"	4 (10.16)	4 (10.16)	4 (10.16)	6 (15.24)	6 (15.24)	6 (15.24)
AIR INTAKE DIAMETER "D"	4 (10.16)	4 (10.16)	4 (10.16)	6 (15.24)	6 (15.24)	6 (15.24)

NOTES:
1) ALL DIMENSIONS SHOWN ARE IN INCHES (CENTIMETERS)
2) ALTERNATE LOCATIONS FOR COMPONENTS/CONNECTIONS ARE SHOWN IN DOTTED LINES.
3) WHEN USING ALTERNATE WATER CONNECTIONS, THE LEFT HAND AIR INTAKE CONNECTION CANNOT BE USED.
4) EXHAUST CONNECTION, AIR INTAKE CONNECTION, AND CONDENSATE TRAP ARE INCLUDED SEPARATELY IN SHIPMENT.
5) RELIEF VALVE, LOW WATER CUT-OFF, PRESS./TEMP GAUGE, AQUASTAT, AND THE 2-1/2" PIPE MANIFOLD FOR THESE COMPONENTS ARE INCLUDED SEPARATELY IN SHIPMENT.
6) THE pH, FOR BOILERS WITH ALUMINUM BODIES, MUST ALWAYS BE WITHIN 6.5 AND 8.0 pH.
7) GLYCOL SOLUTIONS: IF BOILER IS TO BE INSTALLED IN A SYSTEM WITH CONTAINS A GLYCOL SOLUTION, THE GLYCOL MUST BE COMPATIBLE WITH CAST ALUMINUM HEAT EXCHANGERS. USE OF INCOMPATIBLE GLYCOLS WILL VOID THE BOILER WARRANTY.
8) ALL PRECAUTIONS WILL BE TAKEN TO AVOID THE FORMATION AND LOCALIZATION OF OXYGEN IN THE WATER OF A HEATING SYSTEM.
9) AERCO REQUIRES THE INSTALLATION OF A 40 MESH OR FINER Y STRAINER TO KEEP DIRT OUT OF THE SYSTEM AND BOILER. THE STRAINER SHOULD BE INSTALLED IN THE RETURN PIPING WITH ISOLATION VALVES TO ALLOW FOR CLEANING AS NECESSARY.

INDEPENDENT THERMAL MODULE DESIGN

Depending on unit size, each AERCO Modulex boiler contains between two and seven, pre-assembled thermal modules housed within a common enclosure. Each standalone, 151,500 BTU/hr. thermal module features:

- a dedicated controller with built-in combustion safeguard;
- a variable speed fan;
- a modulating gas valve;
- an electronic iginition with flame detector;
- radiating, pre-mix, >3:1 modulating burner;
- flow temperature sensor;
- overtemperature limiting thermostat;
- cast aluminum heat exchanger.



Side view of 5- module unit shows cutaway of the first two thermal modules

As noted, the operation of each 151,500 BTU/hr thermal module is regulated by its own dedicated controller located internally along the front panel of the unit. Equipped with a combustion safeguard, each of these controllers drives the fan speed, gas delivery, burner turndown, etc. for its corresponding thermal module. All the individual thermal controllers are linked in a slave-to-master relationship with the boiler's master controller. It is the master controller which drives or bypasses one or more thermal modules based on the total system load and in response to operating feedback received from each thermal module controller. For added reliability, the unit's Boiler Communication Module also acts as a back-up master controller.

Model Number	Minimum Input	Maximum Input	Thermal Modules	Total Turndown
MLX-303	45,500	303,000	2	6:1
MLX-454	45,500	454,500	3	10:1
MLX-606	45,500	606,000	4	13:1
MLX-757	45,500	757,500	5	16:1
MLX-909	45,500	909,000	6	20:1
MLX-1060	45,500	1,060,500	7	23:1

Two or more AERCO Modulex boilers can be installed and controlled as a unified boiler plant in applications where greater than 1000 MBH is required.

ENHANCED RELIABILITY WITH GREATER SEASONAL EFFICIENCY

The independent operation of two or more thermal modules increases each boiler's turndown range while also increasing its overall reliability. And since thermal efficiency increases as firing rates drop, the simultaneous low-fire operation of multiple modules also ensures that Modulex boilers continuously maximize operating efficiency.

For example, the MLX-1060 combines the power of seven thermal modules, each operating with greater than 3:1 turndown to deliver a 23:1 range of operations. From the low fire input of a single module (45,500 BTU/hr.) to the unit's full fire capacity (1,060,000 BTU/hr.), the boiler precisely matches load without cycling or temperature overshoot. Importantly, it does so by always employing as many modules as possible, each firing at its lowest possible firing rate. Less energy is required for the group of thermal modules, each firing at part load, to heat a building than if only some modules, each operating at full fire, carried the entire load. Consequently, this approach to control results in greater fuel savings than if each thermal module reached its full 151,500 BTU/hr. capacity before the next module came on line.

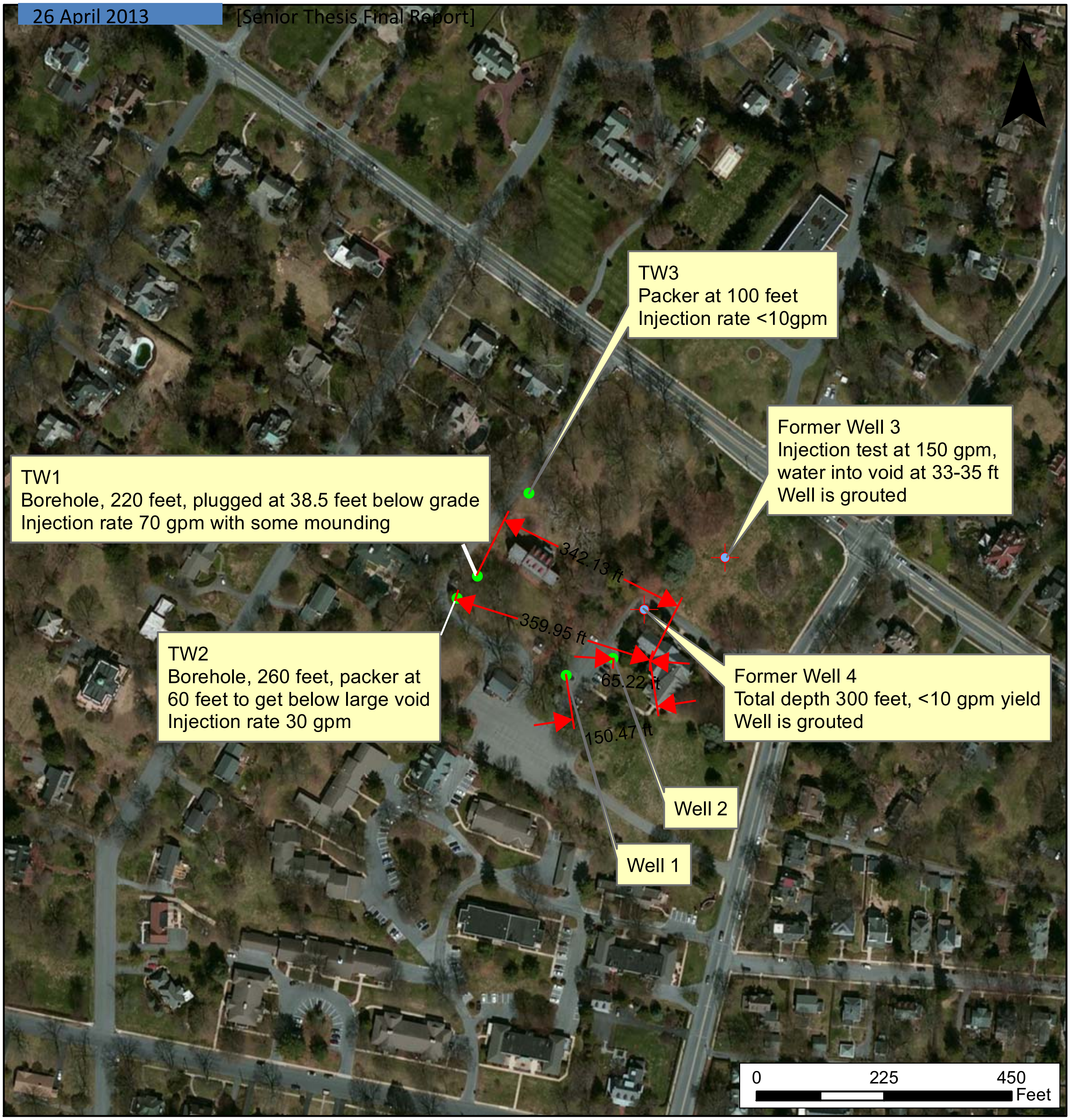
In the event that one module is not working correctly, the remaining modules – hence the boiler unit -- will continue to operate. Independently operating thermal modules deliver built-in redundancy to the boiler through the availability of multiple combustion safeguards, burners, gas valves, blowers, and the back-up master controller. Such a design approach is unique in the industry and can significantly reduce the need for redundant system capacity.

Represented by:

WATER HEATERS • BOILERS • PART... SORIES
AERCO INTERNATIONAL, INC. Å... VE.
NORTHVALE, N.J. 07647-0128 Å(201) 768-2400 ÅFAX 201-768-7789
www.aerco.com

Specifications subject to change.
Consult website or AERCO.
MLX-1 Revised 10/19/10 NJ

Appendix 2.H – Geothermal Well Locations:



Well Locations

Note: a safety factor is achieved by only utilizing implemented wells, not including testing and wasted drilling in the geothermal estimate. Direct routes to the wells are also assumed as a factor of safety. If taken into consideration, the system initial costs would be even more exorbitant

ADVANTAGE ENGINEERS

LancasterHistory.org Site

Lancaster Township
Lancaster County, Pennsylvania

Advantage Project #: 0904166.05
November 2012

*Source - (c) 2010 Microsoft Corporation and its data suppliers

Appendix 3.A – Elec. Prefab vs. Field-built Labor Savings:

Receptacle & Light-switch Estimate: Prefab vs. Field-Built

Cost Code	*Unit Price*	*Material*	*Tax*	*Mtl Total*	*Lab Hrs*	*Lab Rate*	*Lab Total*	*Prime Cost*	*Tools*	*Tools($)*	*Exp*	*Exp($)*	*Mkp*	*Mkp($)*	*Total*	*Qty*	*Unit Price*	*# Units*	*Ext. Total*
1	(508) Prefab 5-20R DRec. w/ 20' MC Tail	$ 12.13	6%	$ 12.86	0.20	$ 19.84	$ 3.97	$ 16.83	2%	$ 0.08	10%	$ 1.69	10%	$ 1.86	$ 20.46	1	$ 20.46	3	$ 61.38
2	(508) Prefab 5-20R Quadruplex w/ 20' MC Tail	$ 15.00	6%	$ 15.90	0.20	$ 19.84	$ 3.97	$ 19.87	2%	$ 0.08	10%	$ 2.00	10%	$ 2.20	$ 24.15	1	$ 24.15	92	$ 2,221.80
3	(508) Prefab 5-20R GFI DRec. w/ 20' MC Tail	$ 27.96	6%	$ 29.64	0.20	$ 19.84	$ 3.97	$ 33.61	2%	$ 0.08	10%	$ 3.37	10%	$ 3.71	$ 40.77	1	$ 40.77	21	$ 856.17
4	(508) Prefab 1P Switch w/ 20' MC Tail	$ 24.41	6%	$ 25.87	0.20	$ 19.84	$ 3.97	$ 29.84	2%	$ 0.08	10%	$ 2.99	10%	$ 3.29	$ 36.20	1	$ 36.20	44	$ 1,592.80
5	(508) Prefab 3W Switch w/ 20' MC Tail	$ 36.19	6%	$ 38.36	0.25	$ 19.84	$ 4.96	$ 43.32	2%	$ 0.10	10%	$ 4.34	10%	$ 4.78	$ 52.54	1	$ 52.54	7	$ 367.78
6	(508) Prefab Single Gang Telecom Box w/ 10' EMT	$ 20.38	6%	$ 21.60	0.15	$ 19.84	$ 2.98	$ 24.58	2%	$ 0.06	10%	$ 2.46	10%	$ 2.71	$ 29.81	1	$ 29.81	20	$ 596.20
7	02/70) Prefab 1.5" Ell	$ 6.00	6%	$ 6.36	0.13	$ 19.84	$ 2.58	$ 8.94	2%	$ 0.05	10%	$ 0.90	10%	$ 0.99	$ 10.88	1	$ 10.88	18	$ 195.84
8	02/70) Prefab 2" Ell	$ 8.00	6%	$ 8.48	0.17	$ 19.84	$ 3.37	$ 11.85	2%	$ 0.07	10%	$ 1.19	10%	$ 1.31	$ 14.42	1	$ 14.42	27	$ 389.34
9	02/70) Prefab 3" Ell	$ 30.00	6%	$ 31.80	0.19	$ 19.84	$ 3.77	$ 35.57	2%	$ 0.08	10%	$ 3.57	10%	$ 3.92	$ 43.14	1	$ 43.14	23	$ 992.22
10	02/70) Prefab 4" Ell	$ 48.00	6%	$ 50.88	0.31	$ 19.84	$ 6.15	$ 57.03	2%	$ 0.12	10%	$ 5.72	10%	$ 6.29	$ 69.16	1	$ 69.16	27	$ 1,867.32
11	Prefab 225A Panelboard w/ (2) 2" EMT Risers & J-Box	$ 598.05	6%	$ 633.93	6.40	$ 19.84	$ 126.98	$ 760.91	2%	$ 2.54	10%	$ 76.35	10%	$ 83.98	$ 923.78	1	$ 923.78	17	$ 15,704.26
12	Field-Built Duplex Receptacle w/ 20' MC Cable	$ 12.13	6%	$ 12.86	0.41	$ 54.99	$ 22.55	$ 35.41	2%	$ 0.45	10%	$ 3.59	10%	$ 3.95	$ 43.40	1	$ 43.40	3	$ 130.20
13	Field-Built Quadruplex Receptacle w/ 20' MC Cable	$ 15.00	6%	$ 15.90	0.41	$ 54.99	$ 22.55	$ 38.45	2%	$ 0.45	10%	$ 3.89	10%	$ 4.28	$ 47.07	1	$ 47.07	92	$ 4,330.44
14	Field-Built GFI Receptacle w/ 20' MC Cable	$ 27.96	6%	$ 29.64	1.47	$ 54.99	$ 80.84	$ 110.48	2%	$ 1.62	10%	$ 11.21	10%	$ 12.33	$ 135.64	1	$ 135.64	21	$ 2,848.44
15	Field-Built 1P Switch w/ 20' MC Cable	$ 24.41	6%	$ 25.87	0.26	$ 54.99	$ 14.30	$ 40.17	2%	$ 0.29	10%	$ 4.05	10%	$ 4.45	$ 48.96	1	$ 48.96	44	$ 2,154.24
16	Field-Built 3W Switch w/ 20' MC Cable	$ 36.19	6%	$ 38.36	0.31	$ 54.99	$ 17.05	$ 55.41	2%	$ 0.34	10%	$ 5.58	10%	$ 6.13	$ 67.46	1	$ 67.46	7	$ 472.22
17	Field-Built 1-Gang Telecom Box w/ 10' EMT & Pull String	$ 20.38	6%	$ 21.60	1.18	$ 54.99	$ 64.89	$ 86.49	2%	$ 1.30	10%	$ 8.78	10%	$ 9.66	$ 106.23	1	$ 106.23	20	$ 2,124.60
18	Field Bend 1-1/2" EMT 90 Degrees	$ -	6%	$ -	0.22	$ 54.99	$ 12.10	$ 12.10	2%	$ 0.24	10%	$ 1.23	10%	$ 1.36	$ 14.93	1	$ 14.93	18	$ 268.74
19	Field Bend 2" EMT 90 Degrees	$ -	6%	$ -	0.31	$ 54.99	$ 17.05	$ 17.05	2%	$ 0.34	10%	$ 1.74	10%	$ 1.91	$ 21.04	1	$ 21.04	27	$ 568.08
20	Field Bend 3" EMT 90 Degrees	$ -	6%	$ -	0.36	$ 54.99	$ 19.80	$ 19.80	2%	$ 0.40	10%	$ 2.02	10%	$ 2.22	$ 24.44	1	$ 24.44	23	$ 562.12
21	Field Bend 4" EMT 90 Degrees	$ -	6%	$ -	0.59	$ 54.99	$ 32.44	$ 32.44	2%	$ 0.65	10%	$ 3.31	10%	$ 3.64	$ 40.04	1	$ 40.04	27	$ 1,081.08
22	Field-Built 225A Panelboard w/ (2) 2" EMT Risers & J-Box	$ 598.05	6%	$ 633.93	6.67	$ 54.99	$ 366.78	$ 1,000.71	2%	$ 7.34	10%	$ 100.81	10%	$ 110.89	$ 1,219.75	1	$ 1,219.75	17	$ 20,735.75

Total Cost Prefab

$ 24,845.11

Total Cost Field-Built

$ 35,275.91

Appendix 3.B – Electrical Take-offs:

EMT Conduit Take-Off												
Item Description	*Connection Description*	*Runs*	*Total Length*	*Unit*	*Elbows*	*Connections*	*Terminations*	*Directional, Length Breakdown /Run*				
								North	*East*	*South*	*West*	*Vertical*
4" EMT, galv. Steel	MDB to ATS-S	1	35	L.F.	4	10	2	21	4	0	5	5
	ATS-S to ESP-1	1	77	L.F.	5	14	2	0	0	58	12	7
	MDB to PP-1	1	11	L.F.	2	5	2	0	0	14	0	7
	ESR-2 to Data	1	88	L.F.	4	12	2	57	14	0	7	10
	ESR-2 to Telephone	2	208	L.F.	8	26	4	114	46	0	28	20
	Total	3	419	L.F.	23	67	12	192	64	72	52	49
3" EMT, galv. Steel	MDB to PP-3	2	280	L.F.	10	34	4	0	18	110	5	7
	MDB to PP-2	2	124	L.F.	12	30	4	0	0	37	18	7
	Total	4	404	L.F.	22	64	8	0	18	147	23	14
2" EMT, galv. Steel	ATL-L to EP-1	1	10	L.F.	2	5	2	0	0	0	3	7
	DS-ATS-S to ATS-S	1	11	L.F.	3	7	2	1.5	0	0	2.5	7
	DS-ATS-L to ATS-L	1	16	L.F.	3	7	2	3	0	0	6	7
	Total	3	37	L.F.	8	18	6	4.5	0	0	11.5	21
1.5" EMT, galv. Steel	MDB to ATS-L	1	32	L.F.	3	8	2	21	0	0	5	6
	MDB to PP-4	1	88	L.F.	5	14	2	0	0	76	5	7
	PP-2 to ELEV	1	191	L.F.	7	24	2	0	58	126	0	7
	ESP-1 to AC-1	1	112	L.F.	3	12	2	0	12	95	0	5
	Total	4	423	L.F.	18	57	8	21	70	297	10	25

RMC Conduit Take-Off												
Item Description	*Connection Description*	*Runs*	*Total Length*	*Unit*	*Elbows*	*Connections*	*Terminations*	*Directional, Length Breakdown /Run*				
								North	*East*	*South*	*West*	*Vertical*
4" RMC, hot-dip galv. Steel	ESR-2 to Pullbox	2	120	L.F.	4	14	2	0	0	0	100	20
	Total	2	120	L.F.	4	14	2	0	0	0	100	20
2" RMC, hot-dip galv. Steel	FPCB to FPTS	1	38	L.F.	5	12	2	12	0	0	20	6
	PP-2 to RP-2B	1	133	L.F.	4	15	2	0	18	108	0	7
	FPTS to Nema-3R	1	100	L.F.	4	13	2	18	79	0	0	3
	Nema-3R to DS-ATS-S	1	76	L.F.	4	12	2	11.5	61.5	0	0	3
	Nema-3R to DS-ATS-L	1	78	L.F.	2	8	2	12	63	0	0	3
	Total	5	425	L.F.	19	59	10	53.5	221.5	108	20	22

Appendix 3.C – DWV Estimate & Durations:

DWV Units Estimate									
Cost Code	***Item Description***	***Qty.***	***Unit***	***Mat. $/Unit***	***Mat. Total***	***Labor $/Unit***	***Labor Total***	***Equip. $/Unit***	***Grand Total***
1	2" Hubless Cast Iron Pipe (Includes Couplings)	40	L.F.	$ 8.56	$ 342.40	$ 11.23	$ 449.20	$ -	$ 791.60
2	3" Hubless Cast Iron Pipe (Includes Couplings)	2.75	L.F.	$ 11.90	$ 32.73	$ 11.75	$ 32.31	$ -	$ 65.04
3	4" Hubless Cast Iron Pipe (Includes Couplings)	13.75	L.F.	$ 15.53	$ 213.54	$ 12.96	$ 178.20	$ -	$ 391.74
4	Delete Hangers, Subtract (-22% mat -47% lab)		%	$ -	$ (369.50)	$ -	$ (734.11)	$ -	$ (1,103.61)
5	2" Sanitary T (Excludes Couplings)	4	EA	$ 13.02	$ 52.08	$ -	$ -	$ -	$ 52.08
6	4" x 2" Sanitary T Tapped (Excludes Couplings)	7	EA	$ 24.65	$ 172.55	$ -	$ -	$ -	$ 172.55
7	3" x 2" Sanitary T Reducing (Excludes Couplings)	3	EA	$ 14.28	$ 42.84	$ -	$ -	$ -	$ 42.84
8	2" 1/4 bend (Excludes Couplings)	2	EA	$ 9.44	$ 18.88	$ -	$ -	$ -	$ 18.88
9	4" Double Y (Excludes Couplings)	2	EA	$ 72.08	$ 144.16	$ -	$ -	$ -	$ 144.16
10	4" Y (Excludes Couplings)	4	EA	$ 27.90	$ 111.60	$ -	$ -	$ -	$ 111.60
11	4" x 2" Y Reducing (Excludes Couplings)	1	EA	$ 18.60	$ 18.60	$ -	$ -	$ -	$ 18.60
12	2" Coupling	30	EA	$ 12.09	$ 362.70	$ 17.08	$ 512.40	$ -	$ 875.10
13	4" Coupling	17	EA	$ 17.07	$ 290.19	$ 22.93	$ 389.81	$ -	$ 680.00

	Mat. Total	***Labor Total***	***Grand Total***
Subtotal	**$ 1,432.76**	**$ 827.81**	**$ 2,260.58**
Tax (6%)	**$ 85.97**	**$ 49.67**	**$ 135.63**
Conduit Grand Total	**$ 1,518.73**	**$ 877.48**	**$ 2,396.21**

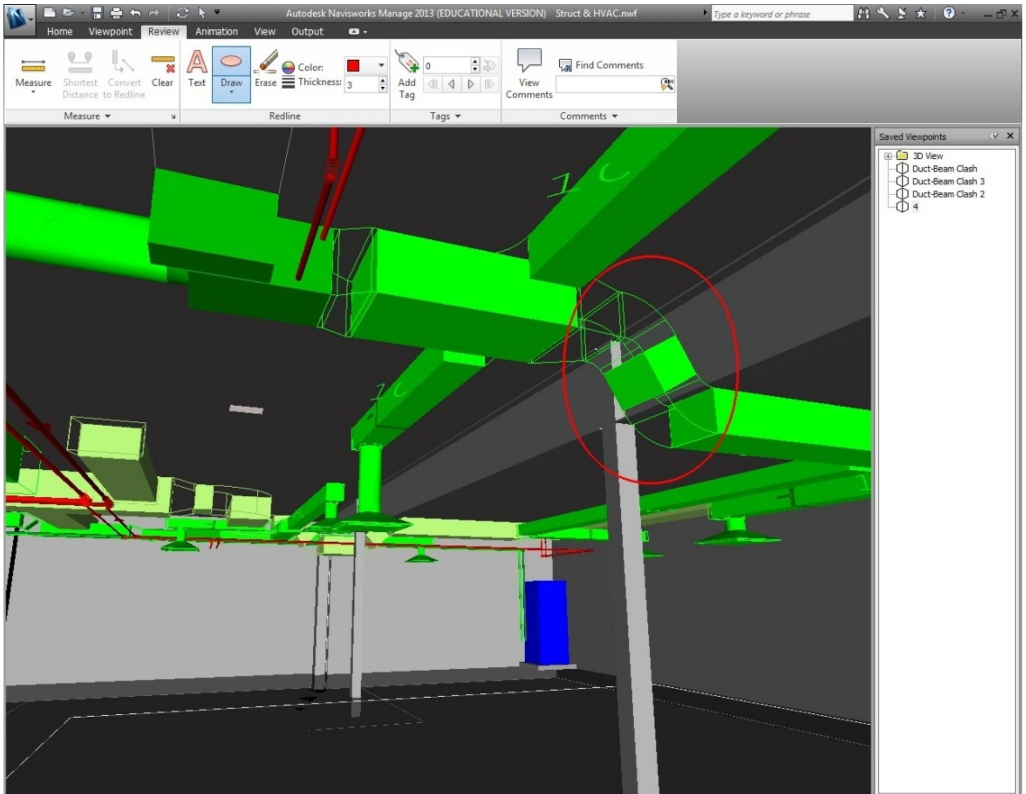
Appendix 4.A – BIM Goals:

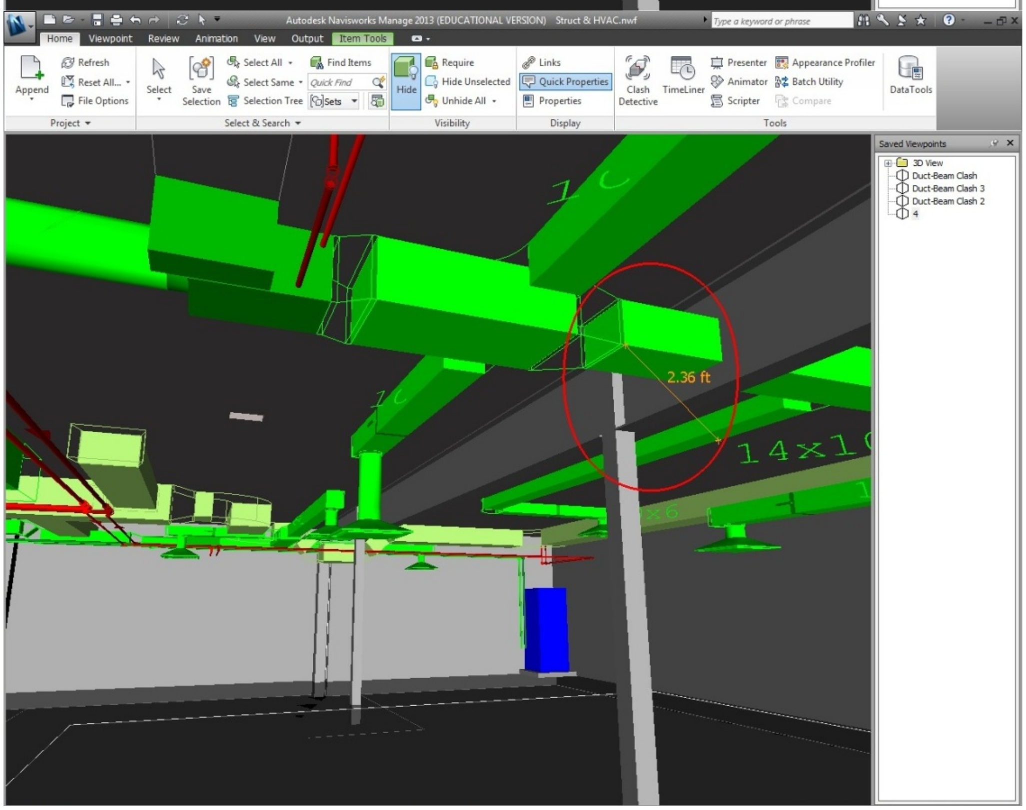
PRIORITY (HIGH/MED/LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES
High	Ensure building is operating to sustainable standards	Building systems Analysis
Medium	Ensure building is operating to specified design	Building systems Analysis
High	Identify opportunities to modify system operations to improve performance	Building systems Analysis
Medium	Increase the efficiency of transition planning and management	Space management & tracking
High	Proficiently track the use of current and space and resources	Space management & tracking
High	Assist in planning future space needs for the facility	Space management & tracking
Medium	Improve the effectiveness of Emergency response	Disaster Planning
Medium	Minimize risks to responders	Disaster Planning
High	Accurately evaluate site layout for safety concerns	Site Utilization Planning
Medium	Effectively communicate construction sequence and layout to all interested parties	Site Utilization Planning
High	Minimize the amount of time spent performing site utilization planning	Site Utilization Planning
Medium	Increase constructability of a complex building system	Construction System Design (Virtual Mockup), 3D Coordination
High	Increase construction productivity, Phase Planning (4D Modeling)	Construction System Design (Virtual Mockup),
Medium	Decrease language barriers	Construction System Design (Virtual Mockup), 3D Control and Planning (Digital Layout)
High	Ensure quality of information	Digital Fabrication
Low	Reduce lead time	Digital Fabrication
Medium	Decrease layout errors by linking model with real world coordinates	3D Control and Planning (Digital Layout)
Low	Reduce rework because control points are received directly from the model	3D Control and Planning (Digital Layout)
High	Reduce and eliminate field conflicts	3D Coordination
High	Reduce construction cost	3D Coordination, Phase Planning (4D Modeling), Cost Estimation
High	Decrease construction time	3D Coordination, Phase Planning (4D Modeling)
High	Better control and quality control of design, cost and schedule	Design Authoring, Sustainability (LEED) Evaluation, Design Reviews
High	Achieve optimum, energy-efficient design solution by applying various rigorous analyses	Engineering Analysis, Facility Energy Analysis
Low	Automate analysis, saving time and cost	Engineering Analysis, Facility Energy Analysis
Medium	Early and reliable evaluation of design alternatives.	Sustainability (LEED) Evaluation, Design Reviews
High	Reduce operational costs of the facility due to the energy performance of the project	Sustainability (LEED) Evaluation
Low	Reduced turnaround time	Code Validation
High	Space and workspace conflicts identified and resolved ahead of the construction process	Phase Planning (4D Modeling)
Medium	Monitor procurement status of project materials	Phase Planning (4D Modeling)
High	Identification of schedule, sequencing or phasing issues	Phase Planning (4D Modeling)

Appendix 4.B – BIM Use Analysis:

BIM USE	VALUE TO PROJECT	RESPONSIBLE PARTY	VALUE TO RESP PARTY	CAPABILITY RATING			ADDITIONAL RESOURCES/COMPETANCIES REQUIRED TO IMPLEMENT	PROCEED WITH USE
	HIGH/ MED/ LOW		HIGH/ MED/ LOW	SCALE 1-3 (1=LOW)				YES/NO/ MAYBE
				Resources	Competenc	Experience		
Building Systems Analysis	High	Architect	Medium	3	3	3	Building Systems Analysis Software	Yes
		MEPF Engineer	High	3	2	2		
		Contractor	High	2	2	2		
Space management & tracking	High	Owner	High	2	3	3	Bi-Directional 3D Model Manipulation	Yes
Disaster Planning	Medium	Contractor	Medium	1	1	1		No
Site Utilization Planning	High	Contractor	High	3	3	3		Yes
Construction System Design (Virtual Mockup)	High	Architect	High	3	2	2		Maybe
		MEPF Engineer	High	3	3	2		
		Structural Engineer	Medium	3	3	2		
Digital Fabrication	Medium	MEP Engineer	Low	2	2	1		Yes
		Contractor	Medium	3	3	2		
		Fabricator	High	3	3	3		
3D Control and Planning (Digital Layout)	Low	Architect	Low	2	2	1		No
		MEPF Engineer	Low	3	3	3		
		Contractor	Medium	2	3	2		
		Subcontractors	Low	1	2	1		
3D Coordination	High	Architect	High	3	3	3		Yes
		MEPF Engineer	High	3	3	3		
		Contractor	High	2	3	3		
		Structural Engineer	High	3	2	2		
Code Validation	Medium	Code	Medium	2	2	2		Maybe
		Owner	Medium	1	1	1		
Phase Planning (4D Modeling)	High	Contractor	High	3	3	3	Teach Subcontractors	Yes
		Subcontractors	Medium	1	3	1		
Design Reviews	Low	Architect	Medium	3	2	2		No
		Owner	Low	2	1	1		
Facility Energy Analysis	Medium	Architect	Medium	3	2	3		Yes
		MEPF Engineer	High	3	2	3		
		Contractor	Medium	2	2	1		
Sustainability (LEED) Evaluation	High	Contractor	High	2	2	1	Knowledge of up-to-date LEED information	Maybe
		Owner	High	2	2	1		
		Architect	High	3	2	3		
Cost Estimation	Low	Architect	Low	2	1	2		No
		Contractor	Medium	3	3	3		
Design Authoring	Low	Architect	Medium	2	2	1		No
		Owner	Low	2	1	1		
		Structural Engineer	Low	2	2	2		
Engineering Analysis	Medium	Architect	Medium	2	2	1	Engineering analysis software	Maybe
		MEPF Engineer	High	3	3	3		
		Structural Engineer	Medium	3	3	3		
Record Modeling	Medium	Contractor	Medium	2	2	1		Maybe
		Facility Manager	High	2	1	1		
		Owner	High	2	1	1		
		MEP Engineer	Medium	2	2	2		

Appendix 4.C – BIM Snapshots:


Autodesk Navisworks Manage 2013 (EDUCATIONAL VERSION) Struct & HVAC.nwf
Saved Viewpoints
3D View
Duct-Beam Clash
Duct-Beam Clash 3
Duct-Beam Clash 2
4


Autodesk Navisworks Manage 2013 (EDUCATIONAL VERSION) Struct & HVAC.nwf
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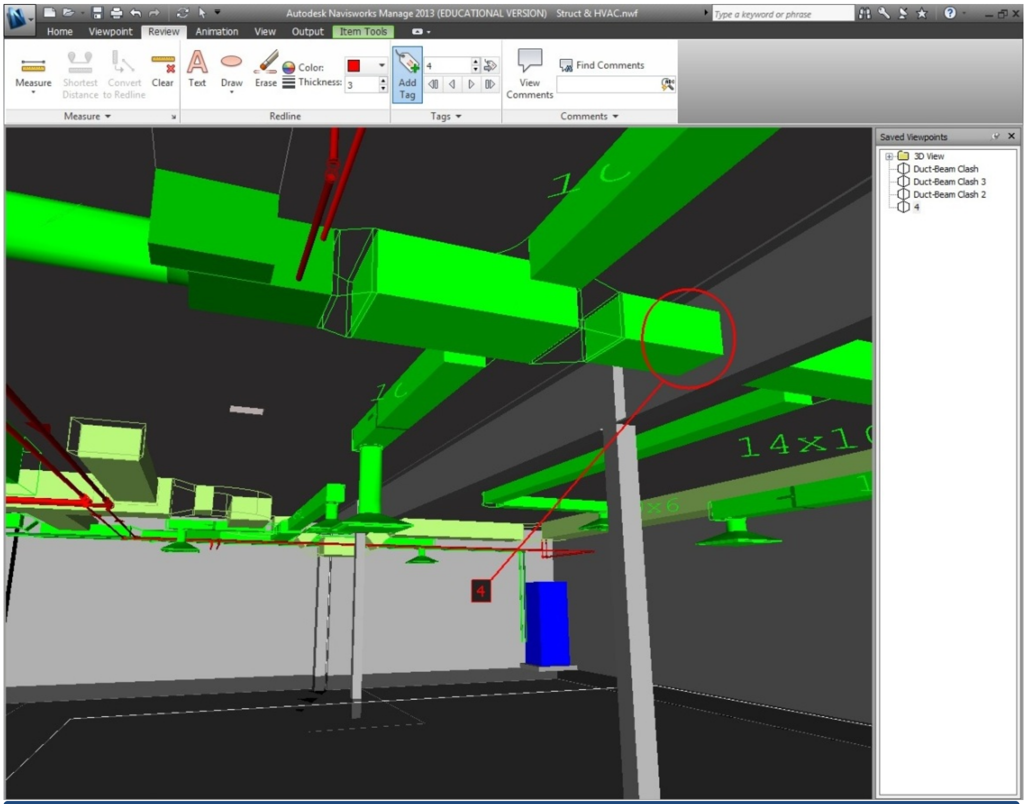
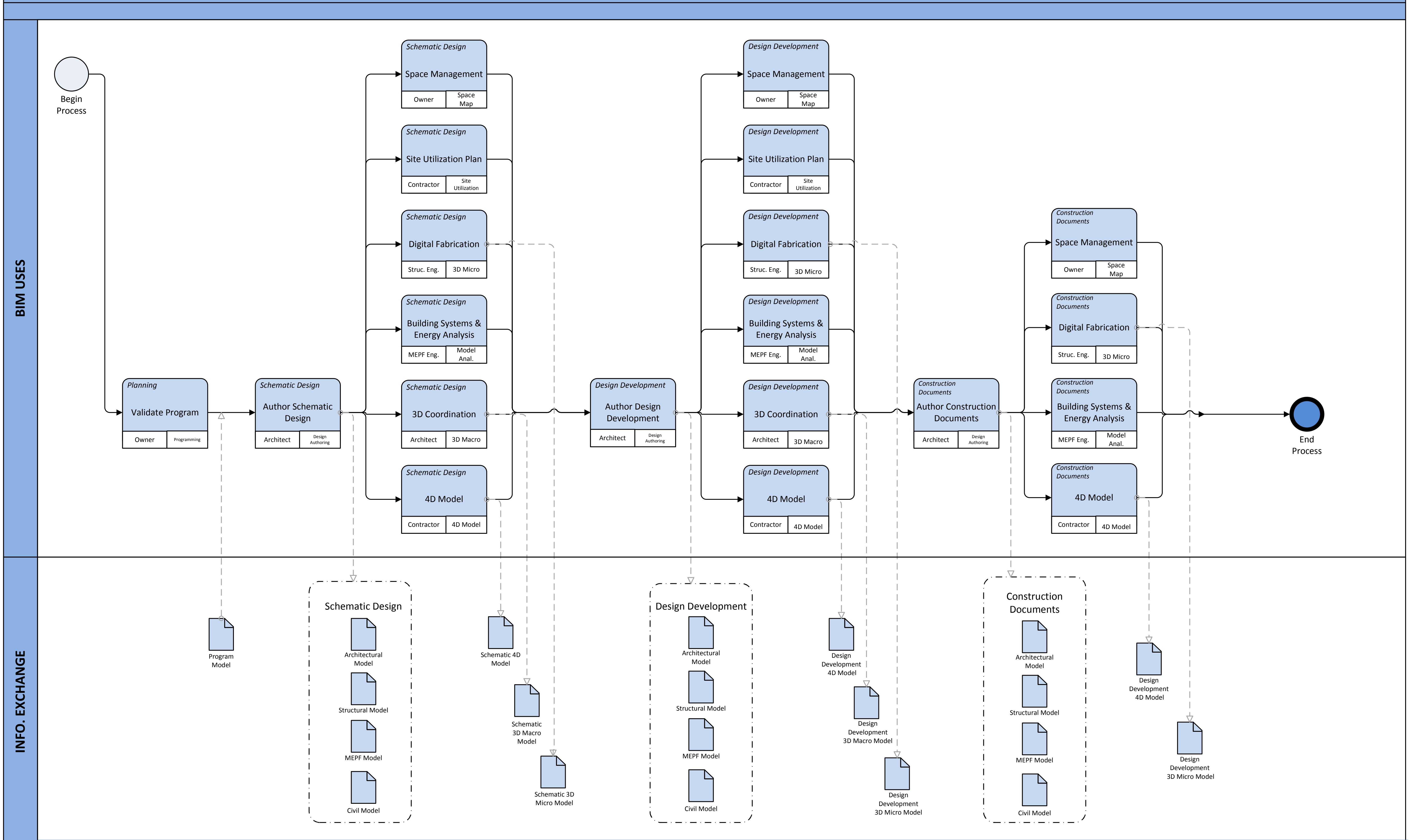
Saved Viewpoints
3D View
Duct-Beam Clash
Duct-Beam Clash 3
Duct-Beam Clash 2
4


Autodesk Navisworks Manage 2013 (EDUCATIONAL VERSION) Struct & HVAC.nwf
Home
Viewpoint
Review
Animation
View
Output
Item Tools
Measure
Shortest Distance
Convert to Redline
Clear
Text
Draw
Erase
Color:
Thickness:
Add Tag
View Comments
Find Comments
Redline
Tags
Comments
Saved Viewpoints
3D View
Duct-Beam Clash
Duct-Beam Clash 3
Duct-Beam Clash 2
14x1

Appendix 4.D – BIM Level 1 Process Map:

Level 1: BIM Execution Planning Process

LancasterHistory.org



Breadth Study Descriptions:

Description of Breadth Studies:

Structural Breadth

The structural breadth topic for Analysis 1will be an evaluation of the LH.O substructure, taking into consideration soil compaction's effects on bearing pressure and foundation design. Construction methods utilized in soil remediation will also be considered. When unsuitable soils were encountered at LH.O and desired compaction could not be reached, excavation and replacement was performed as a solution. Had unsuitable soils been backfilled, the building's structural integrity would have been compromised. To prove this, foundation structural analyses will be conducted, addressing design criteria for both existing soils and structural fill. Analyses will involve re-designs of the building's typical foundation wall for both of these soils. From a constructability standpoint, a new site layout plan will address soil scarification concerns for LH.O. Overall, foundation design calculations will be demonstrated in this breadth to show the importance of proper soil compaction.

Mechanical Breadth

The mechanical breadth topic for *Analysis 2* will be a redesign of the LH.O mechanical system, attempting to increase value. Various conventional mechanical systems will be evaluated for system performances to ultimately replace the project's failed geothermal one. Systems will be sized and designed to meet internal heating and cooling loads. Afterwards, Life Cycle Cost (LCC) will be analyzed for each design option. Analyses will be conducted utilizing assembly estimates, vendor quotes, and GC and subcontractor input. Testing and commissioning requirements will be considered. By nature of LCC studies, system initial design and construction costs will be weighed with operating and energy expenses and system life spans. The system providing the most valuable combination of performance and cost will be selected for further analysis for LH.O.