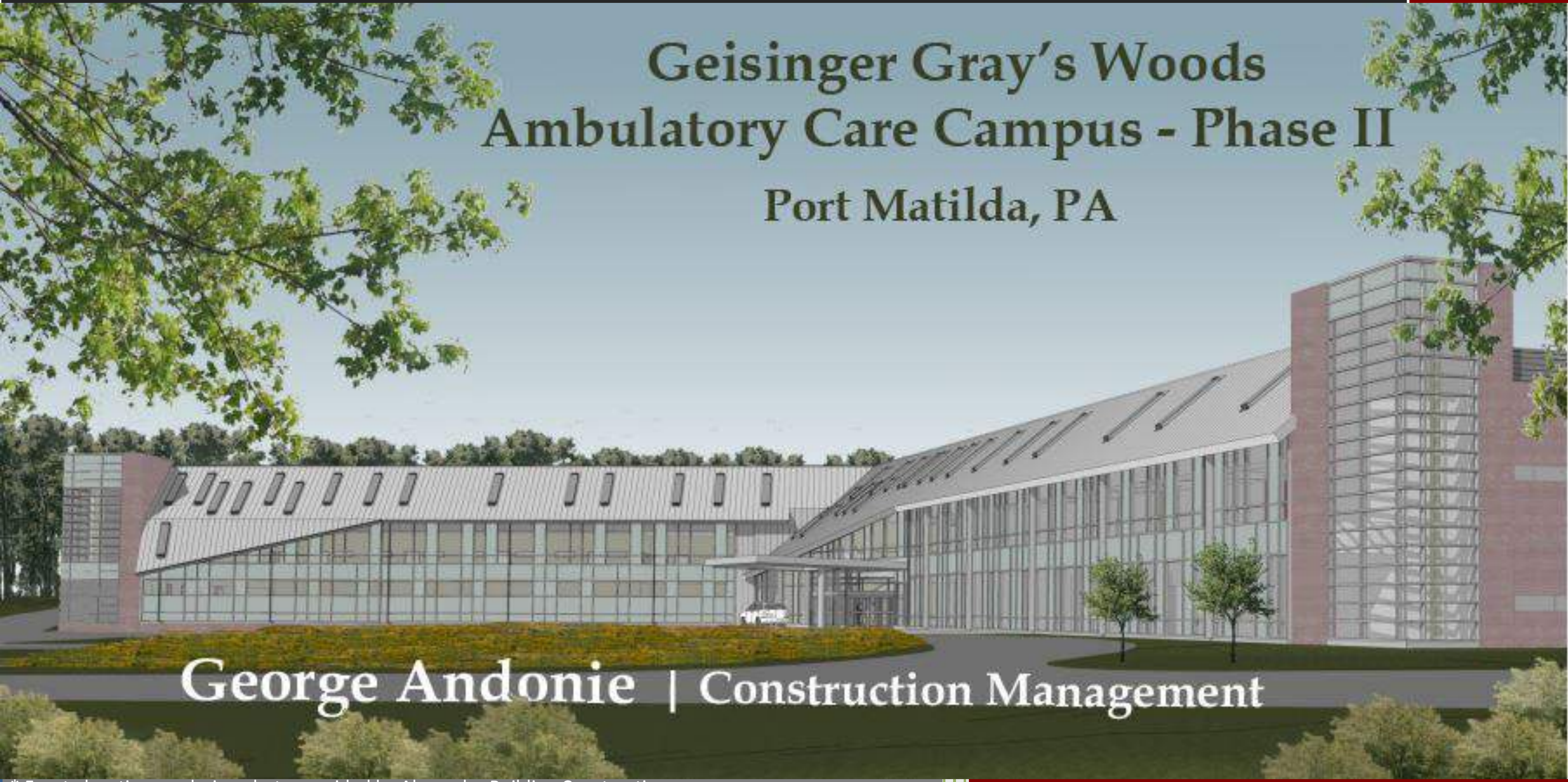
Final Thesis Report



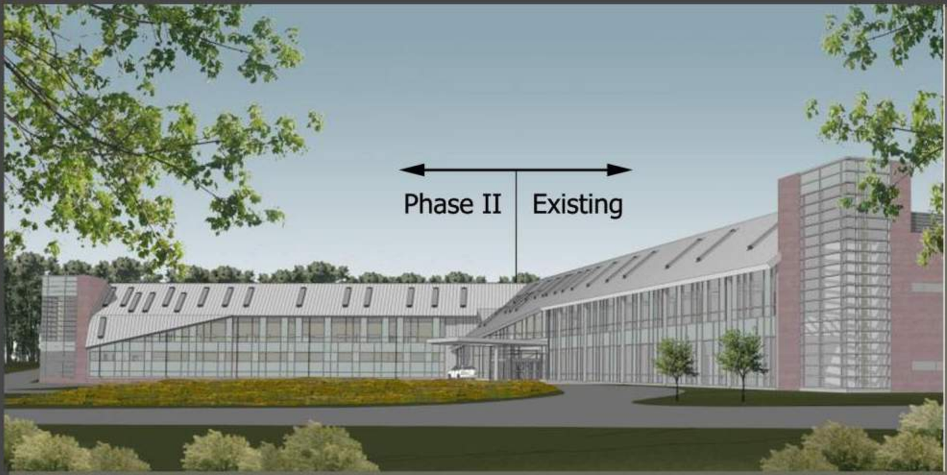
* Front elevation rendering photo provided by Alexander Building Construction

George Andonie
Construction Option

AE Faculty Consultant:
Rob Leicht

Spring '14
April 9th, 2014

Geisinger Gray's Woods Ambulatory Care Campus - Phase II
Port Matilda, PA



North Elevation View

Project Overview:

Owner:	Geisinger Healthcare Systems
Function:	Outpatient Surgery
Size:	77,560 GSF
Height:	2 stories (48')
Cost:	$26.3 Million GMP
Construction:	July '14 - Feb. '14
Delivery:	Design-Bid-Build
LEED	LEED Certified

Project Team:

Contractor:	Alexander Building C.
Architect:	Ewing Cole
Structural Engineer:	Ewing Cole
MEP Engineer:	Ewing Cole
Civil Engineer:	Sweetland Engineering

EWING COLE

GEISINGER HEALTH PLAN®

ALEXANDER
A BUTZ FAMILY COMPANY

Architectural Features:

Follows the design features set by phase I (2008):
- Curtain Walls along northern facade made of aluminum framing & low-E glass
- Brick cavity walls along sides and back facades with metal stud (CFMD) back-up
- EPDM (Synthetic Rubber) flat roof
- Sloped Roof with skylights

3,300SF Plant to house MEP equipment
Metal canopy structures above both of building's main entrances

Structural System:

Cast-in-Place Shallow foundation (3.5' deep):
- Pier, wall footings and grade beams
- 5" Slab on Grade

Two-story steel framed structure
- 30' high steel wide flange members

Composite metal deck floors:
- 3 1/4" LW Concrete on 2" Metal Decking

Sloped Metal Roof
- 6" metal studs over w8 wide flanges

Mechanical System:

Air-Water Distribution System:
Cooling:
- 4 Rooftop AHU's with economizer cycles
- Variable Air Volume (VAV) Control Boxes
- 1,100GPM Cooling Tower
- 250 Ton Water Chiller

Heating:
- 3,500 MBH Gas Hot Water Boiler
- Unit heaters, fan coil units, and radiant heat panels for heating at different zones

Electrical System:

3-phase, 60Hz transformer providing 480/277V
- 2,500A Main Distribution Panel feeding various mechanical equipment and distribution panels

Step-down transformers (208/110V) for appliances
Lighting:
- T8 & Compact Fluorescent Lights
- Occupansy and Photosensors

Emergency Power Systems:
- 400kW Emergency Generator
- Emergency Electrical Room that houses a 300kVA Modular UPS Emergency Power and a 400A Emergency Distribution Panel

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http://www.engr.psu.edu/ae/thesis/portfolios/2014/gma5074/

Executive Summary

This thesis final report will provide an in-depth analysis of the Geisinger Grays Woods Ambulatory Care Campus, Phase II project. Throughout extensive research performed in the Fall Semester, I identified three analyses that focus on problems or opportunities faced during the construction of this facility. They are based on areas of critical industry issues, value engineering, constructability review, and schedule reduction. Analysis topics include the feasibility of implementing virtual mockups for the construction of the facility's operating and endoscopy rooms, prefabricating the building's façade, and re-evaluating the structural composite slab for this project.

Analysis 1 - Virtual Mockups on Operating/Endoscopy Rooms:

The 'In-Place Mockups' used for the construction of the facility's operating and endoscopy rooms resulted in a costly and time-consuming process which obstructed the construction in these areas. Virtual mockups could provide faster, cheaper, and more effective means for reviewing the design of the spaces prior to construction. This analysis focused on evaluating the implementation of virtual mockups for the construction of this facility's operating and endoscopy rooms. The criteria and workflow of the mockup development were captured to better understand whether this tool would be beneficial for the Grays Woods Project. The facility model was developed using Autodesk Revit and Unity Software. It took a total of 20.5 hours to develop a mockup for both rooms, and could potentially cost over $4,000 if implemented on this project. Implementation of virtual mockups was highly recommended as it could potentially save cost, time, reduce risk, and solve design and constructability issues in advance of construction.

Analysis 2 – Brick Façade Prefabrication:

The goal of this analysis was to determine whether prefabricating the building's façade would decrease the project duration and cost, while maintaining similar aesthetics and building performance. A complete analysis of the building façade was performed using Nitterhouse's 'Architectural Precast Panels'. The design required a total of 74 precast panels spanning the building's height. Implementing precast panels costs an additional $112,000 to the project budget, although it could reduce the project schedule by 3 weeks. Through a mechanical analysis, it was determined that the proposed panel would improve heat gain and heat loss by 20%. Nevertheless, prefabricating the exterior façade was not recommended as the increase in cost and additional planning required for implementation outweigh the savings in schedule and improved building performance.

Analysis 3 - Reevaluation of Structural Composite Slabs:

The third analysis looked into reducing the total building costs through value engineering efforts on the composite slabs. With over 38,000SF of lightweight concrete being used for the slabs, the lower material costs of normal weight concrete could have substantial impacts on the project. It was determined through a structural analysis that the proposed design would require over 6.5 tons of additional structural steel to support the increased load of normal concrete. This would increase the assembly's cost by $27,000, or 3% to that of the original design. Throughout the research, many of the risks of using lightweight concrete were exposed. Even though using normal weight concrete would increase project costs, it is recommended as it provides much more reliable performance than lightweight concrete upon placement.

Acknowledgements

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Mathew Hoerner - Alexander Building Construction
Ray Sowers & Ed Gannon - Penn State's OPP
Mark Taylor – Nitterhouse Concrete
Sonali Kumar – Balfour Resource Group
George Burnley – High Concrete Group
PACE Industry Members

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1.0 Project Overview

The Geisinger Gray's Woods Ambulatory Care Campus is a multi-specialty outpatient surgery center located in Port Matilda, PA. The construction of the phase II consists of a 78,000SF addition to the existing building held by Alexander Building Construction. This expansion will house four operating rooms, four endoscopy rooms, two pain therapy rooms as well as several patient rooms, waiting rooms, office areas and clinical spaces to extend its outpatient surgery capabilities to over 100,000 patients around the Centre County Region.

Table 1.0 – General Building Statistics

General Building Information	
Building Name	Grays Woods Ambulatory Care Campus
Location	Port Matilda, PA
Function	Outpatient Surgery Center
Size	77,560 GSF
Height	2 Stories (48' Total Height)
Cost	$26.3 Million GMP
Construction	July '12 - February '14
Delivery	Design-Bid-Build
LEED	LEED Certified

1.1 Client Information

Figure 1.1: Geisinger Health Systems Logo. Image courtesy of www.geisinger.org

Founded in 1915, Geisinger Healthcare Systems is a physician-led health services organization providing care to over 2.6 million people in the state of Pennsylvania. In order to accommodate their continuing expansion around western Pennsylvania, Geisinger Health Services decided to build an outpatient facility on their Gray's Woods Campus in Port Matilda, PA. With over 19 facilities around the state, Geisinger is not a new client in the field of construction. In 2008 they started a new initiative to move into green building in all their future expansions, and for this project they are pursuing for LEED Certified status. In order to complete the project to the owner's satisfaction, Alexander Building Construction, the Construction Manager for this project, will have to emphasize on the design quality, time and budget. Geisinger expects high quality standards for the construction of their new ambulatory care campus at Gray's Woods. Cost and schedule are important in all their projects, as they are both approved by the General Board and wish not to renegotiate the cost nor lose any potential profit due to delays in occupying the facility. Most importantly, Geisinger expects to have a smooth transition between phases of this project. Constructing the phase II addition, while occupying phase I, will bring a big challenge to the construction team when concerning the health and safety standards, as well as minimizing the disturbance to the existing faculty and patients occupying the building. Geisinger has addressed the importance of technologies in regards to design and construction throughout their projects, and is looking towards the future for better ways to design, build and operate their facilities.

1.2 Project Delivery & Staffing Plan

The Geisinger Gray's Woods Ambulatory Care Campus is being delivered through a traditional design-bid-build (DBB) approach, where Alexander Building Construction is acting as the Construction Manager, and Ewing Cole as the Architect/Engineer for this project. Alexander Building Construction was awarded a Guaranteed Maximum Price (GMP) contract for this project. They hold Lump-Sum contracts with all the subcontractors, while self-performing 5-10% of the work. These subcontractors were chose on a best-value bid process, where best value not only means lowest price, but company qualification such as experience, safety, & financial condition. Ewing Cole, the Architect/Engineer, was awarded a 'Cost + Fee' contract for their services. Ewing Cole designed the structural and MEP systems for this facility, and subcontracted Sweet Engineering to prepare the civil designs. The owner also hold separate contracts with geotechnical, security, HVAC controls and commissioning agents for the delivery of this building.

The delivery method utilized for this project was Design-Bid-Build (Figure 1.2). This allowed Alexander Building Construction to provide 3 months of preconstruction services prior to beginning construction. This was a great advantage as Alexander provided input during the design phase of this project, greatly reducing the probability of change orders during the construction process. Alexander, also being the contractor for phase I, was able to better plan and budget the construction costs, therefore guaranteeing a maximum price for the delivery of this facility. Geisinger Health System did not require any bonds for the construction of their Gray's Woods facility. The standard subcontractor's insurance (general liability, workman's comp, etc.) is required by Geisinger for all subcontractors. Alexander, as the Construction Manager, holds general liability insurance for the construction of this facility.

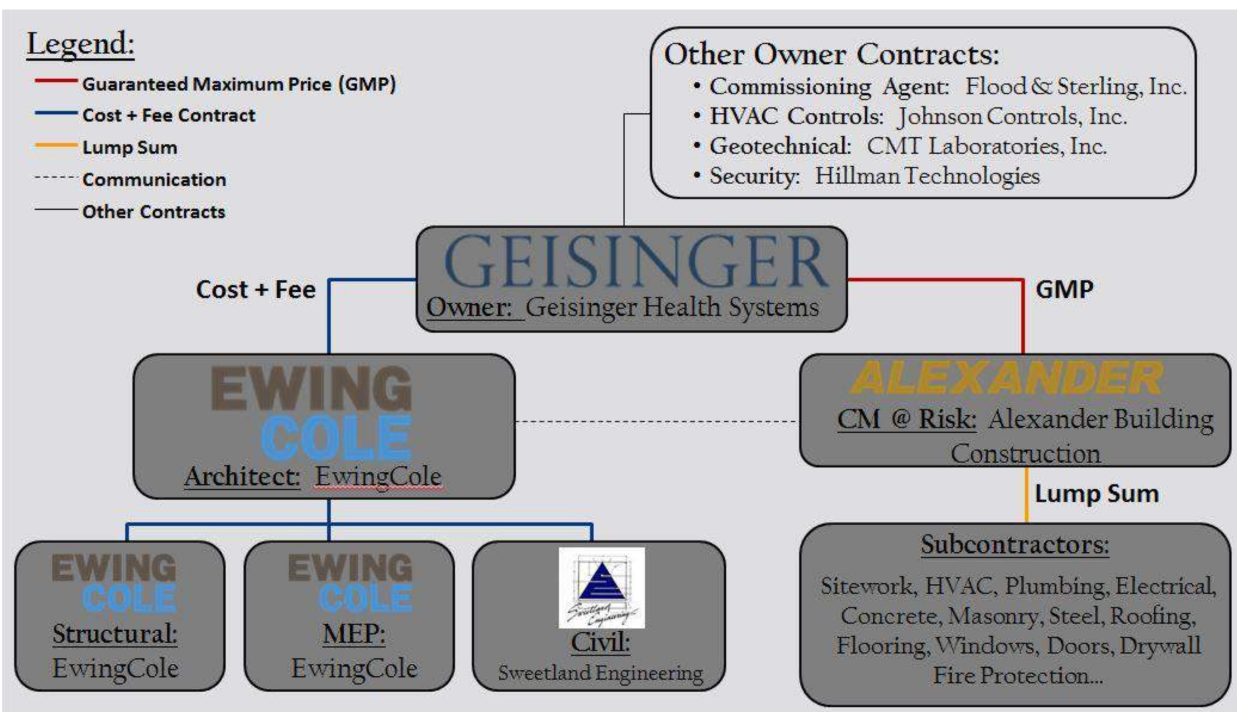


Figure 1.2: Project Delivery Method for the Geisinger Grays Woods Ambulatory Care Campus – Phase II Project. Image by George Andonie

Alexander Building Construction utilized an 8-person staff to provide both supervision and project management services to this project. Additionally, 3 other member provided support activities such as estimating, safety and accounting for this project. The majority of Alexander's management and supervision staff are from the State College branch, which is 13 miles from the project site. This close location facilitated staff and owner meeting, which were held every two weeks at the Alexander Job Trailer. The site superintendent, Richard Thomas, worked in Phase I of the project. This brings a big advantage to the delivery of this project, as he can provide valuable input in the construction means and methods from the challenges that he experienced during the construction of phase I.

1.3 Existing Site Conditions

The Gray's Woods project is located on a 52 acre lot near to the I-99 interchange at Port Matilda, PA. This enormous site houses the existing phase I, a three-tier parking deck, and the new construction of phase II. Because this site is already in use by the current operations, there are some existing utility lines which serve Phase I and the existing site. New electric, telecommunication and TV lines will be added in order to serve Phase II and expanded site, while the existing water, sanitary, and Stormwater lines will be expanded to serve both facilities and surrounding site.

Due to the relatively large amount of space available at Gray's Woods site, the construction team will not have any problems setting up their trailers, parking, material staging and storage areas, as well as waste management bins. The location allows for easy access by construction equipment and employees, as well as patients to park and access the occupied facilities without any disturbances by the construction.

Figure 1.3: Aerial View of the Geisinger Grays Woods Ambulatory Care Campus. Image courtesy of www.pahomepage.com

***Refer to Appendix A for the 'Existing Conditions Site Plan'**

2.0 Design & Construction Overview

2.1 Building Systems Summary

The Geisinger Ambulatory Care Campus, Phase II is a 78,000SF addition to the existing outpatient surgery center at Grays Woods. This project will require an expansion of the existing mechanical, electrical and plumbing systems serving Phase I. Table 2.1 outlines the major building systems associated with the construction of this project, and will be discussed in detail in the following pages.

Table 2.1: Building System Checklist

Building Systems Summary		
Work Scope	**Yes**	**No**
Demolition Required?		✓
Structural Steel Frame	✓	
Cast-in-Place Concrete	✓	
Pre-Cast Concrete		✓
Mechanical System	✓	
Electrical System	✓	
Masonry	✓	
Curtain Wall	✓	
Support of Excavation		✓

Building Enclosure

The building's exterior is mainly comprised of brick, glazing, and aluminum materials. The building's front facade is comprised of an aluminum framed curtain wall system with low emissivity glass. The building's sides and south façade are comprised of brick cavity walls backed by cold formed metal framing (CMFM). A unique feature on the cavity walls used on this building, is that the 4" semi-rigid insulation is on the exterior side of the wall rather than being behind the sheathing. This was done due to the specific vapor emission of this building.

The building's flat roof is protected by loose laid ballasted single ply of EPDM (synthetic rubber) roofing membrane, while the sloped roof portion is completely covered by a metal roofing system along with skylight windows. Figure 2.1 illustrates the curtain wall system and sloped metal roof with skylights located in the Northern Façade.

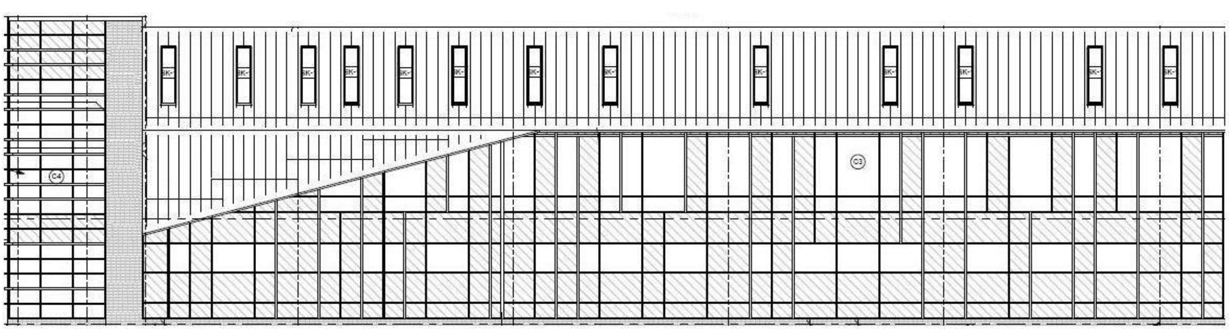


Figure 2.1: Front Façade of the Geisinger Grays Woods Ambulatory Care Campus

Structural System

The Geisinger Medical Center at Gray's Woods addition is a two-story steel braced framed structure supported over cast-in-place spread footings and slab on grade. Pier footings are spaced on an approximately 30' by 30' grid, and support the 5" concrete slab on grade above it.

The second floor slab is comprised of 3 ¼" of lightweight concrete poured over a 2" composite metal decking, reinforced with a welded wire fabric. The building's sloped roof consists of metal roof decks and skylights supported by sloped W8 wide flanges and 6" metal studs.

Chiller Utility Plant

To better serve the building's mechanical and electrical needs, a 3,300 SF Chiller Utility Plant (CUP) was constructed during phase I of this project. This CUP building will house those existing and new water chillers, boilers, pumps, fans, distribution panels and fire alarm system to provide electrical and mechanical support to the whole facility.

Mechanical System

A new 157 kW cooling tower along with the already existing cooling tower will both feed the many mechanical equipment found in the CUP. The CUP will house those existing and new water chillers, boilers, domestic hot water heaters, pumps, fans, and fire alarm system to provide support to the whole facility. Additionally, 4 new air handling units (AHU's) with a built-in economizer cycle will be located in the rooftop to provide cooling to Phase II addition only.

This facility uses an air-water distribution system to provide cooling and heating to the whole building. The distribution of the Variable-Air-Volume (VAV) systems will be done through sheet metal ductwork two-pipe system around the building. The two-pipe reverse return system will supply and return hot water to the Air Volume Control Boxes (AVB's). Air will be distributed through the plenum ceiling and exhausted through 10 different exhaust fans located in the building's ceiling. The building's mechanical system will also receive LEED credits for "Optimizing Energy Performance" and "Carbon Dioxide Monitoring".

Electrical System

The electrical service for this building is supplied via an existing 2,500A, 480/277V, 3-phase distribution panel located in the CUP Building. This switchboard then branches the supply into three feeds, each powering different areas and mechanical systems throughout the building. Various 480 – 208/120V transformers located within the building's electrical room will be used to serve different appliance panels around the building.

The Geisinger Medical Center will replace the existing 250 kW generator serving Phase I by a new upsized 400 kW Emergency Generator to supply emergency power to the whole building in case of any outages. This generator will serve two 400A, 480/277V main emergency distribution panels (MEDP's) in the main emergency electrical room, and will be assisted by 300kVA modular UPS System to allow for uninterrupted power in the event of an outage.

2.2 Engineering Support Systems

Fire Protection

The entire fire protection equipment and installation for the new addition of the Geisinger Medical Center at Gray's Woods was designed to follow the required IBC 2006 and NFPA 13, 25, 70 and 72 regulations. This project uses a Wet Sprinkler System connecting to very similar systems in the existing building. Additionally, fire protecting methods such as automatic fire-rated folding doors, UL rated walls and doors, and Spray on Fire proofing (SOFP) are used to protect the building's occupants as required by code.

Lighting

The lighting for the Geisinger Medical Center Phase II addition utilizes a total of 48 different luminaire types to accommodate the many different areas throughout the facility. The main types of lighting fixtures within the facility include Recessed Fluorescent T5, Recessed fluorescent T8s and LED down lights. A total of 34 pole mounted metal halides provide lighting to the exterior and parking lots around the site.

The building was designed such way that the public spaces, such as the atrium and waiting areas, receive as much natural daylight possible through the use of skylights and curtain walls. Therefore, very few lighting fixtures are visible in these areas. The lighting design also incorporates occupancy and photosensors in an attempt to limit energy consumption within the building whenever unoccupied, or abundant natural light is available in the space.

Transportation

Given that this building is intended to be used for a healthcare facility, elevators will be a crucial element to the mobility between the two floors of this building. One standard pre-engineered hydraulic passenger elevator will be installed in the building's northeastern corner. This 5,000lb capacity elevator, along with two main emergency stairs, will provide patients and doctors access to both floors within the building's new addition.

Telecommunications

In accordance with Geisinger's Information Technology Department's standards, each floor will have a main telecommunication and satellite telecommunication rooms with the purpose of limiting the amount of wiring required for each substation. Also, the AIA Guidelines for Hospitals and Healthcare facilities require nurse stations in each room. Other low voltage communication systems included in this building are public address (PA) and program (music) distribution systems, a cable television (CATV) system, and a security camera system.

2.3 Schedule Overview

The initial phase of Geisinger Gray's Woods Ambulatory Care Campus was constructed in 2007-2008. The current 77,560 Phase II addition began on September 10, 2012 with an anticipated substantial completion date set for January 02, 2014. This translates to total project duration of approximately 18 months, or 384 working days. The detailed project schedule for this project was created using Primavera P6 and contains a little over 160 activities pertaining to the design, procurement, construction and closeout of Geisinger Gray's Woods Phase II Project. The following Table 2.2 summarizes the major dates and durations of the phases in the detailed schedule.

Table 2.2 - Project Milestone and Duration Overview:

Project Milestones & Durations			
Activity	**Start**	**Finish**	**Duration (Days)**
Design	1-Jun-11	5-Oct-11	89
Procurement	30-May-12	19-Oct-12	100
Construction	31-May-12	2-Dec-13	384
Site Mobilization	31-May-12	29-Jun-12	22
Garage Construction	5-Jul-12	5-Dec-12	108
Building Sitework	27-Aug-12	9-Oct-12	31
Building Structure	10-Sep-12	2-Jan-13	80
Building Envelope	19-Nov-12	31-Jul-13	178
Building Interior	31-Dec-12	4-Oct-13	236
CUP & Mech. Yard Work	4-Apr-13	15-Jul-13	71
Completion & Closeout	22-Aug-13	6-Feb-14	118
Total Project Duration	**10-Sept-12**	**02-Jan-14**	**384**

*Project Durations taken From Detailed Project Schedule (Appendix B)

***Refer to Appendix B for the 'Original Project Schedule'**

The construction of the building's superstructure and interior work was completed over two phases: Phase A connecting to the existing building and slowly moving towards phase B. MEP and Interior work was divided into 4 quadrants: Work began at Phase 1A, moving to phase 2A, then towards 1B and finishing up in Phase 2B. This construction sequence was developed in response to some underground plumbing issues encountered at the beginning of the project, which forced vertical phasing sequence rather than horizontal.

The building envelope construction followed a counterclockwise flow, beginning with the brick cavity walls at the west, south, and east facades and moving on to the curtain wall system in the northern façade. During this phase of construction, the existing building's envelope, where both phases will connect, had to be demolished and later tied in to the new construction. Because this was done while occupying phase I, Infection Control Risk Assessment (ICRA) wall panels were put in place to prevent any risk of infections and disturbance to patients in the existing building. These wall panels were placed at the connection between the existing building and new construction, and present a challenge for the tie-in of both phases of the project. This, along with the tie-in of the new to existing MEP systems, was one of the most challenging tasks for the construction of this project.

As the construction of this project comes to an end, system testing and balancing may begin. At this point of construction, medical equipment is being installed in the building's operation and endoscopy rooms by their respective providers. The building has to go through a series of inspections by various organizations, until reaching substantial completion January 2nd, 2014. Upon completing the facility's testing and commissioning process, the owner has plans to occupy the building by February 6th, 2014.

2.4 Cost Overview

The actual cost of construction for the 77,560 GSF addition to the Geisinger's Ambulatory Care Campus at Gray's Woods was $20,079,961 or $260/SF. This only takes into consideration the cost of material, labor and equipment put in place to construct the facility. It is important to note that medical equipment furnishing is not included in this budget, which totals up to $5,220,000 for this project. When including additional project costs, such as general conditions, sitework, insurance and CM fees, the total project cost escalates to $25,789,640, or $333/SF. A cost breakdown of the different building systems, along with a summary of project construction costs (CC) and total project costs (TC) may be seen in Table 2.3.

Table 2.3 - Project Milestone and Duration Overview:

Building Systems Cost Summary			
Building System	**Actual Cost**	**Cost/SF**	**% Cost**
Concrete Foundations	$2,533,175	$32.66	12.62%
Structural Steel & Misc. Metals	$1,558,888	$20.10	7.76%
Masonry	$674,093	$8.69	3.36%
Interiors	$4,233,613	$54.59	21.08%
Roofing and Waterproofing	$960,586	$12.39	4.78%
Plumbing	$2,079,012	$26.81	10.35%
Mechanical (HVAC)	$3,648,511	$47.04	18.17%
Fire Protection	$339,803	$4.38	1.69%
Electrical	$3,488,440	$44.98	17.37%
Conveying Systems	$563,840	$7.27	2.81%
Total Construction Cost	**$20,079,961**	**$260/SF**	**100%**
Total Overall Project Cost	**$25,789,640**	**$332/SF**	**128.43%**

*Project Costs taken from Alexander's Schedule of Values (Appendix C)

In order to better compare the actual project costs to similar projects throughout the United States, an RS Means SF Estimate for the Gray's Woods facility. This estimate totaled up to $22,478,525 or $290/SF. Geisinger's actual costs were considerably higher than those estimated by RS Means. These cost differences may be attributed to the fact that we used a Hospital Building for our SF Estimate, the LEED Certification Requirements on this project, exterior wall type construction, and the different MEP systems used in this building.

***Refer to Appendix C for the 'Detailed Project Costs'**

2.5 General Conditions Estimate

The general conditions estimate for the Geisinger Grays Woods Ambulatory Care Campus totaled to $1,776,746, or 6.8% of the total project cost. As Alexander Building Construction was not able to release the actual GC costs for this project, RS Means 2013 Data was used to price most of the items. The general conditions estimate is based off an 18 month construction schedule, and it's broken down into 5 main categories. These are: Project Team, Field Office, Field Operations, Insurance, and Building Closeout. Table 2.4 below summarizes the general conditions estimate breakdown for the Geisinger Gray's Woods Phase II addition.

Table 2.4 – General Conditions Estimate Summary

General Conditions Estimate Summary		
Category	**Project Cost**	**% GC Cost**
Project Personnel	$805,642.00	45.34%
Field Office	$33,404	1.88%
Field Operations	$283,700	15.97%
Insurance	$517,800	29.14%
Building Closeout	$136,200	7.67%
Total GC Costs	**$1,776,746**	**100%**

*Costs taken from RS Means & Actual Project Costs

The project team costs include all of Alexander's employees associated with the project, and were based upon the staffing plan discussed in section 3.2. Not all project personnel were present during the whole 18 month duration of the project, thus a weighted percentage was made for each employee based on their project participation per month. The project manager and superintendent were the only personnel to be involved during the complete project duration, while the rest of the staff were also working in different projects at that time. Field office costs include all costs incurred from the office trailers on site and anything associated with them. This takes into account all trailer expenses such as office supplies, equipment, telephone, Lighting/HVAC, and travel costs. Field operations costs, on the other hand, include all expenses incurred from constructing, operating, and maintaining activities in the field. This section assumes all costs for field operations, and includes temporary power/water/fencing/toilets, safety & winter protection, surveying and waste management. All the project team, field office and operation costs were under Alexander Construction's General Conditions Budget.

The last two items in the estimate are insurance and building closeout costs, and were assumed by Geisinger Health Systems. Building closeout costs take into account those expenses from testing, commissioning and inspecting the building after construction is complete. Insurance costs include builder's risk, general liability, and performance bonds, and are based on a percentage of the total contract ($26.2M).

***Refer to <u>Appendix D</u> for the 'General Conditions Estimate'**

2.6 LEED Evaluation

While phase I of the Gray's Woods Ambulatory Care Campus was designed a LEED Silver Rating, Geisinger Health Systems decided that the added costs associated with pursuing this rating were too high. For this 78,000SF addition, Geisinger is pursing LEED Certified Status. In order to achieve this desired rating, 40-49 points must be attained. The first step in a LEED analysis is to identify the LEED points that are of the most value to the owner and worth pursuing. Table 2.5 summarizes those LEED points for each category that are expected or not expected to be met on the Gray's Woods project.

Table 2.5 – LEED Evaluation Summary:

LEED Evaluation Summary				
LEED Category	Level of Pursuit			Possible Points
	Yes	Maybe	No	
Sustainable Sites	8	2	8	18
Water Efficiency	2	3	4	9
Energy & Atmosphere	9	9	21	39
Materials & Resources	12	0	4	16
Indoor Environmental Quality	8	8	2	18
Innovation & Design Process	4	2	0	6
Regional Priority Credits	2	2	0	4
Total LEED Points	**45**	**26**	**39**	**110**

*Checklist Based on LEED 2009 New Construction Rating System (Appendix E)

As evidenced in Table 2.5, the Grays Woods Care Campus is expecting to achieve 45 out of 110 possible LEED points. For sustainable sites category, the Grays Woods project obtained LEED points for site selection, public transportation access, maximization of open space, stormwater design, and light pollution reduction. The building's design makes extensive use of natural daylight through its curtain wall and skylight along its northern façade. The design also incorporates occupancy and photosensor lighting control systems to dim the lights when there is natural daylight available, as well as to turn off lights in unoccupied spaces. Alexander Building Construction put a great emphasis in the Material & Resources Category, investing over $95,000 in a waste management program in order to achieve their goal of recycling 95% of the construction waste. Moreover, 20% of the material used in the construction of this project originates from within 500km of the site.

Although the project is 5 points away from being accredited LEED Silver, the project team chose not to pursue this level of accreditation as it involved increased planning and investment. Nevertheless, Alexander Building Construction and Geisinger Health Systems maintained a high level of commitment to sustainable construction on this project through the use of sustainable design features and means and methods of constructing this facility.

***Refer to Appendix E for the 'Project LEED Scorecard'**

3.0 Virtual Mockups on Operating/Endoscopy Rooms

3.1 Problem Identification

One of the major challenges in the construction of the Geisinger Gray's Woods Ambulatory Care Campus was the great amount of changes that went in designing the operating and endoscopy rooms of this facility. It took over 8 weeks of design reiterations in the midst of the construction process to determine a final design for these rooms. Using field mockups for both rooms was not only costly and time-consuming, but also obstructed other trades to begin work in these areas as they were left until the end of the project. Any delays or challenges in the construction of these rooms could potentially escalate in delaying the project overall.

3.2 Proposed Solution

The proposed solution for tackling this problem is developing and implementing virtual mockups for the operating and endoscopy rooms of the Ambulatory Care Campus. Through the use of virtual mockups, the end users could be brought in early in the design phase to provide valuable input in order to have a finalized design prior to beginning construction. End users such as doctors and nurses could walk around the virtual mockup and review the room's layout and practicality of the locations of different medical equipment, connections, tools and casework around the room. For this research, I will explore the efficacy of implementing virtual mockups for the construction of the operating and endoscopy rooms of the Grays Woods project. While developing the virtual mockups I will capture the efforts of the criteria & workflow required for implementing virtual mockups for design-reviews. In addition, a schedule analysis will also help determine how the implementation of a virtual mockup will help the project team inform design decisions without limiting other trades from performing work in these areas.

3.3 Research Goal

After completing this analysis, we are expected to fully comprehend the criteria and workflow required to develop and implementing virtual mockups for the design and construction of the operating and endoscopy rooms of the Grays Woods facility. By developing the virtual mockup and performing a schedule analysis for implementation, we will identify whether using virtual mockups will greatly benefit the construction process of the facility's operating and endoscopy rooms.

3.4 Background Research

The use of construction mock-ups have become common practice to validate design and work through constructability challenges in a project. Physical mock-ups offer significant benefits as a communication tool amongst the project team but must be balanced with a potentially large cost and obstruction to construction schedule.[12] Virtual mockups offer an opportunity to provide less expensive yet similar means to reach consensus decisions among healthcare personnel, designers, and construction contractors. Using a 3-D virtual representation of the spaces could potentially save time, reduce risk, and solve design and constructability issues in advance of construction.

3.5 Current Mockup Evaluation

Construction mockups are an invaluable tool used to experience a realistic representation of a design concept. When used effectively, they can help obtain valuable information regarding the design and workflow of different spaces. Mockups can help the construction team identify potential issues up-front in order to save time, reduce risk, and solve design and constructability issues within a project.

Fig. 3.1: O.R. Mock-Up Process (Picture taken by George A.)

An 'In-Place Mockup' was constructed for the operating room of this facility, in order to gather feedback from the end users with regards to the spacing and equipment layout. Spray paint was used to layout the location of the patient bed and boom swing radius. Cardboards were also placed around the walls to resemble the location of different screens, electrical outlets and data outlets. Snapshots of the field mockup used for the Operating Room of this facility may be seen in Figure 3.1. Once completed, doctors and nurses were continually brought in to these mock-ups, moving the pieces around as they provided input on where different equipment should be located within the space. Clinical scenarios were simulated in order to address the workflow and functionality of the room layout. The project team identified various issues with regards to equipment and casework positioning, the coordination and placement of medical gas piping within the walls, and mounting heights for the different outlets and nurse call buttons. It took over 8 weeks of design reiterations in the midst of the construction process in order to determine a final design for these rooms.

In-Place Mockup: Issues, Challenges & Limitations

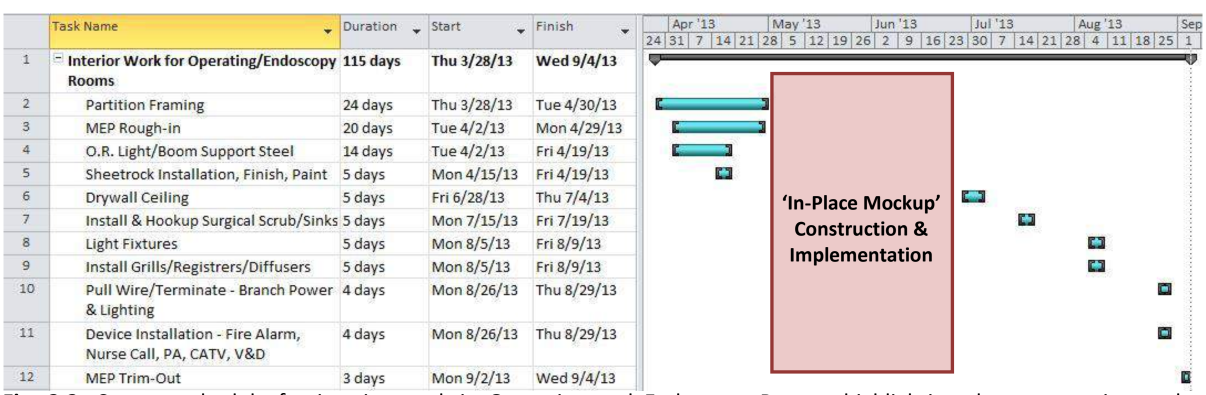
Using field mockups for the operating and endoscopy rooms proved to be an effective means of obtaining design input from the end users. Nevertheless, they also proved to be a costly and time consuming process that put in risk the timely completion of the project. Following, we will discuss many of the issues, challenges and limitations that were encountered through the project's mockup process.

- Level of Detail (LOD): The whole purpose of creating a physical mockup is to portray a realistic representation of a given space. Mockups may vary in levels of detail; the higher level of detail usually results in a higher cost, which may defy the purpose of creating the mockup in the first place. One of the limitations with the implemented mockup was the lack of detail in order to effectively portray the finalized design. The outlets, call buttons, and wall equipment were portrayed by using cardboards, and most of the equipment was laid out in the floor using spray paint. The lack of realistic representation of the given space is a limitation to this mockup, as it may be hard for the end users to have a real feel of the given space.

- Time: Creating physical mockups for the operating and endoscopy rooms proved to be a very time-consuming process in terms of constructing, re-modifying and demolishing. As mentioned earlier, it took over 8 weeks of design reiterations in the midst of the construction process in order to determine a final design for these rooms. Because of this, interior work for the four operating and endoscopy rooms was left until a final design for these spaces was approved.
- Costs: Costs are always an issue when dealing with physical mockups on a project. Physical mockups are costly in terms of initial construction expense, costs associated with making modifications for re-reviews, and the final demolition and disposal.[4] It takes a lot of labor and material in order to construct, re-modify, and demolish these mockups. Even though they may eventually save the project team from having many change orders throughout the construction process, these may not make up for the cost of implementing it.
- Waste Generation: A great deal of waste is generated through physical mockups, as most of the materials are usually disposed upon completing their purpose. This material waste not only costs the project money, but also affects its eligibility of earning LEED points through the 'Materials and Resources' category.
- Addressing Changes: Addressing changes based on the end user's feedback may sometimes be challenging in an 'In-Place Mockup'. Depending on the ease of moving the objects and equipment within the mockup, this may take a long time to perform. Due to the low level of details of the project's operating room mockup, making modifications to the initial mockup was not a big concern. Nevertheless, the project team was limited to changing most of the room layout as the patient bed, booms, and major equipment were all portrayed on the floor through the use of spray paint.

IMPACT ON SCHEDULE

One of the biggest reasons behind implementing virtual mockups over the current mockup process is the impact on the schedule and productivity of the interior work being done in the operating and endoscopy rooms of the Grays Woods Facility. The in-place mockup construction and review process began after completing the interior sheetrock installation in each of the operating and endoscopy rooms. As seen in Figure 3.2, it obstructed the interior work being done in these areas, as they had to be put until the end of the 8-week long process.



	Task Name	Duration	Start	Finish
1	Interior Work for Operating/Endoscopy Rooms	115 days	Thu 3/28/13	Wed 9/4/13
2	Partition Framing	24 days	Thu 3/28/13	Tue 4/30/13
3	MEP Rough-in	20 days	Tue 4/2/13	Mon 4/29/13
4	O.R. Light/Boom Support Steel	14 days	Tue 4/2/13	Fri 4/19/13
5	Sheetrock Installation, Finish, Paint	5 days	Mon 4/15/13	Fri 4/19/13
6	Drywall Ceiling	5 days	Fri 6/28/13	Thu 7/4/13
7	Install & Hookup Surgical Scrub/Sinks	5 days	Mon 7/15/13	Fri 7/19/13
8	Light Fixtures	5 days	Mon 8/5/13	Fri 8/9/13
9	Install Grills/Registers/Diffusers	5 days	Mon 8/5/13	Fri 8/9/13
10	Pull Wire/Terminate - Branch Power & Lighting	4 days	Mon 8/26/13	Thu 8/29/13
11	Device Installation - Fire Alarm, Nurse Call, PA, CATV, V&D	4 days	Mon 8/26/13	Thu 8/29/13
12	MEP Trim-Out	3 days	Mon 9/2/13	Wed 9/4/13

Fig. 3.2: Current schedule for interior work in Operating and Endoscopy Rooms, highlighting the construction and implementation of the 'In-Place Mockup'. (Schedule created by George Andonie using Microsoft Project)

Constructing a mockup and performing design reviews in the middle of the construction process is a time and cost consuming process, which can also put in risk the timely completion of this project. Part of this analysis will focus on identifying how the implementation of virtual mockup will help the project team inform design decisions without impacting construction in these areas.

3.6 Virtual Mockups

Virtual mockups are detailed 3D models of specified areas of a building with the aim to integrate design and construction to promote efficient workflow in the construction of these spaces. In lieu of physical mockups responding to last minute resolutions, virtual mockups have become valuable models used to realize design-related issues earlier and allow for effective team collaborations. According to the Associated General Contractors (AGC) of America, virtual mockups can add value to a project by:

- Creating a better understanding of the end product
- Ensuring the end product meets the owners needs
- Understanding the assembly sequence within a space
- Acting as a marketing tool for the owner
- Streamlining the review process
- Eliminating waste (time + cost)

Virtual mockups may provide many opportunities such as early project implementation at much-reduced costs, integration with design and construction, and improvement of efficiency of the design-review process. They often result in faster, cheaper, and a more effective means to see preliminary design results than physical prototypes.[15] By building a virtual mock-up compared to a physical mock-up, the time to complete an area may be significantly decreased. There is no waste other than computer file that was developed, and most importantly, there is no interruption to the project schedule as this is done prior to beginning construction.

Virtual Mockups on Healthcare Facilities

Healthcare facilities are comprised of highly complex, specialized, and repetitive spaces. Spaces such as patient rooms, operating rooms and intensive care units usually require specific knowledge and input from a wide range of stakeholders in order to ensure that the final design meets their needs. Virtual Mockups are being increasingly used on healthcare projects as they can be useful for the design of these complex and specialized spaces.

Virtual Mockups may greatly benefit a project team by integrating the design and construction phases, therefore promoting efficient workflow in the construction of these spaces. They provide the opportunity for a team of project stakeholders to truly experience design alternatives and concepts in the early stages of the design process, avoiding costly changes throughout the construction. End users of these facilities are able to review the design for space programming, safety issues, finishes and workflow efficiency within the model. Virtual Mockups may also help the construction team address potential issues up-front, such as constructability and assembly needs, providing a visual representation even throughout the construction of these facilities.[15]

Utilizing virtual mockups on a project affords healthcare professionals and their staff the opportunity to evaluate design ideas in order to ensure the best possible layout and space utilization for efficient workflows and better patient outcomes. They allow end users to provide focused feedback based on their opportunity to experience the virtual representation of the design concept. By performing walkthroughs, they can evaluate the location and mobility of the different owner-furnished equipment. This helps address the placement of different equipment connections, as well as doors, windows and cabinetry. In addition, architectural features, lighting and noise levels may be assessed to better identify design changes throughout the design review process. Addressing these early in the design phases allows a more efficient workflow throughout the construction of these spaces, greatly reducing cost and schedule associated with design modifications throughout the construction of these spaces.

CASE STUDIES

Prior studies have shown the value of using virtual prototypes during the design review of patient and procedure rooms in healthcare facilities. In this section, we are to look into precedent uses of virtual mockups in healthcare facilities to better understand the many benefits and limitations of virtual mockups for project design and construction. Two cases were studied: Greenfield Hospital by Mortenson Construction, and St. Francis Hospital by Skanska. Both projects utilized virtual mockups with intentions for better team and process integration in the construction of the specialized rooms.

The first case study was based on the construction of the Greenfield Hospital in Wisconsin. This $200 million, 500,000 GSF Hospital constructed by Mortenson Group, included a total of 300 patient and 47 imaging and procedure rooms. Because of the vast amount of rooms in the hospital, mockups were critical to the success of this project. Mortenson Construction modeled 28 different patient room virtual mockups and other 19 mockups to represent the different imaging and procedure rooms. Figure 5.3 illustrates the virtual mockups used for the construction of this facility. According to Mortenson Construction, they invested a total of 48 hours to create the initial virtual mockups, perform design-reviews, and address changes to all mockups. Being able to reuse different model components throughout all mockups helped to quickly develop the interactive virtual mockups for all patient and procedure rooms of the Greenfield Hospital.

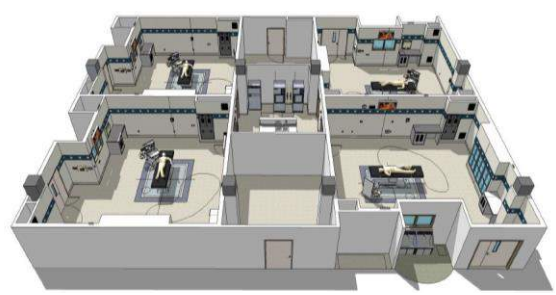


Fig. 5.3: Virtual Mockup of Procedure Rooms at Greenfield Hospital. Image courtesy of Mortenson Construction

A total of 45 Request for Information (RFI's) were identified throughout the creation process of these virtual mockups, and an additional 30 discrepancies after further review. User groups were brought in to perform design reviews on the different mockups, which resulted in numerous changes in casework reconfigurations and revised power and data locations. Utilizing virtual Mockups helped identify major issues and changes before they became a budget and schedule concern. According to Mortenson Construction, utilizing virtual mockups eliminated the need of

Project Manager and Superintended Field Coordination, Subcontractor Rough-in Installation & Adjustment, and greatly reduced after-completion rework in the construction of these rooms, yielding an overall project savings of 0.7%.[4]

The second case study focuses in construction of the $116 million, 444,000 GSF addition to the St. Francis Hospital in Columbus, Georgia. Because of the constrained schedule for an addition to their existing campus, there was inadequate time for a comprehensive physical mockup of the patient and intensive care units. Utilizing a combination of modeling and visualization software, the project team created an accurate representation of these rooms. After modeling the walls, windows, ceilings and floors for each space, the team focused on furnishing the spaces. Seating, bedding, light fixtures, and complicated healthcare equipment were all modeled to portray a realistic representation of the patient and intensive care units. Figure 5.4 shows a comparison between the virtual mockup utilized in this project and the completed patient room at St. Francis Hospital. The virtual mockups allowed the owner to decide on detailed finished and colors, and achieve a final approval of space programming and the functionality of the area. The use of virtual mockups in this project helped the project team to make informed design decisions early in the project, resolving much of the disruptive troubleshooting that would have occurred if they were to use physical mockups later in the building project phase.[27]

Fig. 5.4: Skanska's virtual mock-up vs. completed patient room at St. Francis Hospital. Image courtesy of SKANSA

Benefits and Concerns

Virtual mockups have proved to be very effective and efficient means for reviewing the design of a space prior to construction. There exist many benefits as to why they should be used in healthcare projects as well as limitations for certain owners and projects.

Using virtual mockups early on in projects allows project teams to better plan and coordinate the effectiveness of a room & equipment layout with less space, time and cost compared to a physical mock-up design review. Performing a virtual design review with these technologies also allows for early user feedback and quick design changes while also decreasing potential to rework during construction. These immersive environments are more intuitive and much easier to understand than 2D drawings, while also cheaper to produce than physical mockups. Another advantage of using virtual mockups is the capacity to reuse content between models, as evidenced in Skanska's case study.

There are also some aspects that limit this technology and are holding back virtual mockups from being used regularly on construction projects. One limitation is that virtual design reviews require owners to be involved and committed at an early stage in the project. It requires owners to invest money upfront for future savings, to decide on the objective of the design review, and to make decisions on owner-furnished equipment. Virtual mockups are only as effective as the end product and the quality of the user's feedback. A virtual mockup that limits the users to make changes within the model is not as effective as one that does. Finally, a large limitation is that this is relatively new technology and not all owners, companies and personnel are proficient in utilizing the software and equipment required in implementing them.

3.7 Virtual Mockup Development

Developing the model of the operating and endoscopy rooms of the Grays Woods project was the most time intensive part of this analysis. This process consisted in creating a realistic representation of 2D plans through a 3D model (Figure 5.5). The level of detail needed in the model is quite high, in order to deliver a sense of presence and realism comparable to the true space; this is important as it will allow project stakeholders to review the space layout more effectively. The 3D model will serve as the main tool for design reviews by allowing users to navigate and interact with it to obtain valuable design and constructability input. By addressing the location of different equipment and physical objects around the room, designers will be able to gain input on the location and mounting height of electrical and data outlets.

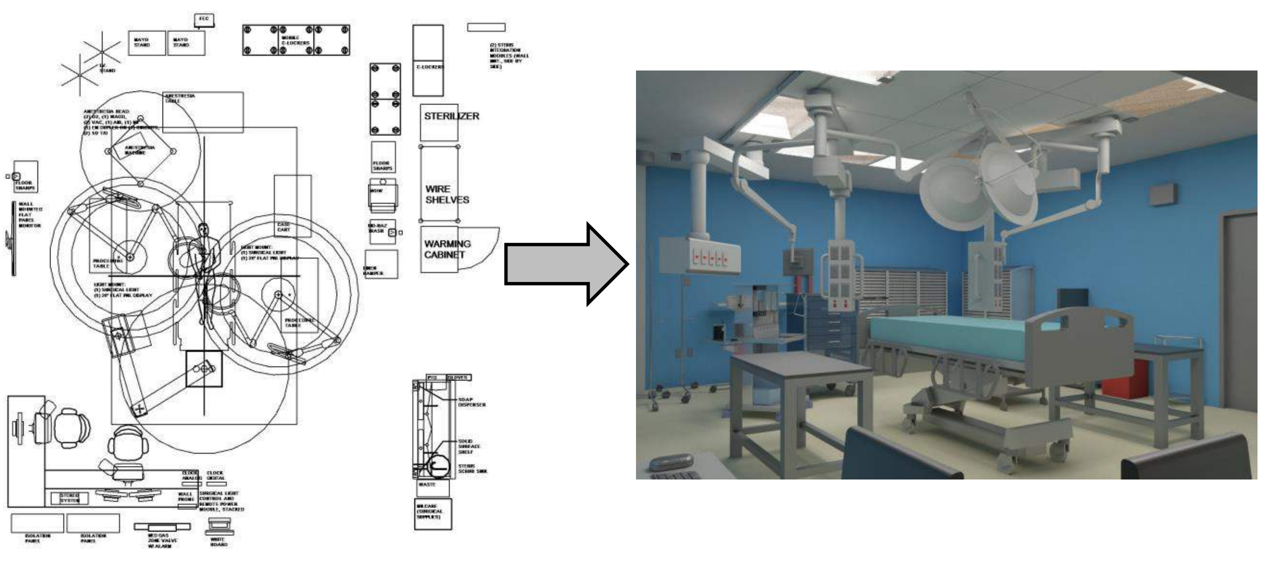


Fig. 5.5: Converting the Operating Room's 2D Plans to a 3D Model. (Plan taken from Sheet A2.1B and rendering produced using Autodesk Revit 2013)

Developing the virtual mockup required the use of various different tools and knowledge learned throughout the Master Level 'Virtual Facility Prototyping; class (AE597F). Following is an overview of the model development workflow, model application, time requirements, and issues encountered throughout this process.

Model Development Workflow

The facility model was developed using Autodesk Revit and Unity Software. The model development process is illustrated in Figure 5.6. Autodesk Revit is a powerful modeling tool that allows users to design 3D building, systems and components. Unity, in the other hand is a cross-platform game engine, which allows users to navigate the models within real-time rendering environment. When used concurrently, both programs provide modeling and navigating capabilities for the user to interact with the virtual mockup and perform design reviews through a collaborative exploration of the designed environment.

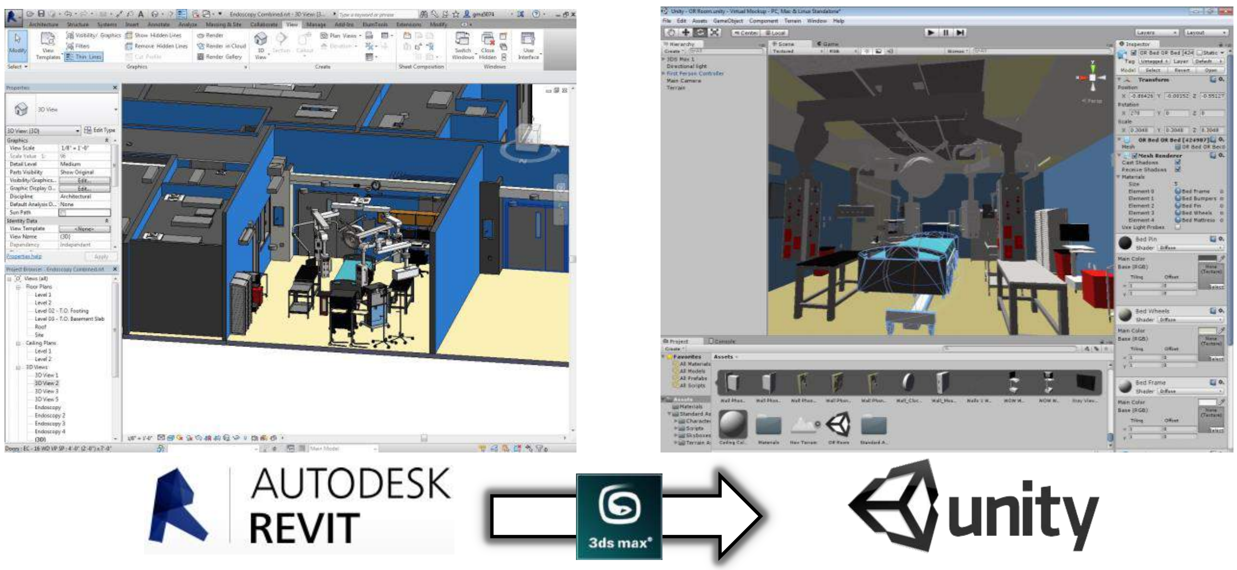


Fig. 5.6: The facility model was developed in Autodesk Revit, exported as a .FBX file format to 3ds max and then to Unity game engine. (Screen Shots taken directly from Autodesk Revit and Unity Software)

The first step to developing the virtual mockup was modeling the operating and endoscopy rooms using Autodesk Revit Software. Ewing Cole provided the architectural, mechanical, electrical and plumbing Revit models used on this project. These were all combined into one model and stripped down in order to focus on the rooms only. The model provided by the architect included all MEP components, but did not include any owner-furnished equipment. Equipment modeling may be the most time consuming step when developing these models. For this project, most of the medical equipment was taken from previous project databases and online libraries, while others were modeled using Revit Software.

In order to navigate and interact with the 3D Model, it needed to be exported to Unity Gaming Software. The Revit Model was first exported to 3Ds Max as an .FBX file format in order to allow for most of the materials to stay in place as well as achieving the proper scale of the model elements before importing it to Unity. Once in Unity, the model was positioned accordingly, and missing textures and colliders were assigned to each component as needed. Although the accuracy of texture is not the main focus for implementing virtual mockup on the operating room, it was very important in order to get the most out of the review process.

The Unity model allowed for model interaction through the use of scripting and other means. For this mockup, scripting was used to display the interactive (GUI Buttons) to change between scenes, display messages to the user, retrieving information, and interacting with objects and elements in the facility.

Once the Unity model was up to the desired final product level, the file was exported to an executable file. The executable file allows the model to be run in 'walkthrough mode' independent from the software. Unity Software offers the option to build the executable file in a variety of different platforms, as illustrated in Figure 5.7. This is convenient for owners, subcontractors, or end users, as they walk-through the space at their own leisure. Although more realistic results can be achieved by running the virtual mockup in an 'Immersive Construction (Icon) Lab', it this provides the advantage of performing design reviews at the job trailer for better convenience.

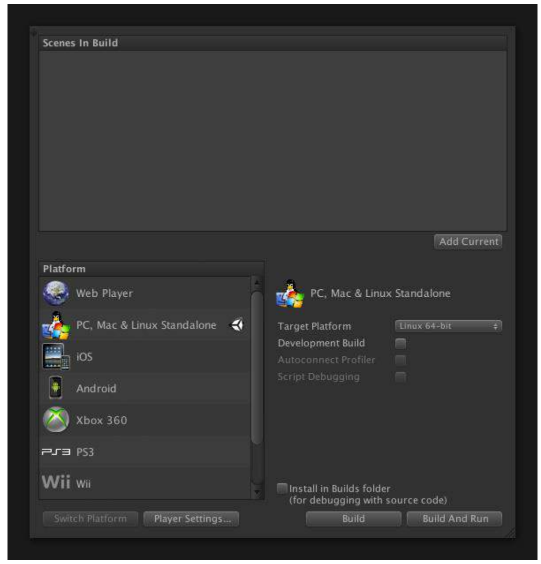


Fig. 5.7: Unity Multi-platform. Image courtesy of www.unity3d.com

***Refer to Appendix F for the 'Virtual Mockup Workflow Diagram'**

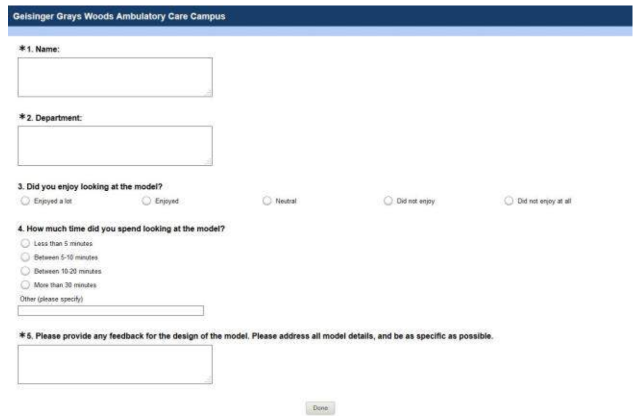
VIRTUAL MODEL APPLICATION

As soon as the application is launched, a start menu is displayed that welcomes the user to the design review of the Grays Woods operating and endoscopy rooms. The user can then choose whether they want to 1) Review the Operating Room, 2) Review the Endoscopy Room, or 3) Quit Application. After having chosen the room, the user enters the virtual model and is able to start the design review process. Navigation is done through a First Person Controller (FPC), using the arrow keys to move around the space while controlling the camera with the mouse. A hand-held game controller could also be used to move around the space. By navigating throughout the room, the user can check for clearances, equipment location, functionality, and general appearance. Upon completing the design review, the users can provide feedback through an online survey which requests for the user's name, department, and other information about their experience with the virtual model. The user can switch between rooms, quit, or provide feedback anytime throughout the design-review process. Figures 5.8 - 5.11 illustrate the interactive sequence as the user runs the Virtual Mockup for the Grays Woods Project. These screenshots were taken directly from the Virtual Mockup Model in the Unity Software.

Fig. 5.8: Start menu of the Virtual Mockup prompting user to choose a space for review

Fig. 5.9: Welcome screen for endoscopy room design review

Fig. 5.10: Welcome screen for operating room design review


Geisinger Grays Woods Ambulatory Care Campus

*1. Name:

*2. Department:

3. Did you enjoy looking at the model?
Enjoyed a lot / Enjoyed / Neutral / Did not enjoy / Did not enjoy at all

4. How much time did you spend looking at the model?
Less than 5 minutes
Between 5-10 minutes
Between 10-20 minutes
More than 30 minutes
Other (please specify)

*5. Please provide any feedback for the design of the model. Please address all model details, and be as specific as possible.

Done

Fig. 5.11: Users can leave feedback upon completing the design review meeting

Time Requirements

The time to complete all of the modeling work was recorded to better understand the time requirements necessary to implement virtual mockups in a project. Table 5.1 summarizes the time required in developing the virtual mockup for the operating and endoscopy rooms of the Grays Woods project. Time was tracked for those tasks that went in developing the virtual mockups only; acquiring all of the relevant information, determining design review goals, and contacting necessary parties was excluded from these steps and time associated.

Table 5.1 –Actual Time Required to Complete Virtual Mockup

Time Requirement		
Step Description	**Duration (Hrs.)**	**Total Time**
1. Obtained Existing Revit Model	-	0
2. Combine Architectural & MEP Revit Models	2	2
3. Strip Out Revit Model	0.5	2.5
4. Model all Owner Furnished Equipment	8	10.5
5. Export Model to 3Ds Max	1	11.5
6. Export Model to Unity	1	12.5
7. Develop Scripting and Textures in Unity	8	20.5
Total	**20.5 Hrs**	

As seen in Table 5.1, it took a total of 20.5 hours to develop the virtual mockups of the operating and endoscopy rooms for the Grays Woods Project. It is important to note that this was my first time creating a virtual mockup, and that there is a significant learning curve in developing these tools. The estimated time considers that the space was previously modeled and most of the equipment used was taken from previous project databases and online libraries. This saved a significant amount of time, as this task is the most time consuming part of the mockup development. As more and more mock-ups are being implemented, equipment and component databases can be created to be used in future projects. Thus, the time in developing the 3D models can significantly decrease moving forward.

Complications, Limitations & Lessons Learned

There were many challenges encountered throughout the development of the virtual mockup, as well as limitations when implementing it for design reviews.

a) Virtual Mockup Development:

Initial design challenges with Unity involved functionality of the software and scripting. Additional help had to be sought from other people and sources in order to learn the foundation of the scripting language. Being relatively new to this process, it took some time to learn the functions of the software, as well as the idea of communicating to a computer with text and commands. Once the basics were learned, it was rather easy to understand the basic tools and commands required for modeling virtual mockups. Unity's user-friendly software proved to be successful for the purpose of modeling virtual mockups, although it takes time to learn the basics of the program at first.

Another design challenge I encountered when modeling was the functionality and interoperability between Revit and Unity Software. A lot of model materials were lost when exporting the model between Autodesk Revit and Unity, regardless of utilizing 3ds Max program. This required additional time in matching the textures for some components in Unity.

While the creation of the rooms was relatively simple, modeling the many specialized types of equipment and fixtures for the model was considerably time-consuming. It would be greatly beneficial to have a digital library of 'generic equipment' and 'template codes' for quickly populating the virtual mockups of particular hospital units. The digital model content developed for these libraries could comprise of patient beds, crash carts, trolleys, and other healthcare related furniture. If equipment manufacturers were to model their products and share them to the general public, this would greatly improve the process of creating the virtual mock-ups. This would greatly benefit the development of virtual mockups through the use of reusable digital model content of equipment between projects, making the design information workflow more achievable in a timely and productive manner.

Overall, there were no major issues that stood out in the creation of the virtual mockups. Even though it was a relatively time-consuming process, there is a huge potential of time savings moving forward. Because I was relatively new to this process, it required more time to develop the virtual mockups for the operating and endoscopy rooms of the Geisinger Grays Woods Ambulatory Care Campus. Nevertheless, professional modelers with access to a 'digital model library' and 'template codes' can significantly reduce the time it takes to develop the virtual mockups.

b) Virtual Mockup Application:

There were many limitations of the developed application that could impact the effectiveness of the design review sessions in a healthcare project. These include the operability of the mockup itself, interactive features within the model, and level of realism.

Based on past research of virtual mockups in healthcare projects, one of the greatest challenges faced during the design reviews was that sometimes users found it hard to orient themselves and identify the room they were reviewing. It may take some time for users to get used to the navigation within the model. This could be improved by incorporating mini-maps to serve as reference by tracking the user's location within the facility. It is also important to note that some users may encounter dizziness and disorientation if the design reviews are performed in stereo mode. These implications could pose problems when reviewing the facilities with virtual mockups.

Another limitation was developing a dynamic environment within the mockup components. Virtual mockups that are limited to static movement represent space layout only. The virtual mockups developed for this project limited the users from interacting with the virtual environment. The built components were static and their locations or movements could not be modified by the users. It would be greatly beneficial if the virtual mockup could represent the boom movement radius, or allow users to move components around in order to better address the room space layout. Unity Game Engine has the potential to create such interactive environments; nevertheless, it requires advanced knowledge in the software and is beyond my modeling capabilities.

The level of realism of the virtual mockup is a major limitation of the developed virtual mockup. Incorporating more realistic textures and rendering of the lighting would greatly improve the effectiveness of virtual mockups in addressing the perception of a space. Due to some limitation of the modeling tools to produce perfectly rendered, realistic, and accurate models to match the final materials and lightings, it may be a concern that end users may receive an incorrect impression about the design. This could cause unforeseen outcomes as the model may not reflect the realistic representation of the constructed spaces.

It is important to have these challenges and limitations in mind when developing virtual mockups for a project, as they may hinder from receiving quality feedback in the design review meetings.

3.8 Virtual Mockup Implementation

Schedule Implications

A key characteristic of virtual mockups is that they allow implementation for design-reviews throughout the design and construction phases of a project. Figure 5.2 illustrates the implementation Virtual Mockups within the design and construction project timeline. Unlike the "In-Place Mockups" used in the project, they provide the advantage of addressing issues in the design stage to better plan for the construction of the spaces.

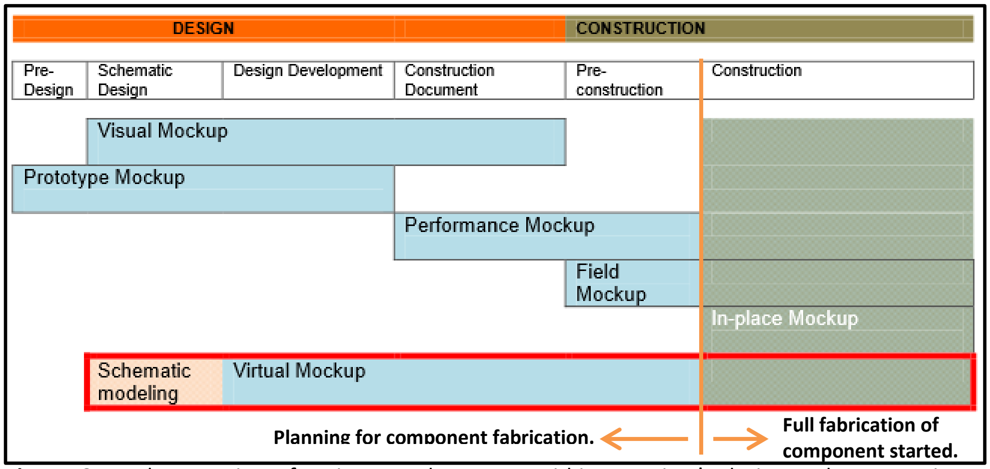


Fig. 5.12: Implementation of various mockup types within a project's design and construction phases. Image courtesy of www.brikbase.org[15]

To get the most benefit out of the virtual mockup, it should be implemented early in the design process in order to address all issues prior to construction. The development process should begin as soon as there is enough design content to create a virtual representation of the 2D drawings. The virtual model will help identify potential issues with the space layout and help test various design changes prior to beginning construction. Weekly or bi-weekly design-review meetings should be held between the shareholders, owner, contractor, and all involved subcontractors to assess the room layout, constructability issues, and even architectural features of the space. At this stage, the 3D Model will undergo a series of modification according to the feedback received during these meetings. The design-review process is generally a repetitive process that may go throughout the entire building design phase. This process may vary from project to project, and is usually complete whenever the project team feels they have covered all details and can commit to a final design.

Within the construction phase, the virtual mockup will aid in communicating the design to all parties, particularly contractors. It will allow for contractors to gain a better understanding of how the design can be constructed, serving as a guide for the construction and installation of the systems in these spaces. By promoting added visualization and better communication, the virtual mockup can greatly increase field productivity and reduce costly RFI's and unforeseen change orders.

Although a schedule of the mockup implementation was not created, discussion with the project team confirmed that this would greatly streamline the construction process by resolving issues early in the project.

ASSOCIATED COSTS

Research about virtual mockup application was conducted to determine reasonable costs associated with implementing virtual mockups on a project. Costs were based on research performed and industry recommendations on typical costs of developing and implementing the virtual mockups on a project. Table 5.2 summarizes the typical costs associated with implementing virtual mockups on a project.

Table 5.2 – Costs Associated with Implementing Virtual Mockups

Cost Summary			
Item Description	**Mhrs**	**Hourly Wage**	**Total Cost**
Develop & Modify Model	23	$35/hr	$805
Design-Review Meetings (GC)	50	$65/hr	$3,250
Total	**$4,055**		

*Costs taken from RS Means 2013

As seen in Table 5.2, it may cost about $4,055 to implement virtual mockups in a project. The estimated costs include those personnel expenses for developing and reviewing the 3D Model. Estimated durations were taken from the actual model development and talks with industry professionals. It was determined earlier that it takes 20.5 hours to develop the virtual mockup for one operating room. Assuming it takes an additional 1.5 hours to address all changes and modifications, the cost of developing the model was $805. Design-review sessions vary greatly between projects, depending on the detail and amount of components being reviewed. Speaking with Douglas Workman, it was determined that it could take around 10 hours to perform a complete design review of the facility's operating room. Assuming 4 members would attend each meeting, the cost for performing design-reviews would $3,250. All wage costs were calculated using RS Means 2013.

It is important to note that the cost of implementing virtual mockups may greatly vary with the level of resources available from project to project. Expenses for infrastructure, equipment and software can escalate the costs of implementing virtual mockups. Infrastructure & equipment expenses consider the rental of space and equipment to perform design-review meetings. For this project, design-review meetings could be held at Penn State's Immersive Construction (Iconn) Lab without any additional costs. The developed virtual mockup has the versatility that it may be run using different platforms; therefore, it can be done at the project trailer as long as there is a computer, projector and enough space to hold the design-review meetings. Software product licenses may be the most expensive, and most important, components to developing virtual mockups. There were three different software products used in this project, and they all played a different role in completing the virtual mockup. The first and most important software was Autodesk Revit 2013, and has the highest cost at approximately $7,000 for a product license. The next software used was Autodesk 3DS Max 2013, which costs approximately $3,500 for a product license. The final software, Unity 3D, has a free version that may be downloaded online. These costs could be absorbed between different projects if the owner or contractor implements virtual mockups throughout various projects.

Retrospective Feedback

While the developed virtual mock-up was not able to be tested in a design-review environment, feedback was received from speaking with the project team. For this, I met with Douglas Workman (Project Manager) and Josh Progar (Project Engineer) in order to show them the developed application and receive feedback on their behalf.

In an open conversation with both, they recognized that the virtual mockup could provide value to the design and construction of the operating and endoscopy rooms. According to Josh, the detail and quantity of the model was more than adequate for the intended use. Comparing it to the actual in-place mockup used for the operating and endoscopy rooms, the developed mockup would be helpful in providing a virtual representation of the built space. They agreed that using virtual mockups could potentially cut down time and costs that went into addressing the large number of change orders, RFI's, and design modifications for the construction of the patient and endoscopy rooms of the Grays Woods Project. In addition, Douglas pointed out that it would allow a more rapid and efficient resolution of issues during the design-review phase, as these could be done from any location without the need of having all the end users in the same place.

Douglas Workman attended a design-review for an independent study based on the Grays Woods Project during its early stages of construction. This independent study, conducted by former AE Student Matthew Hoerner, researched the efficiency and effectiveness in utilizing 'Head Mounted Displays' (HMDs) for design reviews of healthcare facilities. When asked about his previous experience in the design-review meeting, Douglas said that he liked the collaborative environment to address design changes. He stated that**,** "On really complex medical rooms, such as Operating Rooms, this type of 3D effort would be beneficial. It is very challenging to make a complex space comprehensible to medical staff." Both Douglas and Josh were receptive to the idea of utilizing Virtual Mockups for this project, and would encourage the use of this technology on future healthcare projects.

3.9 Conclusion & Recommendations

Virtual mockups may provide many opportunities such as early project implementation at much-reduced costs, integration with design and construction, and improvement of efficiency during the design-review process. They often result in faster, cheaper, and more effective means for reviewing the design of a space prior to construction.[15] The virtual mockup on the operating and endoscopy rooms of the Grays Woods project were designed in Revit Architecture, exported as an FBX file format to 3ds max and then to Unity Game Engine. It took a total of 20.5 hours to develop both virtual mockups, and could potentially cost over $4,000 if implemented on this project. To get the most benefit out of the virtual mockup, it should be implemented early in the design phase in order to address all issues prior to construction. Within the construction phase, the virtual mockup will aid in communicating the design to all parties, particularly contractors. I would highly recommend the implementation of this technology in future healthcare projects, as it could greatly streamline the design and construction process by resolving issues early in the project timeline.

4.0 - Brick Façade Prefabrication

4.1 Opportunity Identification

When analyzing the schedule for the Geisinger Gray's Woods Ambulatory Care Campus project, a major activity stood out - the construction of the building envelope. This activity incurred a total of 178 days in the project schedule, second longest after interior work. Stick-building the exterior brick facade requires an extensive amount of labor-hours and scaffolding to install. This time-intensive process hinders the schedule from being accelerated, and the building from being watertight beforehand. Any delays in the construction of this activity could potentially push back the substantial completion date, or even incur additional costs for the construction of this project.

4.2 Proposed Solutions

The Grays Woods project presents an opportunity to change from typical stick-built exterior wall construction into a modular design. An analysis will need to be performed to determine whether the use of prefabricated brick panels will improve schedule, cost, and building performance. Nevertheless, this implementation would require a supporting mechanical analysis. For this, insulation & thermal performances of the proposed system will be calculated and evaluated against the existing wall panels. A feasibility analysis based on cost, schedule, and mechanical performance will help evaluate whether prefabricating the building's wall enclosure is a viable approach for the project.

4.3 Research Goal

The goal of this analysis is to determine whether there is an alternative construction that could decrease the duration and cost of the brick veneer façade, while maintaining similar aesthetics and building performance. By assembling these modules under a controlled environment, an overall improvement in productivity, safety, quality, and constructability is expected in the construction of the building's exterior wall panels.

4.4 Background Research

Multi-trade prefabrication & modularization was a key topic of discussion during the 22nd Annual PACE Roundtable. After discussing this topic with various industry professionals, it was noted that several projects that made use of prefabrication have found significant reduction in their construction schedule. By working offsite under a controlled environment and installing the modules on a just-in-time basis onsite, there is an increase in productivity, safety and quality in the construction of these components.

Although prefabrication may greatly reduce a project's schedule, it may not always provide desirable results with regards to project costs. Having the components produced offsite may greatly reduce labor costs, but additional costs could be incurred through the transportation and erection of these components. Other limitations discussed in the PACE Roundtable were long lead times, inspections, and payment limitations. It is important to account for these variables when analyzing whether using prefabrication on a project.

4.5 Current Building Façade

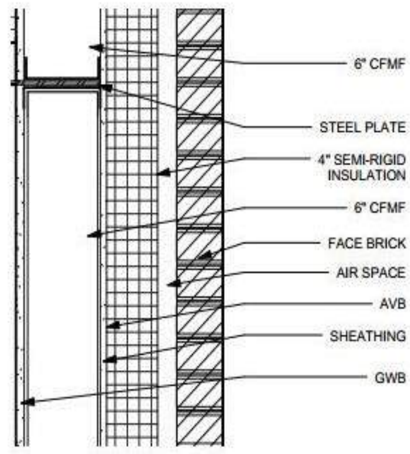


Figure 6.1: Brick Cavity Wall Detail. Image taken from Sheet A3.4.2

The building enclosure of the Geisinger Ambulatory Care Campus consists of non-structural 3½" face brick veneer walls with cold-formed metal stud backup. A 4" semi-rigid insulation, 1½" air space, sheathing and air vapor barrier provide the necessary thermal and moisture performances in order to deliver comfortable indoor environment to its building occupants. Figure 6.1 shows the detail of a vertical section of the existing brick veneer wall. Extensive amount of time and labor were required to stick-build the complete brick exterior walls of this facility. The plan was to begin at the west building facade and work their way around in a counter-clockwise manner; this would streamline the production of the different trades working in the exterior wall construction. Starting with the exterior wall metal framing, the consequent trades would follow in order to have the building dried-in & conditioned by July 30th, 2013. The process of building the exterior wall on-site took a total of 178 workdays. The completion of this activity highly depended on the weather and the productivity of each trade; any delays in the construction could potentially push back the substantial completion date, or even incur additional costs for this project. Prefabricating the brick wall construction offers an advantage by assembling them under a controlled environment, potentially decreasing total erection time by up to 75%[13]

4.6 Prefabricated Panel Design Alternatives

Research was performed in order to gain a better understanding of the types of prefabricated panels available in the market. Three types of panels were identified, each built with different material assemblies to provide a unique solution to the panelization of the building's enclosure. The first alternative consists of precast concrete panels with an exterior brick texture. The second option is precast panels with embedded bricks, and the final alternative is to completely preassemble the exterior wall panels off-site and transport them onsite to erect in place. Following is a description of each different type of prefabricated panel, along with manufacturer information; these will later be used in order to determine the most suitable prefabricated panel for this project.

1) High Concrete's Architectural Insulated Wall Panels:

Architectural Precast Panels may provide a great solution to prefabricated exterior wall claddings. This type of prefabricated wall panel uses a layer of precast concrete on its exterior in order to replicate a brick finish. High Concrete Group is a manufacturer of this type of a wall system, which was implemented in the construction of the Millenium Science Complex Building at Penn State. Due to their success in this project and closeness to the project site, I thought they would be a good option for this building's exterior brick panels. High Concrete Group was contacted in order to obtain further procurement and installation information.

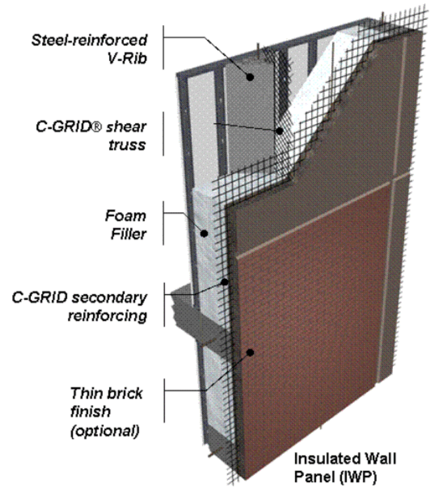


Figure 6.2: CarbonCast© Architectural Insulated Wall Panels. Image courtesy of High Conrete

High Concrete Group offers a variety of different wall assemblies to accommodate a project's needs. George Burnley, an engineer at High Concrete Group, recommended in using their CarbonCast© Architectural Insulated Wall Panels (Figure 6.2) for this this project. This wall could vary thicknesses, depending on the target level of insulation and architectural details trying to incorporate. The recommended wall composition consists of structural steel backup frame with a 4" precast concrete attached to each side. The exterior panel's finish is sandblasted in order to simulate real brick. The 4" interior space is filled with expanded polystyrene (EPS) foam to provide an adequate R-Value of 20. Based on the recommended panel composition, size, finish, and project location, the average cost of this system is about $38/SF including fabrication, delivery and installation. According to George, these panels would work best if designed to be oriented vertically, but horizontal orientation is also possible if needed. The panels would be fabricated and trucked in from Denver, Pennsylvania at a distance of 160miles from the site. The expected weight of these panels should be around 100psf, and the installer should be able to install around 15 panels per day.

From a design standpoint, this system offers flexibility in replicating various different concrete colors, textures, and forms. Nevertheless, using concrete cladding may be challenging when trying to match real brick from the existing structure. Using a monolithic concrete panel over bricks reduces the amount of joints in the wall, therefore providing a better performance against water and moisture penetration.

2) Nitterhouse's Architectural Precast Panels:

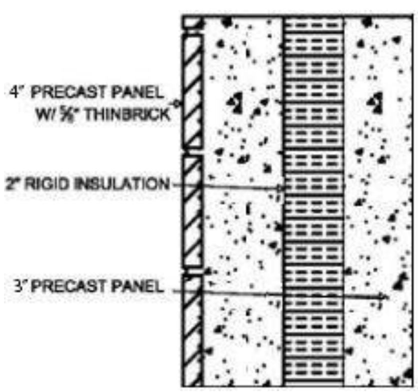


Figure 6.3: Architectural Precast Panels. Image courtesy of Nitterhouse Concrete

Nitterhouse Concrete offers a different alternative to precast panels, which uses embedded thin bricks rather than concrete cladding. This design incorporates the appearance of real brick with a prefabricated wall panel system. Mark Taylor, President and CEO of this company, recommended using their 9" 'Insulated Architectural Precast Panels' for this project. The 9" is made up of a 3" interior concrete face, 2" rigid insulation, and a 4" exterior face, as illustrated in Figure 6.3. The exterior face of the panel consists of 5/8" thin set brick over 3-3/8" thick cast concrete. This wall assembly has an approximate weight of 87.5psf, compared to the 54psf of the original design.

These panels are assembled at Nitterhouse's manufacturing plant in Chambersburg, PA, at a distance of 100 miles from the project site. The panels are first formed, and a thin set brick is arranged within a plastic grid inside the form. Concrete is then placed, vibrated and leveled. The concrete curing temperature is regulated under a controlled environment, usually resulting in higher concrete strengths. After the concrete is cured, the set grid is removed, revealing the joints of the brick. This process makes the panels look as if they would have been hand crafted.

One of the disadvantages to using this system is that it does not come assembled with metal backup and drywall for the interior side of the precast walls. The thermal 'R-Value' of the proposed composite wall panel assembly is 14.38. Additional insulation will have to be provided in order to achieve adequate thermal insulation for the exterior wall. This additional insulation, drywall and backup would have to be installed on site and the precast wall panels attached to them. This would only reduce the scheduled activity of laying brick and insulation on site, rather than prefabricating the whole exterior brick façade.

Mark explained that typical lead-time to fabricate the panels is 5-6 months from award of the project to the start of delivery. The cost of the panels including fabrication, delivery and installation would be around $25/SF. When including additional assembly materials, the cost per square of the exterior panel totals $45/SF. Precast panels would be shipped flat to the site on trucks and scheduled to be brought directly from the plant to the crane in order to assure a continuous erection. The installer should be able to erect an average of 16 panels a day on the building, regardless the size of the panel.

3) Panelized Brick Veneer Wall System (PBVW)

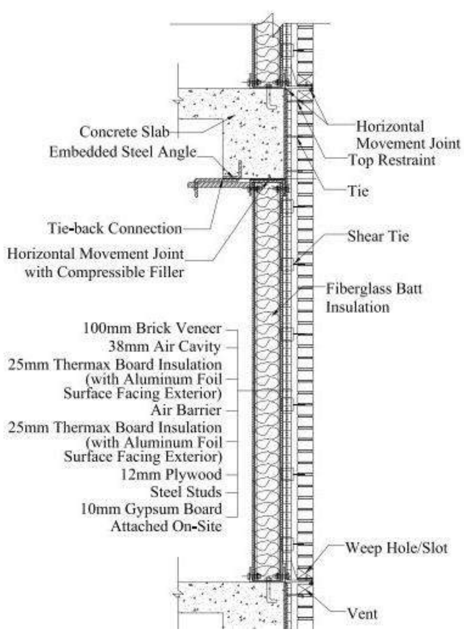


Figure 6.4: PVBS System Section. Image courtesy of Dr. Ali Memari

Although there are many wall manufacturers that can prefabricate panels with a variety of face shell textures including bricklike patterns, many owners and architects would still like to use real exterior clay brick veneer walls because of their aesthetically pleasing appearance. This type of prefabricated brick walls would require assembling the wall panels in a manufacturing plant within close location to the project, or even fabricated onsite. The "Introduction of a Panelized Brick Veneer Wall System and Its Building Science Evaluation" paper by Dr. Ali Memari provides a design guideline to these panels. Figure 6.4 shows the detail of a vertical section of the entire proposed wall panel as installed. The panelized brick veneer wall system would have to be reinforced in both directions by structural steel framework in order to support the weight of the brick veneers and steel stud backup during transportation and erection.[13]

This system may be the most effective in replicating the real properties of the existing exterior brick wall, as it uses the same materials that would be placed on site. As seen in Figure 6.4, the fiberglass batt insulation, vapor barrier, plywood and drywall are all attached to the steel stud backup, which is supported directly by the floor slab. The brick veneer is attached to the rest of the structure through shear ties and are supported by shelf angles. Additionally, this panel uses weep holes and vents for water and moisture control as traditional brick veneer walls. By replicating the features of the stick-built assembly into a prefabricated panel, this solution offers the most durable and maintenance-free wall assembly out of all other options. In a similar manner, the panel provides the same R-value (25) and weight (54psf) to that of the existing wall assembly.

Although this type of panelized brick veneer walls requires assembling and connecting the materials as if done on-site, the process is done under a controlled environment which will facilitate the construction and quality control of the exterior brick walls. Workers will not have to lay bricks at high elevations, and continuous production is guaranteed as it won't be influenced by the weather. With a lead time of over 6 months, these panels may be fabricated ahead of time and erected in place when needed. This process may greatly reduce the construction schedule by removing the construction of the exterior façade from the critical path. Nevertheless, this process may greatly increase the overall cost of the project as it requires additional efforts to transport and erect into place. This wall assembly estimated to cost around $52/SF, assuming that they are fabricated within a 20 mile radius. Although similar amount of man hours would be required to fabricate the panels, additional structural support and equipment is needed in order to transport and erect them in place. Therefore, these panels offer a great solution for owners who wish to reduce the project schedule despise escalating construction costs.

4.7 Choosing the Right Prefabricated Panel

In his book 'Building Science for Building Enclosures', John Straube explains how building enclosures follow three main functions: Support, Control, and Finish. When choosing an alternative exterior wall envelope for the Geisinger Grays Woods Facility, we have to focus on one that not only meets these functions, but surpasses those existing wall conditions.

- Support: Building enclosure walls should be designed to rest, distribute and transfer the physical and mechanical loads acting on them.[25] Since the existing exterior wall lies on top of the floor slabs, the proposed panels may be non-structural. Nevertheless, they should be designed to resist wind loads, moisture, thermal and similar environmental loads induced on them.
- Control: Building enclosure walls should be designed to control the flow of matter and energy due to the separation of the interior and exterior environments.[25] All proposed walls comply with the building codes with respect to fire rating and insulation, but each has different thermal properties based on the materials they use. A wall panel with the greatest possible wall insulation is possible in order to prevent heat loss and heat gains and maintain a comfortable indoor environment to its occupants. A mechanical breadth analysis will help understand how the chosen panel affects the building's mechanical performance in order to determine whether it would be beneficial for this project.
- Finish: Building enclosure walls should be designed to meet human desire on appearance and aesthetics.[25] Considering that this construction will be connecting to an existing building, matching the facility's brick color and texture is crucial in this project. Therefore, aesthetics play a huge role in deciding the most suitable brick panel system for this building.

HOUSE OF QUALITY

All three manufacturers provided different alternatives to the existing brick veneer wall system for the Grays Woods Ambulatory Care Campus. In order to determine the most suitable component for this specific project, factors such as panel materials, method of prefabrication, aesthetics, assembly location, cost, thermal performance, size and weight will have to be considered.

House of Quality is a widely known tool in construction used to translate a client's need into a design. By correlating the customer requirements and the product characteristics, it helps define, numerically, what product best suits the owner's needs and requirements.[23] House of Quality was developed behind the idea of developing products based on the needs of the customer; it will serve as a good tool to identify the most suitable prefabricated wall panel to be used for this analysis based on the owner's requirements.

The first step to developing a house of quality diagram is identifying the owner's needs. These derive from the owner's overall goals and objectives for this project. In order from importance, the following owner needs were identified:

- Exterior Façade Matching Existing (30%)
- Low Construction Cost (20%)
- Short Installation Schedule (16%)
- Good Thermal Performance (14%)
- Durable Wall Exterior (12%)
- Maintenance-Free Wall Assembly (8%)

A weighted importance (represented as a %), was given to each requirement based on the owner's goals and objectives. Geisinger Health Systems, the owner for this project, puts a lot of emphasis in the overall project cost and schedule; but most importantly they expect a high quality exterior building finish that matches the existing building. Thermal performance, durability and maintenance are all properties that tie back to quality and operation costs. In general, the owner expects to have a high quality building enclosure that meets the existing building façade aesthetics, with the lowest possible cost and schedule; this is portrayed through the different owner requirements identified in the house of quality.

After identifying the owner's goals and objectives, the next step to this process was translating them into particular product specifications. We identified three different alternatives for the building's enclosure, each with different performances and specifications. Focusing on the different performance criteria for each wall is important in order to identify the most adequate wall assembly for this project. It is best to choose performance criteria that may be quantified as this aids in comparing how each panel performs against each other. However, a relative performance rating may be used for those that were not able to be quantified. The following design requirements were used in this House of Quality:

- Assembly Location (Miles)
- Insulation Properties (R-Value)
- Impact Resistance (Relative)
- Face Material Aesthetics (Relative)
- Cost of Assembly ($/SF)
- Installation Time (Hr./SF)
- Component Weight (PSF)

These design characteristics were then compared through a correlation matrix. This matrix, which is more often referred to as the roof, is used identify how these performances work together (+) and where they conflict each other (-). As this House of Quality is being used for pre-designed wall panels, this correlation matrix will only be helpful in illustrating how the different performance criteria correlate within each other.

Once all owner and design requirements have been identified, we can begin forming an interrelationship matrix between them. This matrix is what's used to compare how well each of the building's enclosure performances matches each of the owner requirements. Symbols are used on the upper box to establish the strength of the relationship between the customer requirement and the performance measure. Each symbol represents a specific value: Strong relationship (9), medium relationship (6), or weak relationship (3). No values were assigned where there was no relationship evident. The bottom box contains the weight of each requirement that the panels are attempting to fulfill. This weight is calculated by multiplying the assigned relationship (1, 3 or 9) by the weighted importance (%) for each different owner requirement.

Once all correlations have been made, the weights are summed up throughout the column to obtain a total weight for each different design requirement. Using the existing wall panel as a baseline, each design requirement was ranked based on their performance against the existing design. Those design specifications that matched, or better yet, surpassed that of the existing design (highlighted with a red box) were weighted with a 1.0; the second best were weighted 0.8, and the third best with a 0.6. The given weights were then multiplied by the total weight for each different design requirement, and then summed across the row to obtain a total value. The panel with the highest total value would be considered the most suitable panel for this project based on the owner's needs and requirements.

***Refer to Appendix G for the House of Quality Diagram**

4.8 Prefabricated Panel Design & Installation Process

Based on the House of Quality performed to compare all different prefabricated panel alternatives, Nitterhouse Concrete proved to be the most suitable panel design for the Geisinger Grays Woods Ambulatory Care Campus. Nitterhouse Concrete's embedded thin brick panels offer the best between all panels: Real brick aesthetics with the benefit of fast installation and low cost escalation through precast panel prefabrication. Following the prefabricated panel selection, we are determined to design and perform an evaluation for the Geisinger Grays Woods Building.

Prefabricated Panel Design

One of the biggest benefits of assembling panels under a controlled environment is that it allows for much safer and comfortable working conditions. Quality and productivity are greatly increased, as the manufacturing process is not influenced by harsh weather like rain, snow, or extremely low temperature. Assembling the wall panels in a plant also allows a lot of design flexibility. A wide range of panel sizes and designs can be easily accommodated to meet a project's needs. The biggest challenge is determining the most cost efficient design as each project has a unique façade layout.

Figure 6.5: Installation of thin brick under a controlled environment. Image courtesy of Scott System

As mentioned earlier, the panel manufacturing process is pretty straightforward. The panels are first formed, and a thin set brick is arranged within a plastic grid inside the form (Figure 6.5). Concrete is then placed, vibrated and leveled to complete the 4" exterior concrete face. A 2" layer of rigid insulation (Poluisocynaurate) is then set under a final 3" concrete face. The panel formwork and window frames can be easily modified from panel to panel to accommodate different panel sizes and shapes. Mitered joints (Figure 6.6) will be used to connect panels on the building's corners.

When it comes to determining the adequate panel sizing, there are two important factors to consider: consistency and transportation constraints. Panels are costly to put in place, regardless of their size. The amount of panels we have in our project can largely impact the total cost of the system. Because of this, it is necessary to design a layout that requires the least amount of panels, while still maintaining a repetitive and acceptable panel size for transportation.

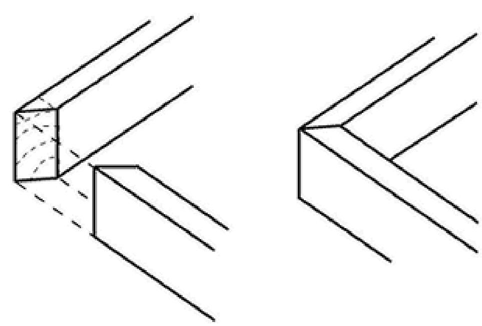


Figure 6.6: Mitered Joint on Panels. Image courtesy of www.dydata.com

In consultation with Mark Taylor, President and CEO of Nitterhouse Concrete Products, it was determined that it would be more cost effective to orient panels vertically in the building. This orientation will allow the panels to span the complete building height, therefore reducing the total amount of panels used on the façade. Mark explained that it is usually better to use wide panels in order to cast the openings within the panels. Panels may not exceed 12' wide though, due to transportation and erection issues. Because of this limitation, the level of customization needed for each panel could greatly increase cost of fabrication. Horizontal panels are also acceptable in the design, although they would need to span from column to column for support. Panel design repetition is also desired in order to reduce the amount of customization and maintain forming and labor costs low. The more repetition and simplified the panels are, the easier and cheaper they are to fabricate. Taking into account the requirements and recommendations discussed earlier, a wall panel breakdown was laid out to determine the amount of panels required, their sizes, and the erection sequence.

The façade of this building wasn't designed for use of prefabricated panels, which provides some unique challenges when breaking down the panel layout. A total of 74 precast brick panels will be used in the design of the building's façade. Panels will be oriented vertically from the building's foundation up to the roof, with a maximum span of 40 feet. While a consistent width was maintained for the majority of panels, it was at times necessary to increase the width to maintain a consistent layout on the various elevations. A total of 14 different panel widths with varying heights, each with its unique color code, were used in the design. This should facilitate production by having a repeatable panel formwork. All window, door and louver opening locations would have to be addressed individually for each panel, as there was not a consistent layout throughout the building façade. Figures 6.7-6.10 illustrate the proposed panel breakdown for the Geisinger Grays Woods Facility:

Figure 6.7: East Elevation Panel Breakdown. Image by George Andonie, modified from Sheet A3.1.1

Figure 6.8: North Elevation Panel Breakdown. Image by George Andonie, modified from Sheet A3.1.1

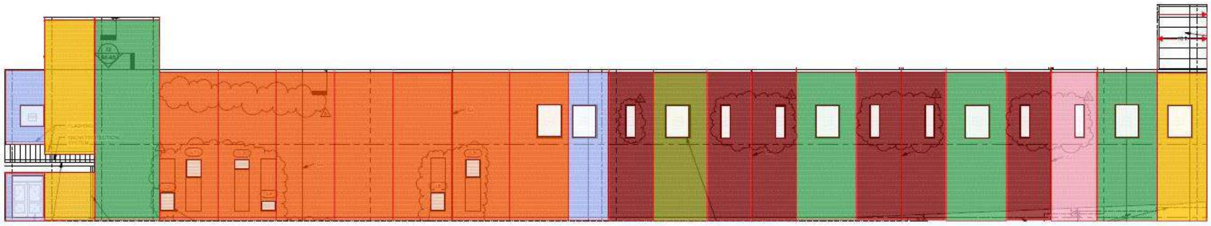


Figure 6.9: South Elevation Panel Breakdown. Image by George Andonie, modified from Sheet A3.1.2

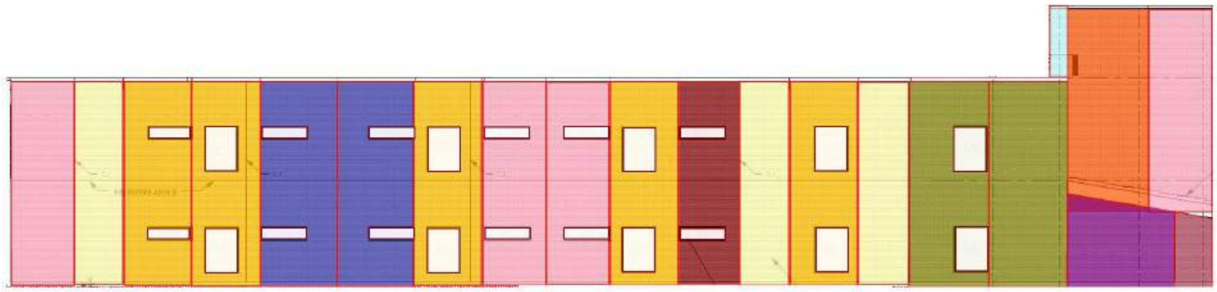


Figure 6.10: West Elevation Panel Breakdown. Image by George Andonie, modified from Sheet A3.1.2

***Refer to Appendix H for a Detailed Prefabricated Panel Layout Breakdown**

TRANSPORTATION & DELIVERY

One of the key factors in choosing Nitterhouse as the manufacturer for the prefabricated brick panels was its close location to the project site. The panels are being fabricated at an estimated distance of 103 miles from the site, and an expected travel time of 2 hours and 7 minutes. The recommended route recommended by truckmiles.com was taking US-22 West, as seen in Figure 6.11.

Figure 6.11: Route from Nitterhouse Concrete to Project Location. Image courtesy of Google Maps

Pennsylvania shipping permit regulations were found using wideloadshipping.com. The state of Pennsylvania requires permits for hauling loads over 8' 6" wide, and escort vehicles in the front and back for loads over 13' wide. The maximum panel overhang allowed is 6' off the rear of the trailer. With this in mind, panel sizes may be transported flat, one per truck, and may not exceed 60' in length and 12' width. Widths over this size would require special permits and make transportation more expensive. The prefabricated wall panels will be transported from the fabrication site directly to the crane for erection. Panels that are 22,500 pounds or less can be paired up on 'vertical' panel trailers, as long as the total payload is less than the legal weight limit of 45,000 pounds.

According to wideloadshipping.com, you are allowed to travel from sunrise to sunset in most areas in PA as long as it's not within larger city limits. Hauling on Sundays is not allowed, but you are permitted to travel until Noon on Saturdays. Therefore, careful planning has to take place in order to schedule panel erection during the week, and deliveries to be made just-in-time for installation.

SITE LOGISTICS & TRADE COORDINATION

As with any construction project, site logistics is always a major concern. It takes a lot of planning upfront to ensure everything on the site will run smoothly and not hinder the flow of construction. The current site layout will be able to accommodate the delivery and installation of the prefabricated wall panels.

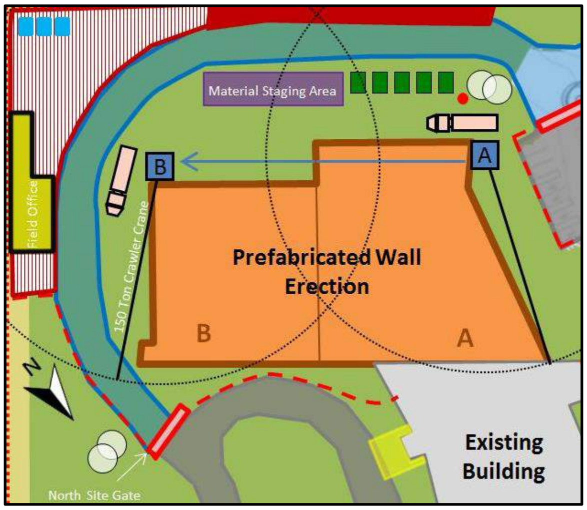


Figure 6.12: Site Layout for Prefabricated Wall Erection. Image by George Andonie

The logistical concerns on-site would remain minimal with the proper just-in-time delivery sequence. The prefabricated panels should be delivered on-site at the specified and planned time period for erection. Delivery trucks will enter the site through Gray's Woods Boulevard and then travel towards the specified crane location. Wall panels will be picked up directly from the truck with and hoisted in place by the crane. According to Mark, the installer will be able to set an average of 16 wall panels per day. Should the project fall behind schedule, wall panels may be stored in the material staging area reachable for crane pick. The site layout, shown in Figure 6.12, illustrates the location of the gate entrance, trucks, and crane location (A & B) throughout the prefabricated panel erection process.

The panel erection process will be done in two stages, similar to the steel erection sequencing. Following the structural steel erection, the crawler crane will move back to 'Stage A' in order to install panels on the east and south facades. Once completed, the crawler crane will then move towards 'Stage B' in order to complete erecting the wall panels along the southern and west building facades. Considering that panel installation follows structural steel erection, the same 160-ton crawler crane will be used for both processes. This 160-ton crane has a maximum line pull of 50,250 pounds, well over the largest panel load of 31,500 pounds.

***Refer to Appendix I for the 'Panel Erection Site Layout'**

SUSTAINABILITY

A lot of construction waste is usually generated through the construction of exterior wall facades. With the panels being manufactured in a factory setting rather than on-site, the panel construction process produces less construction waste and uses fewer natural resources. In addition, using prefabricated panels make the project eligible towards the credits of Energy and Atmosphere (EA), Materials and Resources (MR), and Innovation in Design (ID).

4.9 MECHANICAL ANALYSIS (BREADTH #1)

The efficiency of the building's mechanical system relies heavily on the thermal performance of the exterior enclosure. Changing the composition of the building's envelope can have a major impact on a building's mechanical system. For this analysis, we will be evaluating the thermal properties of the proposed prefabricated system, and compare its performance against the existing system. In addition, an energy evaluation will be performed to compare the overall effect of the prefabricated wall panels on the building's energy consumption versus that of the existing design. This mechanical analysis will be an effective tool to understand whether implementing precast exterior wall panels would be beneficial for this project.

THERMAL PROPERTIES

Understanding the thermal properties of both the existing and proposed prefabricated façade is crucial to determine the effects that the alternate wall assemblies have on the building's performance. The change in the wall's thermal performance will have to addressed in order determine whether there should be any major changes to the building's mechanical system. Concepts learned through AE310 (Fundamentals of Heating, Ventilating and Air-Conditioning) and AE542 (Building Enclosure Science and Design) will be used to perform this mechanical breadth. Additionally, the 'Heat, Air and Moisture Building Science Toolbox' computer program will facilitate the analysis of the exterior wall systems.

The R-values of different materials are used to determine the assembly's effectiveness to insulate from exterior thermal loads. Each material composing the exterior wall assembly has its own R-Value, which generally increases as the material thickness increases. By taking the inverse of the sum of the building wall assembly, we are able to determine its coefficient of heat transmission, or U-Factor. This value indicates the amount of heat that will move through the wall assembly. It is expressed in $\frac{\text{BTU}}{(\text{hr}*\text{ft}^2*{}^\circ\text{F})}$, and the lower the U-Value the better assembly's ability to resist heat movement. Four assumptions were made when performing this analysis:

i. Materials are homogeneous in nature
ii. Temperature changes do not affect thermal performance
iii. Air space always remains the same
iv. Vapor barrier has a negligible thermal resistance property

Although the vapor barrier is assumed to be negligent to the wall assembly's thermal resistance, it plays a vital role in preventing moisture from penetrating and getting trapped inside the wall assembly.

The R-values of each assembly was calculated and then compared side-by-side. While the metal backup, sheathing, and insulation will remain the same between both systems, there is a minor change in the insulation thickness. The prefabricated wall panels will only require a 2" layer of semi-rigid insulation, as opposed to the 4" used in the existing design; this is because the prefabricated panels have a 2" layer of 'Polyisocyanurate Insulation' incorporated within the precast panel. Table

6.1 and Table 6.2 summarize the thermal properties for each of the exterior wall systems. Note that those components that remain the same are below the dotted line in the tables, while those that are modified are above the dotted line.

Table 6.1 – Prefabricated Brick Panel R-Value Calculation

Prefabricated Brick Wall R-Value			
	Material Component	**Thick.**	**R-Value**
R_0	**Outside Air Film**	-	0.17
R_1	**Exterior Face Thin Brick**	5/8"	0.12
R_2	**Exterior Concrete Wythe**	3-3/8"	0.58
R_3	**Insulation (Polyisocyanurate)**	2"	13
R_4	**Interior Concrete Wythe**	3"	0.23
R_5	**Air Cavity**	1-1/2"	0.98
R_6	**Semi-Rigid Insulation**	2"	7.12
R_7	**Air Vapor Barrier**	-	Negligible
R_8	**Sheathing**	1/2"	0.64
R_9	**Cold Formed Metal Stud**	6"	7.28
R_{10}	**Gypsum Wall Board**	5/8"	0.46
R_{11}	**Inside Air Film**	-	0.64
	Total	1' 7-5/8"	31.22
		U-Value	**0.032031**

*R-Values taken from Nitterhouse Concrete Manufacturer

Table 6.2 –Existing Brick Wall R-Value Calculation

Existing Brick Wall R-Value			
	Material Component	**Thick.**	**R-Value**
R_0	**Outside Air Film**	-	0.17
R_1	**Exterior Face Brick**	3-5/8"	0.64
R_2	**Air Cavity**	1-1/2"	0.98
R_3	**Semi-Rigid Insulation**	4"	14.24
R_4	**Air Vapor Barrier**	-	Negligible
R_5	**Sheathing**	1/2"	0.64
R_6	**Cold Formed Metal Stud**	6"	7.28
R_7	**Gypsum Wall Board**	5/8"	0.46
R_8	**Inside Air Film**	-	0.64
	Total	1' 4-1/4"	25.05
		U-Value	**0.03992**

*R-Values taken from ASHRAE 2009 Fundamentals (Tables 4 & 7)

As we have determined, the assumed R-value for a typical 9" precast panel assembly attached to sheathing, insulation, and metal stud backup was slightly higher than that of the existing brick façade of the Geisinger Grays Woods project. The U-value of the proposed panel system increases by 0.007889. The precast brick panel highly benefits from the double layer of 2" semi-rigid insulation, as well as the increase in wall thickness in order provide better insulation to the building overall.

***Refer to <u>Appendix J</u> for the 'Prefabricated Panel Thermal Properties Specification'**

Thermal performance comparison (H.A.M. Analysis)

As we have determined, there will be little to no difference between the façade thermal characteristics. Nevertheless, it is important to model the wall's thermal performance has to be modeled in order to understand how the proposed wall behaves at the project location's climate conditions. The performance of both wall assemblies were modeled in The Heat, Air, and Moisture (HAM) analysis software made by the Building Science Toolbox. This program contains stored data for weather conditions of different project locations, as well as material properties for the different wall components. The following project climate conditions, illustrated in Figure 6.13, were used for this analysis:

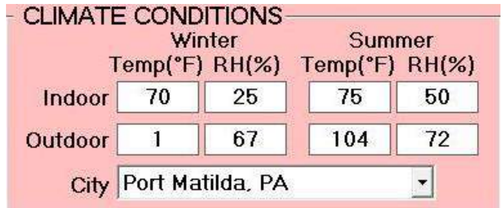


Figure 6.13: Port Matilda Project Conditions. Image taken from H.A.M. Analysis Software

Using the calculated thermal properties for each assembly along with the climate conditions of Port Matilda, PA, the thermal performances of both wall assemblies were modeled under winter and summer conditions. The resulting thermal gradients through the two exterior wall components are illustrated in Figure 6.14 and Figure 6.15.

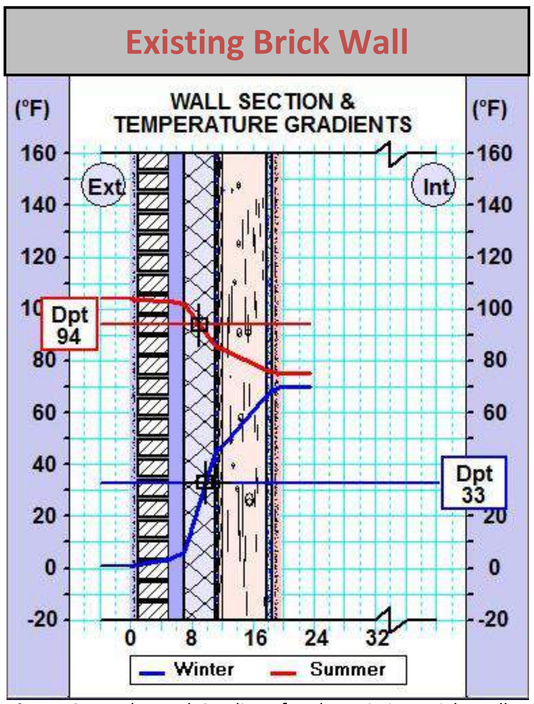


Figure 6.14: Thermal Gradient for the Existing Brick Wall. Produced using H.A.M Analysis Software

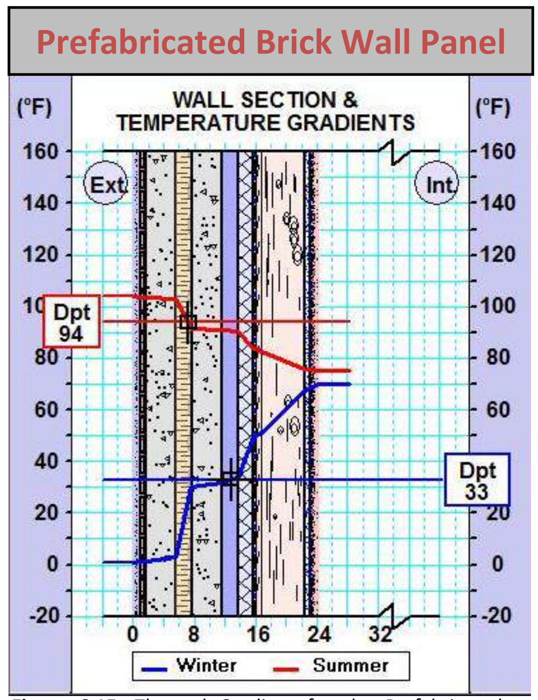


Figure 6.15: Thermal Gradient for the Prefabricated Brick Wall Panels. Produced using H.A.M Analysis

As seen, both wall assemblies effectively maintain comfortable internal environment regardless of the outside weather conditions. Both wall assemblies provide stable indoor air temperature throughout summer and winter seasons. To more accurately analyze the performance of the prefabricated wall panels, a second analysis in HAM was performed to evaluated condensation potential within the panel. After running the analysis, no condensation was found to occur in the proposed prefabricated brick panel system.

***Refer to Appendix K for Thermal Performance and Condensation Analysis Results**

Energy Performance Analysis

Even though prefabricating the exterior wall panels will not induce any major impacts to the building's mechanical system, it is important to address the change in the building's thermal performance through an energy performance analysis. This energy evaluation will be an effective means of comparing the overall effect of the prefabricated wall panels on the building's energy consumption versus that of the existing design.

Using the calculated R-values of each assembly and the engineering weather data for Port Matilda, PA, we are able to calculate the heat-loss in the winter and heat-gain in the summer for each assembly. Heat flow rate (Q), expressed in BTU/hr, is used to determine the amount of heat flowing through the exterior wall enclosure. It is calculated using Equation 6.1: $Q = (\text{U-Value})*(\text{Area})*(\Delta T)$, where area is the surface area of wall enclosure exposed to the outside and ΔT the temperature difference across the wall assemblies. It is important to note that heat flowing out of the windows, curtain wall, and roof are not taken into account in these calculations. Therefore, it is difficult to determine whether the savings in heat-loss and heat-gain justify a reduction in size of the existing Air Handling Units (AHU's) supplying the facility. Nevertheless, a substantial improvement of 20% in heat gain and heat loss could be observed by using prefabricated wall panels on the building's exterior, which may contribute to savings in the operation costs of the building. Table 6.3 summarizes the calculations for heat loss and heat gain for each wall assembly.

Table 6.3 – Heat Loss & Heat Gain Comparison

Heat Loss & Heat Gain Calculations						
Wall Assembly	U-Value	Area (SF)	Heat Loss (Winter)		Heat Gain (Summer)	
			ΔT (°F)	BTU/Hr	ΔT (°F)	BTU/Hr
Existing Brick Assembly	0.03992	17,551	69	48,344	29	20,318
Precast Wall Assembly	0.03203	17,551	69	38,790	29	16,303
Difference	**0.00789**	**-**	**9,554 BTU/hr**		**4,015 BTU/hr**	

*U-values and temperature gradients taken from Table 6.1, Table 6.2 and Figure 6.9
* Heat Loss & Heat Gain calculated using Equation 6.1

A fuel and energy consumption analysis will help determine how much money, in energy costs, will be saved or induced by the owner by the daily operation of this facility. Because annual heating and cooling loads can be reduced through the precast panel system, savings occur with the energy costs required to heat and cool the building. The annual heating fuel consumption was calculated using Equation 6.2:

$$\text{Annual Heating Fuel Consumption (AHFC)} = \frac{24 * Q * \text{HDD}}{\Delta T_w * \text{HV} * \text{HEE}}$$

The equation was obtained from the book "Engineering Weather Data" and uses the calculated heat loss (Q), the heating degree days (HDD), temperature difference across the assembly during winter (ΔT_w), the heating value of natural gas (HV), and the heating efficiency of the AHU's. The fuel consumption for each wall system was calculated, along with the difference between the two fuel consumptions. The fuel consumption savings (difference between the annual heating fuel consumptions) was multiplied by Pennsylvania's average cost for natural gas to calculate the annual cost savings for heating load. The total annual cost savings for heating of the Grays Woods facility was $320, and the calculations can be seen in Table 6.4 below.

Table 6.4 – Annual Heating Fuel Consumption Cost Comparison

Annual Heating Fuel Consumption (Winter)			
Variable	**Unit**	**Existing Brick Assembly**	**Precast Panel Assembly**
Heat Loss (Q)	**BTU/hr**	48,344	38,790
Annual Heating Degree Days (HDD)	**°F * # Days**	6087	6087
Winter Temperature Difference (ΔT)	**°F**	69	69
Heating Value of Natural Gas (HV)	**BTU/ft^3**	1027	1027
Heating Efficiency of Equipment (HEE)	**%/100**	0.8	0.8
Annual Heating Fuel Consumption	**Cubic Feet**	124,579	99,959
Average Cost of Natural Gas (PA)	**$ / 1000ft^3**	**11.67**	**11.67**
Annual Heating Cost ($)		**$1,617**	**$1,297**

*Pennsylvania's Average Price of Natural Gas Cost taken from U.S. Energy Information Administration

The annual cooling energy consumption was calculated using Equation 6.3, which was adjusted to find cooling energy:

$$\text{Annual Cooling Energy Consumption (ACEC)} = \frac{24 * Q * CDD}{\Delta T_S * CV}$$

The equation uses the calculated heat gain (Q), cooling degree days (CDD), temperature difference across the assembly during summer (ΔT_S), and the cooling value (CV) of the AHU's. The energy savings (difference between annual energy consumptions) was multiplied by Pennsylvania's average electricity in $/KWh to calculate the annual cost savings for cooling load. The total annual cost savings for cooling of the Grays Woods facility was $79, and the calculations can be seen in Table 6.5 below.

Table 6.5 – Annual Cooling Energy Consumption Cost Comparison

Annual Cooling Energy Consumption (Summer)			
Variable	**Unit**	**Existing Brick Assembly**	**Precast Panel Assembly**
Heat Gain (Q)	**BTU/hr**	20,318	16,303
Annual Cooling Degree Days (HDD)	**°F * # Days**	622	622
Winter Temperature Difference (ΔT)	**°F**	29	29
Cooling Value (CV)	**BTU/KWh**	3415	3415
Annual Cooling Energy Consumption	**KWh**	3,063	2,457
Average Electricity Cost (PA)	**$/KWh**	**0.0921**	**0.0921**
Annual Cooling Cost ($)		**$398**	**$319**

*Pennsylvania's Average Electricity Costs taken from U.S. Energy Information Administration

It is important to note that these values represent a scale of the building's overall energy consumption, as it only takes into account the heat transfer through its exterior wall enclosure. Including other substantial sources of heat gain and heat loss such as windows, doors, curtain wall, and roof would better portray the overall building cost savings.

4.10 Feasibility Analysis

A feasibility analysis detailing cost and schedule will further help in determining whether the proposed prefabricated panel system is viable for the Grays Woods Project. For this, a quantity takeoff was performed in order to calculate the total number of prefabricated panels and square footage, accordingly. We will be referring to this takeoff in order evaluate cost, schedule and energy performances of the proposed prefabricated panel for this project.

***Refer to the 'Complete Precast Panel Takeoff' in Appendix L for the following sections**

Schedule Analysis

Traditional brick facades are handcrafted brick by brick, which is time consuming and labor intensive. The main advantage of prefabricating the building's exterior is the speed at which they can be installed. As it had been advised by Mark Taylor, an average of 16 panels could be erected per day. Taking this into account with the 74 total panels used in all four building facades, a total duration was calculated for each façade. Durations were rounded up for each façade in order to allow for contingency for any inefficiencies or delays that may occur. The panels on the South, East, and West facades will each be erected in two days, while the smaller panels located in the building's northern façade may be installed in one. Table 6.6 summarizes the panel installation durations for this project:

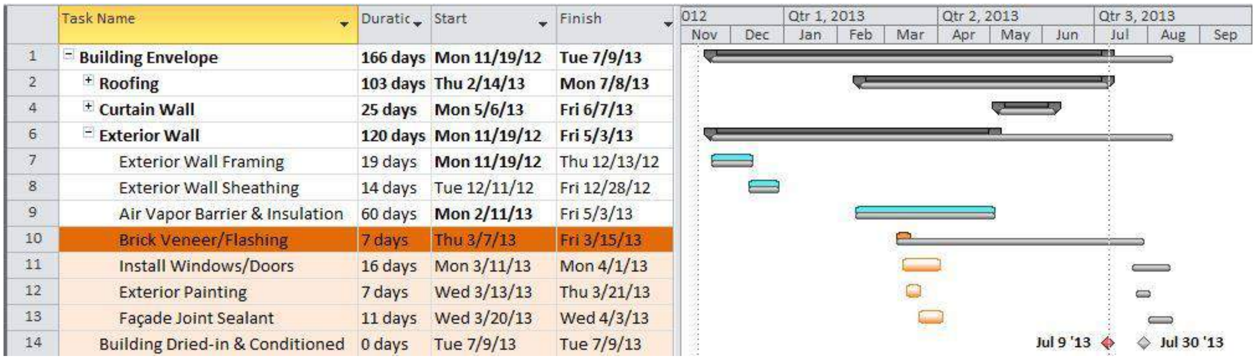
Table 6.6 –Prefabricated Panel Schedule Summary

Panel Installation Durations			
Façade Orientation	**Panel Qty.**	**Calculated Duration**	**Adjusted Duration**
East Façade	19	1.27 Days	2 Days
South Façade	25	1.67 Days	2 Days
West Façade	22	1.47 Days	2 Days
North Façade	8	0.53 Days	1 Day
Total	**74**	**4.93 Days**	**7 Days**

*Durations taken from Precast Panel Takeoff (Appendix L), and assume productivity of 16 Panels/Day.

Compared to the original duration of 103 days, utilizing precast brick panels can significantly reduce the building's exterior wall construction duration. It is important to note that this duration accounts for the brick veneer activity only, as the installation of metal stud, insulation, and sheathing are done on site for both systems.

Duration changes were projected in the existing schedule to determine the impact of the implementation of precast panels. A summary of the proposed schedule can be seen in Figure 6.15. The schedule compares the change between both systems through a project baseline. As seen, all activities prior to the brick veneer remained the same as the proposed system would not affect these activities. The brick installation, called out in dark orange in the project schedule, was shortened by 96 days. This reduction allowed the following activities, highlighted in light orange, to be completed earlier than what was actually planned.



	Task Name	Duration	Start	Finish
1	Building Envelope	166 days	Mon 11/19/12	Tue 7/9/13
2	Roofing	103 days	Thu 2/14/13	Mon 7/8/13
4	Curtain Wall	25 days	Mon 5/6/13	Fri 6/7/13
6	Exterior Wall	120 days	Mon 11/19/12	Fri 5/3/13
7	Exterior Wall Framing	19 days	Mon 11/19/12	Thu 12/13/12
8	Exterior Wall Sheathing	14 days	Tue 12/11/12	Fri 12/28/12
9	Air Vapor Barrier & Insulation	60 days	Mon 2/11/13	Fri 5/3/13
10	Brick Veneer/Flashing	7 days	Thu 3/7/13	Fri 3/15/13
11	Install Windows/Doors	16 days	Mon 3/11/13	Mon 4/1/13
12	Exterior Painting	7 days	Wed 3/13/13	Thu 3/21/13
13	Façade Joint Sealant	11 days	Wed 3/20/13	Wed 4/3/13
14	Building Dried-in & Conditioned	0 days	Tue 7/9/13	Tue 7/9/13

Figure 6.15: Summary of the proposed schedule for building enclosure (Full Schedule can be found in Appendix M)

After projecting the changes in the original schedule, the 'Building Watertight' milestone was pushed up to July 9th, 2013. This allows for some interior work to begin earlier in the project, especially the installation of moisture sensitive building materials. The reason why there was only a 21 day reduction to the schedule, compared to the 96 day reduction of the brick veneer activity is because of the installation of the metal panel roofing. This activity limits the building from being water tight earlier. Considering that the building enclosure falls in the project's critical path, it could also reduce the overall project completion by the same amount.

***Refer to Appendix M for the 'Proposed Schedule for Building's Enclosure'**

Cost Analysis

Now that a schedule reduction has been determined, a cost analysis will be performed in order to determine the feasibility of prefabricated wall panels for this project. For this, a direct cost comparison between the proposed and existing enclosure was performed. With masonry being the major material being modified, this item constitutes the main cost difference between both systems. In accordance to Mark Taylor, the average cost of the prefabricated brick panels (including material, delivery and installation) is $25/SF. The actual cost of the brick masonry wall is $16.10/SF, and it was taken from RS Means. Additional scaffolding costs have to be taken into account for erecting the current brick masonry costs, and were taken from actual project costs. The internal components installed on site will remain the same between both components and will not impact the costs. Nevertheless, insulation costs will vary between both systems; the proposed panel system requires 2" of semi-rigid insulation, as opposed to the 4" layer used in the existing design. In addition, the panels will require a significant amount of sealant for the panel-to-panel connections. A construction cost estimate was performed for each panel, and is summarized in Table 6.7.

Table 6.7 –Building Enclosure Material Cost Comparison:

Building Enclosure Construction Cost Comparison						
Material Description	Total	Unit	Prefabricated Panels		Traditional Brick	
			Cost/SF	Total Cost	Cost/SF	Total Cost
Exterior Face Wall	17,551	SF	$25.00	$438,775	$16.10	$282,571
Interior Component (Sheathing, Vapor Barrier & Metal Backup)	17,551	SF	$19.63	$344,485	$19.63	$344,485
Insulation (2" or 4")	17,551	SF	$1.37	$24,045	$2.68	$47,037
Caulking	3,360	LF	$2.16	$7,258	-	-
Transportation	-	-	Included	Included	-	-
Erection Equipment (Scaffolding or Crane)	-	-	Included	Included	-	$47,037
Total			**$48.2**	**$814,563**	**$38.4**	**$721,130**

Costs provided by Nitterhouse Concrete, RS Means 2013, and Actual Project Costs

As determined, the precast system costs over $93,433 more than the traditional brick veneer currently in use. This estimate only takes into account the cost of material, labor, and equipment put in place to construct each assembly. To provide a more accurate cost estimate, changes in general condition costs have to be taken into consideration. Further investigation of the schedule and discussion with the project team has led to the conclusion that pushing the 'Building Watertight' milestone by 21 days could push the project schedule by the same duration.

The general conditions estimate from Section 4.5 of this report was used to determine the general conditions cost savings. Completing the project earlier than originally planned would save 21 days of project personnel, field office and operation expenses, which equated to $43,663. Table 6.8 summarizes the total cost impact of implementing wall panels on the Geisinger Grays Woods project. As seen, the precast panels will increment the total project cost by $49,770.

Table 6.8 –Prefabricated Panel Schedule Summary:

Building Enclosure Cost Comparison Summary		
Item Description	Prefabricated Panels Total Cost	Traditional Brick Total Cost
Cost of Assembly	$814,562.69	$721,130
General Conditions Cost	$742,260.05	$785,922
Total	**$1,556,823**	**$1,507,052**

*Estimated Assembly costs based on RS Means 2013, Nitterhouse Concrete, and Actual Project Costs

4.11 Conclusion & Recommendations

This analysis presents an alternative modular system to the current stick-built exterior wall construction. The construction of the building envelope took a total of 178 days, and required an extensive amount of labor-hours and scaffolding to install. On the other hand, prefabricating the exterior façade presents the opportunity to improve schedule, cost, and building performance. Through extensive research and the use of 'House of Quality' tool, it was determined that Nitterhouse's 'Architectural Precast Panels' would be the best alternative for the building wall prefabrication. The design required a total of 74 precast panels spanning the building's total height. Panels would be fabricated at an estimated distance of 103 miles from the site, and transported directly to the crane for erection. The current site layout will be able to accommodate the delivery and installation of the prefabricated wall panels, so no major changes had to be done. Implementing precast panels costs an additional $50,000 to the project budget, although it could reduce the project schedule by 3 weeks. Through a mechanical analysis, it was determined that the proposed panel would improve heat gain and heat loss by 20%, which can translate to energy savings for heating and cooling.

After a careful consideration of the impact on the cost, schedule, and building performance, it was determined that it might not be of the owner's best interest to pursue this alternate construction method. I would not recommend the use of prefabricated wall panels over the traditional brick veneer system, as the increased cost and planning required for implementation outweigh the savings in schedule.

5.0 - Reevaluation of Structural Composite Slab

5.1 Opportunity Identification

The MEP, interior, and structural systems of the Geisinger Gray's Woods Ambulatory Care Campus account for over 80% of the building's total cost. In an attempt to lower the building costs, value engineering efforts should be done to any of the following building systems. While the MEP and interior finishes are vital to the quality and performance of the healthcare facility, the building's structural system could be an area to focus in order to identify possible cost reduction practices.

5.2 Proposed Solution

An analysis will be done to re-evaluate the building's structural system, with the objective of lowering the building costs while still maintaining the structural integrity of the medical office building. There is an opportunity of looking into the building's composite metal decking, which uses lightweight concrete for the second floor slab. Although both lightweight and normal-weight concrete can fulfill the same structural function, there is a significant cost premium for lightweight concrete. With over 38,000SF of lightweight concrete used for the slabs, project costs could be substantially lowered by using normal concrete instead. By altering the lightweight structural concrete slabs to normal weight concrete, a breadth analysis of the building's structural system would be required to address any structural design modifications.

5.3 Research Goal

The goal of this analysis is to reduce project costs by testing a value engineering solution: changing the composite metal deck slab from lightweight to normal weight concrete. Through this analysis, it is expected to get a better understanding of the advantages and disadvantages of using each type of concrete in a project. A feasibility analysis based on the material savings and construction implications will help in determining whether this value engineering solution provides any cost savings for the project.

5.3 Background Research

When performing value engineering on a project, the main focus is to identify potential areas to save costs and/or schedule time that will not infringe upon the intent of the design. These should add value to the building, rather than reducing the cost through lower quality. The Gray's Woods structural system provides many opportunities for value-engineering efforts. The building is a two-story steel braced framed structure supported over cast-in-place spread footings and slab on grade. The design uses normal weight concrete for the building's foundation, whereas lightweight concrete for the second floor deck slabs. Although both lightweight and normal-weight concrete can fulfill the same structural function, there is a significant cost premium for lightweight concrete. When looking into the concrete properties, normal weight concrete is significantly heavier than lightweight concrete. Not only does it incur more loads in the building's structure, but may also impact the fireproofing and moisture content performances of each.

5.5 Existing Conditions

As stated previously, the second floor slab of the Geisinger Ambulatory Care Campus facility consists of lightweight concrete on composite metal decking. This composite structural system performs by interlock both the lightweight concrete and metal deck, creating a reinforced concrete slab that serves the dual purpose of permanent form and positive reinforcement. The second floor composite metal decking is composed of 3 ¼" of lightweight concrete poured over a 2", 18 gauge metal decking

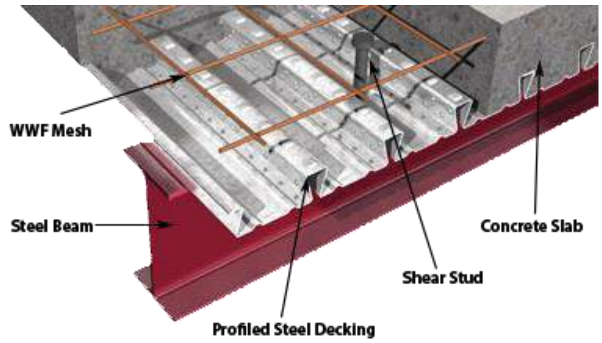


Figure 5.1: Composite Metal Decking. Image courtesy of http://www.nexus.globalquakemodel.org

The 38,000SF composite second floor is supported by steel beams, girders and columns over typical 30' x 30' bays. Overall, there are 40 bays within the first and second floors; other areas, such as the north and west perimeters of the building, are not consistent with this bay size. Each bay comprises of 4 beams spaced at 10' from center. Shear studs are used to transfer the shear stress between the concrete and metal to the wide flange steel beams, and a 6x6-W1.4xW1.4 welded wire fabric (WWF) mesh provides tension reinforcement the concrete slab. This composition is better illustrated in Figure 5.1.

The current structural steel system for the building's second floor was designed in order to provide the minimum 2-hr fire rating required for two-story steel structures. The slab thickness, decking, and concrete type used were all factored to determine the best assembly to support this rating without the need of additional fire protection. Therefore, Spray on Fire Proofing (SOFP) was only used on the roof decking, elevators, and air shafts on this building.

5.6 Understanding The Differences Between Lightweight & Normal Concrete

Lightweight concrete has been utilized in construction for various centuries; it is commonly used to reduce the dead load of a concrete structure while still attaining similar compressive strength as normal weight concrete. Using lightweight aggregates in the concrete can help achieve an increased air volume and low density concrete, reducing the concrete weight by over 30%. It is worth evaluating the different properties of normal and lightweight concrete, as they play a big role in affecting slab performance.

Cost Implications

Although both normal and lightweight concrete can fulfill the same structural function, there is a significant cost premium for lightweight concrete. According to Centre Concrete Company, the concrete provider for this project, a cubic yard (cy) of normal weight concrete (3,000psi) costs around $102, while the cost of lightweight concrete (3,000psi) was around $134 per cubic yard. The material unit cost of lightweight concrete is slightly higher due to the aggregate processing and shipping costs from nonlocal sources.

With this in mind, altering the second floor slab to normal weight concrete should be a large source of cost-savings for the project. This savings in material costs, though, may be offset by having to re-modify the building's structural system. It is through a structural analysis that we will be able to identify whether any changes have to be made to the current building structural system. If any, the material savings costs will be weighed-in with those incurred structural costs in order to make a final recommendation on whether this change would be beneficial to this project.

Material Density

As the name implies, there is a significant difference between the material densities of each concrete. While normal concrete mixes typically weigh 145 to 155pcf, lightweight concrete may weigh between 110 to 115pcf. With over 30% reduced loads over the entire building structure, there is a potential to reduce the sizing of columns, footing, and other load bearing elements.

This difference in material densities primarily lies in the aggregates used on their mix. Normal concrete aggregates are typically natural crushed stone, whereas lightweight aggregates are produced by heating clay, shale, or slate in temperatures up to 2,000 °F.[33]

Fire Protection

When designing a composite deck, fire protection requirements generally control the selection of the topping thickness. Lightweight concrete is more fire resistant than normal-weight concrete due to its lower thermal conductivity and increased air volume content. This characteristic allows lightweight concrete to have thinner slab sections than comparable normal weight slabs that have identical fire ratings, as evidenced in Table 5.1. In order to achieve 2-hour fire rating without the need of additional spray on fire proofing, a 3 ¼" LW or 4 ½" NW concrete thickness is required. This difference in slab thickness could potentially offset the material cost savings, as less material could be required with the use of lightweight concrete.

Table 5.1 – Slab Thickness and Fire Rating Comparison

Restrained Assembly Fire Rating	Minimum Slab Thickness on 2 or 3 in. Steel Floor or Form Deck without Spray-Applied Fireproofing	
	Lightweight Concrete (107-113 pcf)	Normal-weight Concrete (147-153 pcf)
1 hour	2⅝ in.	3½ in.
2 hours	3¼ in.	4½ in.
3 hours	4³⁄₁₆ in.	5¼ in.

*Table courtesy of www.structuremag.org

Floor assemblies of a two- story steel structure requires, by code, to have a minimum 2-hour fire rating. The United Laboratories (UL) 'Fire Resistance Directory' is used to determine the composite deck profile that meets the minimum fire rating requirements. The critical factors that determine the rating assembly are type of protection (sprayed on fire proofing or unprotected), type of concrete & thickness, and composite metal decking type. This will be later used to determine an alternate normal weight composite metal decking assembly that meets the minimum 2-hour fire rating.

Methods for Placing & Finishing

There is typically no difference in cost for placement and finishing lightweight and normal-weight concrete, as no additional efforts go into mixing, pouring and finishing between both types. Pumping structural lightweight concrete is quite common and easily achieved, as the lower density allows for an easier concrete flow. There is really no need to over-finish a floor made with lightweight concrete, as it can easily flow and set level on a surface. Nevertheless, special attention has to be placed when placing lightweight concrete, as the pumping pressure may have a great impact in the overall density. Pumping the concrete over the recommended pressure can drive water in between the aggregates, resulting in a decrease in the concrete's volume and increase in the concrete's density.

Moisture Content (Curing)

The porosity of the lightweight aggregates allows them to absorb, retain and release more moisture than normal aggregates. Because lightweight concrete has this increased capacity for moisture absorption, it can take two to three times longer than regular aggregate concrete to dry. A study performed in 1998 reported that a 4 inch normal concrete slab took 46 days to reach a moisture vapor emission rate (MVER) of 3lb/1000ft^2, while lightweight concrete with the same thickness took 183 days to achieve the same EMVR.[32] According to the Floor Covering Installation Contractors Association (FCICA), the excessive presence of moisture can result in deterioration of moisture-sensitive flooring materials and adhesive bond between adhered material layers.[18]

For this project, Alexander Construction failed to meet the acceptable slab moisture content for flooring installation on the second floor slab. This cost the project team over $102,000 in moisture-mitigation techniques in order to keep the schedule on track and begin installing the flooring on the second floor slab. As seen, this characteristic can present setbacks to the project schedule or cost for dehumidification processes and equipment.

Slab Performance (Vibrations)

Hospitals and similar healthcare facilities have strict requirements on building vibration performance, due to the use of highly-sensitive medical equipment. Excessive structural vibrations can greatly interfere with the performance of medical procedures, compromise the operation of sensitive equipment, and have adverse effects of patient discomfort. Floor vibrations can arise from a variety of different sources within inside and outside the building. The main sources of floor vibration are human foot traffic, mechanical equipment, and exterior wind loads.

For this reason, it is important to address vibration performances during the design stages of a project. Using regular concrete with a thicker floor slab can greatly improve a building's vibration performance. This increase in weight improves the damping in the floor, increasing the amount of force necessary in order to excite vibration on the building's floor structure.[17]

Table Comparison

As seen, using different types of concrete can greatly impact many building aspects such as performance, loading, costs, assemblies, and slab fire ratings. Figure 5.2 below highlights the main differences between normal and lightweight concrete. Comparing the differences side-by-side is helpful in understanding the different performance characteristics of normal and lightweight concrete; nevertheless, it is imperative to perform a detailed cost comparison between each better understand how changing from one design to the other affects the overall project cost.

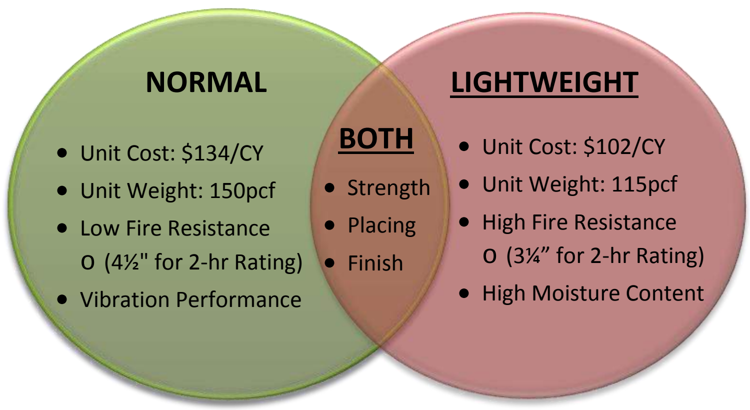


Figure 5.2: Normal vs. Lightweight Comparison. Image by George Andonie

5.7 Structural Analysis (Breadth #2)

With over 40 pounds per cubic foot heavier than lightweight concrete, normal concrete significantly increases the loads to the building's structure. A structural analysis will help determine adequate structural member sizing that can support the additional building loads. For this analysis, a 30'x30' bay was evaluated in order to represent the entire structural system. This bay sizing was kept constant so it would not interfere with existing column spacing and interior architectural layouts.

The structural calculations were performed as outlined below:

- Determined an adequate NW decking assembly
- Checked beam sizing for additional loads
- Checked girder sizing for additional loads
- Checked column sizing for additional loads
- Checked footing sizing for additional loads

Composite Metal Decking Assembly

The first step to this analysis consisted in determining an adequate composite metal decking assembly that meets loading, deflection, and fire protection requirements. As discussed earlier, a 4½" normal weight concrete thickness is required to achieve the 2-hour minimum fire rating for unprotected decks. To ensure minimum changes to the intent of the existing design, the original 2", 18 gauge metal decking (Figure 5.3) with a double span condition was used.

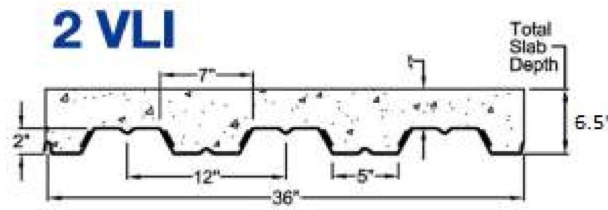


Figure 5.3: Vulcraft 2VLI Floor Decking Detail. Image courtesy of Vulcraft

After choosing the alternate composite deck assembly, two conditions had to be met: 1) Maximum Unshored Clear Span, and 2) Superimposed Live Load for the clear span. The maximum unshored clear span conditions the maximum allowable beam spacing without requiring any additional shoring. It is important to select a design that does not require any shoring, as this adds cost and schedule to a project. From the Vulcraft "Steel Roof and Floor Decking Catalog" (Table 5.2), a 2VLI18 metal deck with double span conditions has a maximum unshored clear span of 10'6"; therefore, the existing 10' space between beams is acceptable for this design. Superimposed live load is used to check the deck's strength and deflection for a given clear span. Based on the 10' beam span used in the redesign, we are allowed a maximum of 222psf to ensure no deck deflection. The proposed redesign effectively meets both minimum requirements.

Table 5.2 – Vulcraft 2VLI Normal Weight on Composite Floor Decking Span & Loading Tables

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 SPAN	2 SPAN	3 SPAN	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6
	2VLI22	5'-11	6'-11	7'-11	400	390	339	297	263	234	210	189	171	155	141	129	118	108	99
6.50	2VLI20	6'-11	8'-9	9'-0	400	400	400	337	297	264	237	213	193	175	159	145	133	122	112
(t=4.50)	2VLI19	7'-10	9'-8	10'-0	400	400	400	400	374	293	262	236	213	193	176	161	147	135	124
69 PSF	2VLI18	8'-7	10'-6	10'-11	400	400	400	400	400	373	340	268	243	222	203	187	172	159	147
	2VLI16	8'-10	10'-8	11'-0	400	400	400	400	400	400	387	309	280	256	234	215	198	183	169

***Refer to Appendix N for 'Vulcract's Decking Catalog'**

RESIZING STRUCTURAL MEMBERS

After identifying an adequate normal weight composite deck for the second floor slab, the next step was to address the increase in loads to the steel structure. Note from Table 5.2 above that NW concrete slabs with a 2" composite decking weighs 69psf, compared to the original 42psf from lightweight decking. With a heavier concrete slab, the structure's beams, girders and columns have to be resized in order to support the increased loads. The maximum shear and bending moments were calculated based on the loads supported by each member. These were later compared against the '*AISC Steel Construction Manual*' in order to determine the most economical design that meets both the maximum resisting moment, shear stress, and deflections.

For sizing calculations, the following values were assumed:

- Live Loads:
  - Hospitals (Operating & Patient Room, Laboratories) = 60psf
  - Wall Partitions = 20psf
  - Snow Loads (Port Matilda, PA) = 30psf
- Dead Loads:
  - 2" Deck with 4.5"NW Concrete = 69psf
  - 3" Roof Deck = 3psf

  - Roof Fireproofing = 3psf
  - Roof Self-weight = 30psf
  - Beam Self-weight (Allowance) = 5psf
  - Girder Self-weight (Allowance) = 2psf
  - *Superimposed Dead Loads = 10psf
- Column Height (KL) = 15'

*Note: Superimposed dead loads account for all those loads that are not part building structure self-weight. These include mechanical and electrical equipment, ceiling, flooring, and any other similar loads. The dead loads for the materials making up both the roof and floor assemblies were taken from tables in AISC's '*Steel Construction Manual*'. Floor decking dead loads were all taken from Vulcraft's '*Steel Roof and Floor Decking Catalog*'. All live loads were taken from ASCE-7, and were reduced when applicable. The following structural calculations are based on concepts learned through AE404 (Building Structural Systems in Steel and Concrete).

***Refer to Appendix O for Beam, Girder, Column, and Footing Sizing Calculations**

CHECKING BEAM & GIRDER SIZING:

Based on previous calculations, it was determined that the original beam spacing will stay constant for the purpose of this redesign. The current 30' x 30' bay consists of four W18x35 beams spaced at 10' apart. Structural calculations were performed in order to determine whether beam sizing had to be done.

For these calculations, building live loads and dead loads were factored using ASCE's load combinations in order to determine a distributed load on the beam. Using shear and moment diagrams, the maximum shear force (V_u) and bending moment (M_u) that each beam is expected to experience were determined. Maximum bending moment (M_{Max}) values control beam and girder sizing. Using tables from the ASCE's *Steel Construction Manual*, an economical member size with a greater moment capacity (M_ϕ) than the maximum bending moment (M_{Max}) was chosen.

Although bending moments control beam and girder sizing, it is important to check that the maximum shear force (V_u) is lower than the chosen beam's shear capacity (V_ϕ). Both the chosen beams and girders satisfy this condition.

The final step to this process was checking the beam's deflection. Beam deflection is important as it greatly impacts the structure's serviceability. Serviceability refers to the performance of structures under normal services loads, and is concerned with vibration, height restrictions, and member failures. Having excessive deflections of beams and slabs may cause sagging floors, excessive vibrations, interfere with proper equipment operation, or even present challenges with flooring, partitions and fitting of windows and doors.[29] To check for deflection, the maximum deflection caused by the beam loading should be smaller than the maximum permissible dead and live load deflection (L/240). Both the beam and girder have a smaller deflection that 1.5 inches, therefore satisfy the deflection criterion.

After performing these structural calculations, it was determined that the original beam size would remain the same, although the girder sizes would increase from W24x62 to W24x68 for each typical bay. Changes from the current lightweight design to the normal weight design are noted in Figure 5.4.

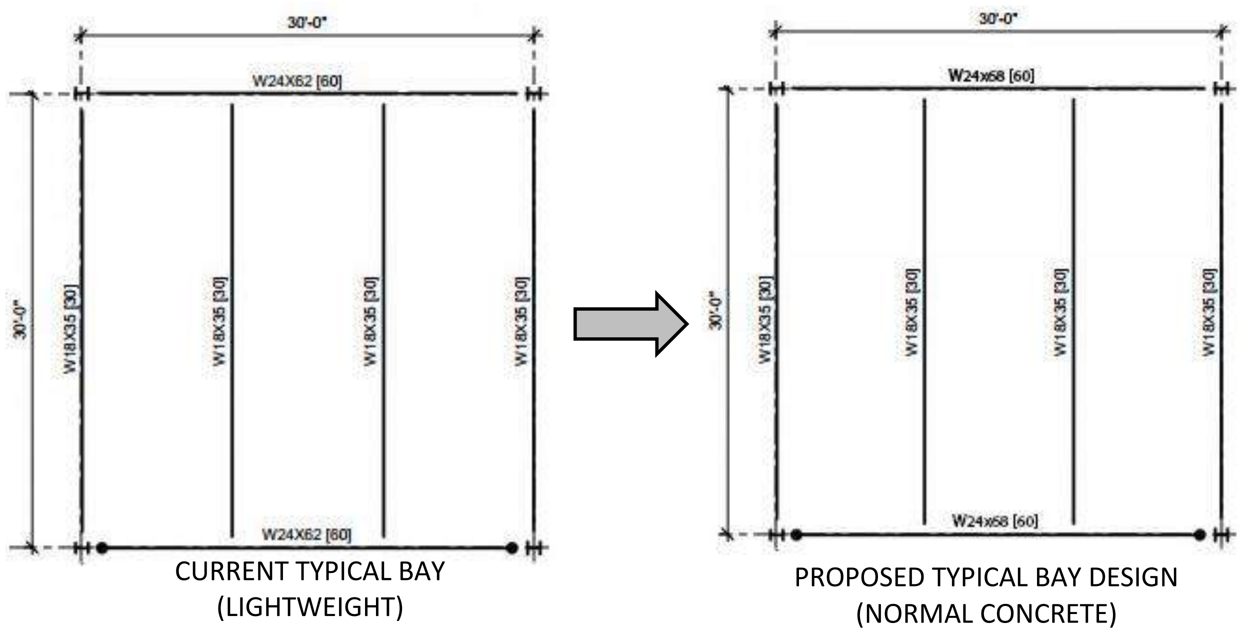


Figure 5.4: Framing bay comparison between normal-weight and lightweight concrete slabs on composite metal floor deck. Images taken and modified from the Project's Structural Drawings (Sheet S2.2.A)

CHECKING COLUMN & FOOTING SIZING:

While beam and girder sizing is controlled by maximum shear moments, column and footing sizing is determined by the factored axial compressive force (P_u). To calculate this force, the floor and roof loads have to be taken into account. The floor loads acting on the column result from the two girders and two beams connecting to it. Therefore, this is calculated by adding the loads of all beams and girders at this point. Roof dead and live loads were calculated separately, and factored using ASCE's load combination. The roof's dead load considers the load of the roof itself, deck with fireproofing, beam allowance and other superimposed. The roof's live load is driven by the snow loads for Port Matilda, PA, and were calculated using tables from ASCE-7.

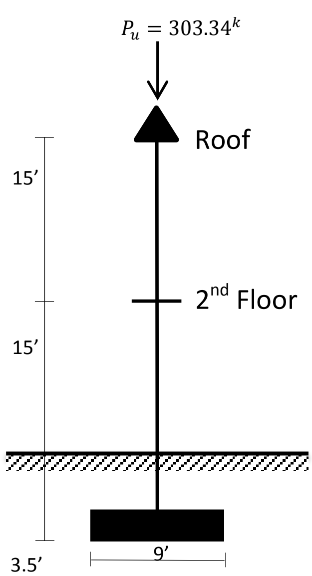


Figure 7.5: Building's column and footing framing diagram. Image by George Andonie.

When combining all floor and roof loads, the total axial loads (P_u) on the column sums up to 303.34kips. Assuming that the effective length (KL) of the column is 15', ASCE's *Steel Construction Manual* Tables were used to define a column that met this loading requirement. The determined column size was W10x49, same as the original design. The columns size, loading and height are all illustrated in the framing diagram on Figure 7.5.

The calculated axial load (P_u) was also used to evaluate whether the existing footing size was acceptable for this loading design. Dividing the axial force by the footing area (9'x9') determined the soil bearing pressure exerted by the footing. This pressure did not exceed the soil's allowable bearing capacity of 4,000psi. Therefore, modifying the building's composite floor decking does not induce any changes to the structure's column and footings.

5.8 Feasibility Analysis

Performing a feasibility analysis focusing on cost, schedule and construction implications will help determine whether changing the second floor decking from lightweight to normal weight concrete is beneficial for the Grays Woods Project. For this, a material comparison will have to be performed in a typical bay in order to compare both systems effectively.

Because the beam and column spacing were kept constant, both systems will require the same quantity of structural members. Steel beams, columns, and footings did not require any modifications, as the existing design could support the increase in loads. Nevertheless, steel girders had to be increased from W24x55 to W24x68 to support additional loads. In addition to this modification, the proposed design requires a thicker layer of concrete material in order to achieve the minimum 2 hour rating for floor assemblies. This though, eliminates the need of additional spray on fire proofing for both floor assemblies. Table 5.3 summarizes the changes in material sizing from the existing lightweight to proposed design.

Table 5.3 – Material Sizing Modifications from Existing Lightweight to Normal Weight Floor Slabs

Existing LW Design	
Item Description	**Size**
LW Concrete Material	3.25"
Concrete Placing	<6"
Concrete Reinforcing	6x6 W1.4xW1.4
Floor Decking	2VLI18
Shear Studs	½" Diameter
Steel Beams (4)	W18x35
Steel Girders (2)	W24x62
Steel Columns (2)	W10x49
Additional Fireproofing	-

Proposed NW Design	
Item Description	**Size**
NW Concrete Material	4.5"
Concrete Placing	<6"
Concrete Reinforcing	6x6 W2.1xW2.1
Floor Decking	2VLI18
Shear Studs	½" Diameter
Steel Beams (4)	W18x35
Steel Girders (2)	W24x68
Steel Columns (2)	W10x49
Additional Fireproofing	-

As seen, the proposed normal weight concrete slab system requires an additional 1.25" of concrete. This increase in thickness calls for stronger WWF reinforcement as well. Beam and column connection, as well as shear stud connections, are expected to remain the same for both systems. The values in Table 5.3 will be used in order to perform a detailed cost analysis for each of the two composite floor slab systems.

Cost Evaluation

Cost is the main factor that will determine the feasibility of the changes in the project's floor decking design. Using Table 5.3 as a reference, a direct cost comparison between both systems was performed. This comparison details the differences in material, labor, and equipment between both systems. All costs were obtained from RSMeans 2013, with the exception of concrete material unit costs. Actual concrete costs used on this project, provided by Centre Concrete Company, were utilized for a more accurate cost comparison. The current lightweight concrete design of a typical 30' x 30' bay costs around $23,640. Table 5.4 summarizes the cost breakdown of a typical bay for the current design.

Table 5.4 –Cost Summary of Typical Bay for Current Design

2" Decking with LW Concrete					
Item Description	**Size**	**Units**	**Qty.**	**Cost/Unit**	**Total**
***LW Concrete Material (3,000psi)**	3.25"	CY	11.79	$134.00	$1,579.86
Concrete Placing	<6"	CY	11.79	$37.00	$436.23
Concrete Reinforcing	6x6 W1.4xW1.4	SF	900	$0.36	$324.00
Composite Metal Decking	2VLI18	SF	900	$3.79	$3,411.00
Shear Studs	½" Diameter	EA	240	$2.30	$552.00
Steel Beams (4)	W18x35	LF	120	$56.96	$6,835.20
Steel Girders (2)	W24x62	LF	60	$95.66	$5,739.60
Steel Columns (2)	W10x49	LF	60	$79.38	$4,762.80
Additional Fireproofing	-	-	-	-	-
*Cost provided by Centre Concrete Co. All other costs were taken from RS Means				**TOTAL**	**$23,640.69**

With the redesign of lightweight to normal weight concrete, the price per typical bay slightly increased. The proposed normal weight concrete design of a typical 30'x30' bay costs about $23,640. Table 5.5 summarizes the cost breakdown of the proposed design.

Table 5.5 –Cost Summary of Typical Bay for Proposed Design

2" Decking with NW Concrete					
Item Description	**Size**	**Units**	**Qty.**	**Cost**	**Total**
NW Concrete Material (3,000psi)	4.5"	CY	15.3	$102.00	$1,560.60
Concrete Placing	<6"	CY	15.3	$37.00	$566.10
Concrete Reinforcing	6x6 W2.1xW2.1	SF	900	$0.43	$387.00
Composite Metal Decking	2VLI18	SF	900	$3.79	$3,411.00
Shear Studs	½" Diameter	EA	240	$2.30	$552.00
Steel Beams (4)	W18x35	LF	120	$56.96	$6,835.20
Steel Girders (2)	W24x68	LF	60	$104.16	$6,249.60
Steel Columns (2)	W10x49	LF	60	$79.38	$4,762.80
Additional Fireproofing	-	-	-	-	-
*Cost provided by Centre Concrete Co. All other costs were taken from RS Means				**TOTAL**	**$24,324.30**

As seen in the tables above, a typical bay of the proposed design of normal weight concrete costs around $680 more than that off the existing system. All material quantities, with the exception of concrete, remained the same between both systems. Even though there was an increase in concrete material in the proposed normal weight system, it still resulted in a slightly lower concrete material cost. Concrete costs proved to be similar between both designs, although the additional 360 lbs of steel per bay in the proposed design will greatly increase the system's cost.

Multiplying these costs by the amount of bays in this building (40), we obtained an overall cost for each system. Table 5.6 provides a side-by-side comparison between the overall costs of each system.

Table 5.6 –Overall Cost Comparison between Proposed and Current Design

Overall Cost Comparison			
Item Description	**System A: Proposed NW**	**System B: Existing LW**	**Cost Ratio (A/B)**
Concrete Material & Placing	$85,068.00	$80,643.60	1.05
Concrete Reinforcing	$15,480.00	$12,960.00	1.19
Composite Metal Decking	$136,440.00	$136,440.00	1.00
Headed Shear Stud Connectors	$22,080.00	$22,080.00	1.00
Structural Steel Framing	$713,904.00	$693,504.00	1.03
Additional Fireproofing	-	-	-
TOTAL	**$972,972.00**	**$945,627.60**	**1.03**

Costs taken from 30x30' Typical Bay Detailed Estimate (Assuming 40 Bays)

As seen in the table above, changing the floor slab's lightweight concrete to normal weight concrete increases the project's cost by $27,344. A cost ratio aids in understanding how the prices compare between the two systems. The cost ratios that fall below 1.0 represent a cost decrease in that specific item, while ratios above 1.0 indicate a cost increase for that item. After taking into consideration the overall cost difference between both systems, it has been determined that the proposed normal weight system increases the cost by 3% to that of the original design.

SCHEDULE EVALUATION

Considering that both systems will require the same quantity of structural members, the current project schedule should remain the same. Lightweight concrete is poured, finished and cured in the same manner as normal concrete. Even though there the proposed system would require additional 3.51 cubic yards of concrete, this should not induce any substantial changes to the current project schedule.

CONSTRUCTION IMPLICATIONS

We have compared earlier the advantages and disadvantage of using both lightweight and normal weight concrete in a project. In this section, we will address some of the construction implications that may arise from changing the building's floor slab from lightweight to normal weight concrete. It is important to keep these in mind when determining whether such change would be beneficial for a project. The main three construction implications identified throughout this analysis are: Member deflections, slab moisture content, and plenum ceiling height.

1. Floor-to-Floor Height:

   Changing the lightweight concrete to normal concrete increases the composite slab thickness by 1.25". Speaking with the project team, it was determined that this loss of floor-to-floor height could be absorbed by the ceiling plenum. The current ceiling plenum, which houses all the facility's mechanical, electrical, and plumbing services, is 5'8" from the bottom of the floor slab to the dropped ceiling. Decreasing the plenum space by 1.25" would only make the space a little tighter without compromising the installation of the MEP equipment located in the ceiling plenum. Therefore, changing to normal weight concrete will not present any major changes to the overall building height.

2. Beam Deflections:

   The main concern with using normal over lightweight concrete is the addition of weight to the building's structure. Having a thicker slab comprised of highly dense concrete can create beam deflections. Checking for these deflections was a major step in sizing the structural steel members for this analysis, as they may have a huge impact on the structure's serviceability. As discussed earlier, having excessive deflections may cause sagging floors, vibrations, and decrease plenum space height. This is always a concern since it can present challenges with fitting of floors, windows, and equipment on the ceiling plenum. Additional efforts may be required in order to address these issues later on the project. Excessive vibrations may also interfere with equipment operation, and even result in failure of the building's structure. Hence, it is very important to address this issue in determining the feasibility of the proposed design. Through a structural analysis, it was determined that the maximum beam deflection caused by the beam loading was smaller than the maximum permissible dead and live load deflection (L/240). The structural members are sized properly to withstand the increase in weight caused by the normal weight concrete. Therefore, deflection will not be of any concern when changing the lightweight to normal weight concrete for the building's raised floor slab.

3. Improvement in Quality Control – Moisture Content & Fireproofing

   Even though lightweight concrete may significantly reduce the loads on a building's structure, there were a few quality control issues identified with using lightweight concrete on floor slabs. Based on discussions with experts, lightweight concrete may usually result in unsatisfactory outcomes with regards to moisture content and fireproofing upon placement.

   As discussed earlier, lightweight concrete has an increased capacity for moisture absorption. It will continue to soak up moisture for weeks after being wetted for the curing process, therefore taking up two to three times longer than regular concrete to dry.[16] It is because of this that the Floor Covering Installation Contractors Association (FCICA) recommend designers not to specify lightweight structural concrete for floor decking, as the risks of moisture-related problems associated with this concrete outweigh the possible benefits. In this project, the project team faced some challenges to meet the acceptable moisture content installation for the building's second floor slab, which cost them over $102,000 in order to resolve the problem; using normal weight concrete instead may have helped in deferring from the setbacks to project's cost and schedule.

   Industry professional Edward Gannon explained how lightweight concrete can also present issues with fireproofing upon placement. Because lightweight concrete has an increased air volume content, it has better insulation properties than normal weight concrete. Nevertheless, the concrete's density may vary greatly from the mixing to concrete placement. If not mixed with the required water-cement ratio and pumped under adequate pressure, water can be driven in between the air aggregates. This will result in decreasing the concrete's volume, therefore increasing its density from the intended 110pcf. Even a small increase in density can have a large impact on the assembly's fire rating. Consistent testing has to be performed when placing the lightweight concrete to confirm that it will meet the minimum required fire rating without the need of additional fireproofing.

Normal weight concrete, in general, may be beneficial to the project as it provides a much more reliable performance than lightweight concrete upon placement. As Ed Gannon says, normal weight concrete is a much safer, straightforward method; it requires a less stringent quality control in order to attain the desired results with moisture content and fireproofing.

5.9 Conclusion & Recommendations

This analysis looked into reducing the total building cost through value engineering efforts on the composite floor slabs, while still maintaining the structural integrity of the medical office building. A typical 30' x 30' bay was evaluated in order to represent the entire structural system. Through a structural analysis it was determined that steel beams, columns, footings would not require any modification, although steel girders would have to be increased from W24x62 to W24x68. In addition to this modification, the proposed design requires an additional 1.25" layer of concrete to achieve the minimum 2 hour rating for the floor assembly. These modifications escalate the assembly cost by $27,344, or 3% to that of the original design. Negligible time would be added to the project regarding the structural portion, as both systems will require the same quantity of structural members.

Through extensive research and discussion with industry professionals, many of the risks of using lightweight concrete were exposed. Lightweight concrete can present many challenges with moisture content and fire protection if not mixed or pumped appropriately. These challenges can present setbacks to the project schedule or cost for dehumidification or additional fireproofing efforts, as it was experienced on this project.

Although the initial intent of this analysis was redesigning the structural system with normal concrete to reduce project costs, I now believe that this should be done because of the improved quality control in hand with normal concrete. Normal concrete may be beneficial to the project as it requires a less stringent quality control in order to attain the desired results with moisture content and fireproofing. Even though this method would cost the project team additional $27,344, I would definitely recommend it as it provides much more reliable performance than lightweight concrete upon placement.

6.0 MAE Requirements

The integrated BAE/MAE requirements for this thesis report were met by integrating some of the topics and materials discussed in the master's coursework into this project. The courses referenced included AE 597F [Virtual Facility Prototyping], AE 570 [Production Management in Construction], and AE 542 [Building Enclosure Science and Design]. The information from these two classes gave support to Analyses 1 and Analysis 2 of this report.

AE 597F: Virtual Facility Prototyping:

Throughout this master-level course, I have learned to use a variety of programs and tools, such as Revit Architecture, 3Ds Max, and most importantly Unity, which were essential to the completion of Analysis 1. The knowledge and modeling experience acquired throughout this course were fundamental in developing the virtual mockups for the operating and endoscopy rooms of this facility. Transferring between programs as well as textures and scripting were made possible because of the information learned in this class. Lack of knowledge in these programs and processes would have made the development of the virtual mockups impossible.

AE 570: Production Management in Construction

This master-level course focuses on the exploration of production management tools to efficiently manage the delivery of construction projects. One of the planning tools learned in the course was the 'House of Quality', which is a widely known tool in construction used to translate a client's need into a design. This tool was used in Analysis 2, and aided in identifying the most suitable prefabricated wall panel to be used for this analysis based on the owner's needs.

The second analysis focused on modularization, which was also a major topic of AE 570. Collaborative efforts are required of team members, and it was necessary to understand this whole process before planning how to manage the work. The information covered in this course helped determine what areas to focus on for the research, and effectively plan the design, transportation, coordination and erection of the prefabricated wall panels in order to enhance the construction of the building's enclosure.

AE 542: Building Enclosure Science And Design

Finally, coursework from the building enclosure master-level class was integrated in the prefabricated wall panel analysis. Throughout this course, we learned about the design principles of building enclosures and their impact on the building's performance. The H.A.M. tool used to model the wall assembly's thermal performance was introduced in this class. In addition, energy consumption and heat transfer calculations learned throughout this class were implemented in this analysis in order to recommend a reasonable alternative to the existing enclosure system.

7.0 Final Recommendations

Throughout the 2013/2014 academic calendar year, the Geisinger Grays Woods Ambulatory Care Campus Phase II project was examined to identify project challenges and propose alternative means and methods as solutions to those challenges. This senior thesis report was used to show the findings of the three topics analyzed: implementation of virtual mockups for the construction of the facility's operating and endoscopy rooms, prefabricating the building's façade, and re-evaluating the structural composite slab. These topics discussed were not actually implemented onto this project and research done was strictly performed based on the senior thesis requirements.

Analysis 1 - Virtual Mockups on Operating/Endoscopy Rooms:

This first analysis focused on evaluating the implementation of virtual mockups for the construction of this facility's operating and endoscopy rooms. After developing the virtual mockup and presenting it to the project team, it was determined that this could greatly benefit the project by allowing project stakeholders to address space layout prior to construction. The project team was very receptive to the idea of utilizing virtual mockups, and recognized that they could potentially cut down on time and costs that went into addressing the large number of change orders, RFI's, and design modifications for the construction of the patient and endoscopy rooms. Hence, virtual mockups should be implemented on the Geisinger Grays Woods project because they could potentially save cost, time, reduce risk, and solve design and constructability issues in advance of construction.

Analysis 2 – Brick Façade Prefabrication:

The second analysis evaluated an alternative modular system to the current stick-built exterior wall construction. A complete analysis of the building façade was performed using Nitterhouse's 'Architectural Precast Panels', with hopes of improving project schedule, cost, and building performance. Implementing precast panels would cost the project an additional $112,000 to the project budget, although it could reduce the project schedule by 3 weeks. In addition, the proposed prefabricated wall system could improve heat loss and heat gain by 20%. Nevertheless, I would not recommend the use of the prefabricated wall system as the increased cost and planning required for implementation outweigh the savings in schedule and improved building performance. Geisinger Health Systems puts as much emphasis in the overall project cost and schedule, and improving the project schedule over economic feasibility is not something that they would pursue.

Analysis 3 - Reevaluation of Structural Composite Slabs:

The third analysis attempted to reduce total building costs by changing the existing lightweight structural concrete slab to normal weight concrete, which is significantly cheaper. However, redesigning the structural system with normal weight concrete escalated the assembly's cost by $27,344, due to the upsizing in structural steel to support the additional loads.

Even though using normal weight concrete would increase project costs, I would still recommended it as it has proven to provide much more reliable performance than lightweight concrete. According to research, lightweight concrete can present many challenges with moisture content and fire protection if not mixed or pumped appropriately. These challenges can present setbacks to the project cost or schedule for dehumidification or additional fireproofing efforts, as it was experienced in this project. Normal concrete may be beneficial to the project as it requires a less stringent quality control in order to attain the desired results with moisture content and fireproofing. In addition, using regular concrete with a thicker floor slab can greatly improve a building's vibration performance, which is of great importance in healthcare facilities with highly-sensitive medical equipment.

Final Conclusion:

Two out of the three proposed analysis have been recommended to be applied to the Geisinger Grays Woods Ambulatory Care Campus project. Implementing virtual mockups and changing the composite floor slabs to normal weight concrete will help the construction of this facility to be more efficient, while achieving an improved quality end-product. Investing in these recommendations can help reduce risks that could potentially escalate the project's cost and schedule. A significant amount of experience was gained through these analyses, which will be beneficial when entering the design and construction industry.

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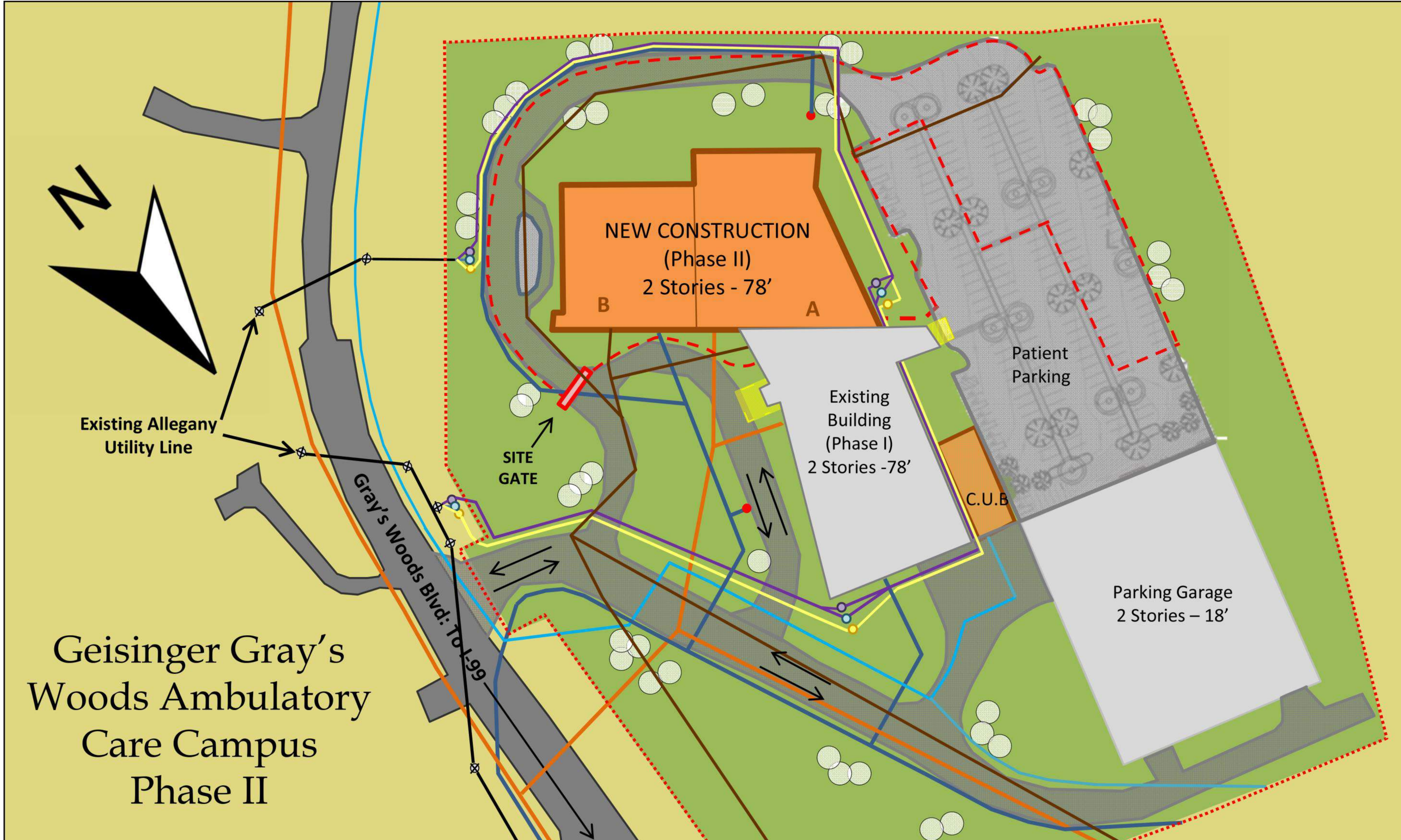
APPENDIX A

Existing Site Conditions



Geisinger Gray's Woods Ambulatory Care Campus Phase II

Existing Conditions Plan:

George Andonie
April 16, 2014

Legend:

- Property Line
- Site Fence
- Fire Hydrant
- Existing Trees
- New Building Construction
- Existing Structure
- Access Roads
- Patient Access
- Utility Pole
- Electric Junction Box
- Telecomm Junction Box
- TV Junction Box
- Alleghany Utility Line
- Electric Line
- Gas Line
- Telecomm & TV Line
- Water Line
- Sanitary Line
- Stormwater Line

APPENDIX B

Original Project Schedule

Activity Name	Original Duration	Start	Finish
Geisinger Grays Woods	686	01-Jun-11	06-Feb-14
Design Development	89	01-Jun-11	05-Oct-11
Design Development	89	01-Jun-11	05-Oct-11
Procurement	100	30-May-12	19-Oct-12
Obtain Site Permit	0	30-May-12	
Obtain Trailer Permit	0	04-Jun-12	
Obtain Garage & Building Fdtn. Permit	0	02-Jul-12	
Obtain Building Permit	0	19-Oct-12	
Construction	384	31-May-12	02-Dec-13
Site Mobilization	22	31-May-12	29-Jun-12
Temporary Fencing	1	31-May-12	31-May-
Temporary Parking Laydown	4	11-Jun-12	14-Jun-12
Construction Office Trailer	11	15-Jun-12	29-Jun-12
Garage Construction	108	05-Jul-12	05-Dec-12
Commence Garage Construction	0	05-Jul-12	
Complete Garage Construction	0		05-Dec-12
Rear Canopy Entrance	167	17-Aug-12	12-Apr-13
Rear Canopy - Caissons	2	17-Aug-12	20-Aug-12
Rear Canopy - Pedestals	4	11-Sep-12	14-Sep-12
Rear Canopy - Steel Structure	2	13-Nov-12	14-Nov-12
Rear Canopy - Envelope/Finishes	47	07-Feb-13	12-Apr-13
Building Sitework	31	27-Aug-12	09-Oct-12
Temporary parking Demolition	6	27-Aug-12	04-Sep-12
Mass Earthwork	6	30-Aug-12	07-Sep-12
Prepare Building Pad	4	05-Sep-12	10-Sep-12
Commence Building Construction	0	10-Sep-12	
Site Utilities - Stormwater,Electrical,Telecomm & Oxygen	12	10-Sep-12	25-Sep-12
Building Retaining Walls	10	26-Sep-12	09-Oct-12
Building Structure	80	10-Sep-12	02-Jan-13
West (Phase A)	68	10-Sep-12	13-Dec-12
Foundation Excavation	14	10-Sep-12	27-Sep-12
Foundations	14	14-Sep-12	03-Oct-12
Foundation Waterproofing	6	20-Sep-12	27-Sep-12
Backfill/Compact Foundations	14	24-Sep-12	11-Oct-12
Erect Structural Steel, 1st + Roof	8	22-Oct-12	31-Oct-12
Steel Detailing, 1st + Roof	3	01-Nov-12	05-Nov-12
Metal Decking - Floor & Roof	2	06-Nov-12	07-Nov-12
Slab on Deck - 2nd Floor	7	08-Nov-12	16-Nov-12
Underslab Electrical & Plumbing Rough-in	11	13-Nov-12	28-Nov-12
Slab on Grade Pour	8	04-Dec-12	13-Dec-12
East (Phase B)	66	28-Sep-12	02-Jan-13
Foundations Excavation	14	28-Sep-12	17-Oct-12
Foundations	14	02-Oct-12	19-Oct-12
Foundation Waterproofing	6	11-Oct-12	18-Oct-12
Backfill/Compact Foundations	14	15-Oct-12	01-Nov-12
Erect Structural Steel, 1st + Roof	8	01-Nov-12	12-Nov-12

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

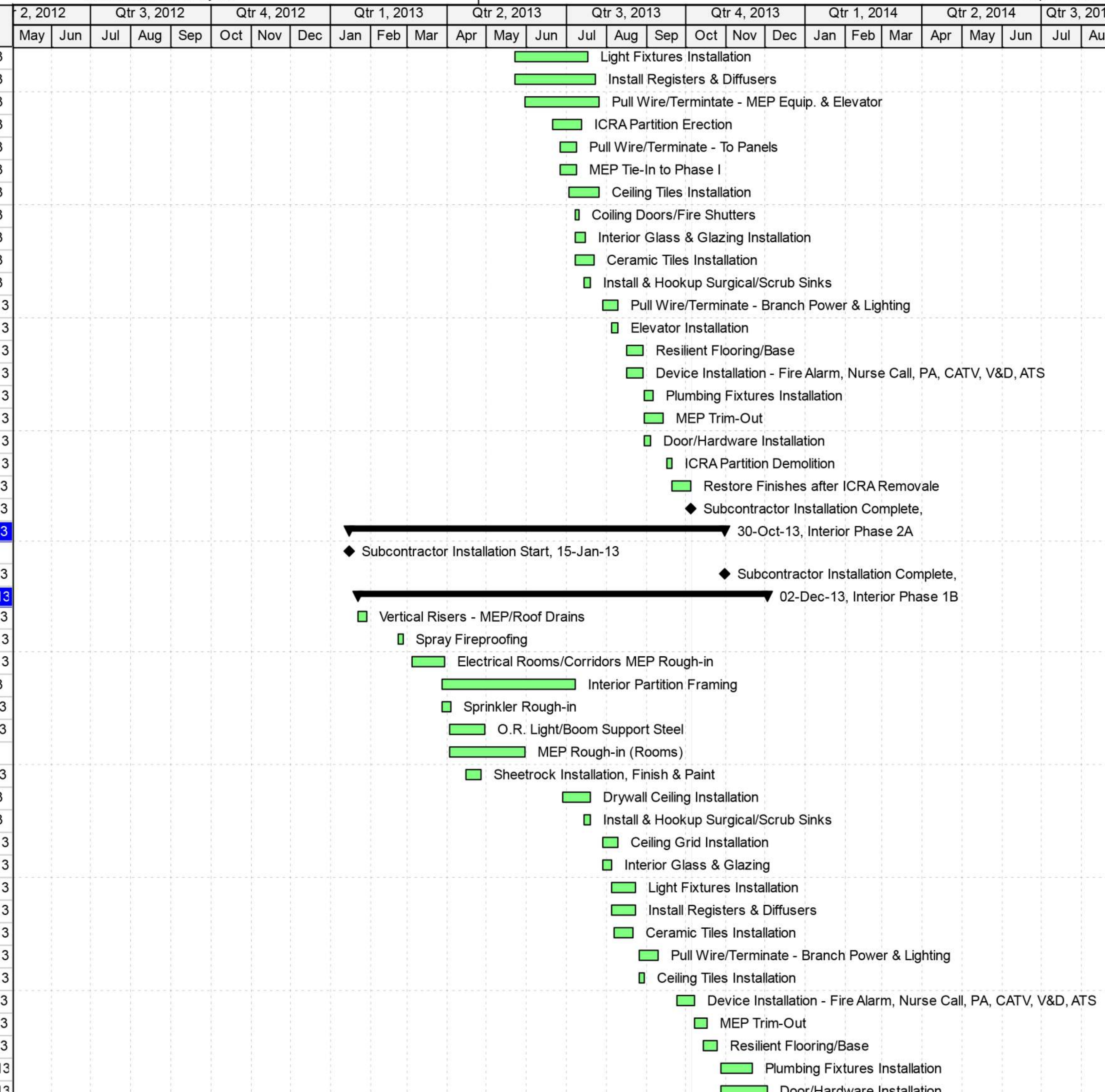
TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
Building Top-out	0		12-Nov-12
Steel Detailing, 1st + Roof	3	13-Nov-12	15-Nov-12
Metal Decking - Floor & Roof	9	16-Nov-12	29-Nov-12
Slab on Deck, 2nd Floor	9	20-Nov-12	03-Dec-12
Underslab Electrical & Plumbing Rough-in	10	29-Nov-12	12-Dec-12
Slab on Grade Pour	13	13-Dec-12	02-Jan-13
Building Envelope Mockup	**35**	**01-Oct-12**	**16-Nov-12**
Commence Building Envelope Mockup	0	01-Oct-12	
Complete Building Envelope Mockup	0		16-Nov-12
Building Envelope	**189**	**19-Nov-12**	**15-Aug-13**
Exterior Wall Framing	19	19-Nov-12	14-Dec-12
Roof Blocking, Parapet & Drain Installation	16	05-Dec-12	27-Dec-12
Exterior Wall Sheathing	14	11-Dec-12	31-Dec-12
Membrane Roofing	30	19-Dec-12	31-Jan-13
Air Vapor Barrier & Insulation	60	11-Feb-13	03-May-
Metal Panel Roofing	103	14-Feb-13	10-Jul-13
Brick Veneer/Flashing	103	07-Mar-13	31-Jul-13
Curtain Wall Installation	25	06-May-13	10-Jun-13
Install Skylights	21	10-Jun-13	09-Jul-13
Demolish Existing Building Facade	11	19-Jun-13	03-Jul-13
Perimeter Roofing after Brick Veneer	11	27-Jun-13	12-Jul-13
Snow Guard Installation	3	03-Jul-13	08-Jul-13
Roof Sheetmetal Flashing & Trim	12	08-Jul-13	23-Jul-13
Building Dried-in & Conditioned	0		30-Jul-13
Windows/Exterior Alumninum Entrances	11	23-Jul-13	06-Aug-13
Exterior Door Installation	5	23-Jul-13	29-Jul-13
Metal Panel Roof Screen Wall	9	24-Jul-13	05-Aug-13
Metal Panel Soffit and Eaves	7	24-Jul-13	01-Aug-13
Exterior painting	7	25-Jul-13	02-Aug-13
Facade Joint Sealants	11	01-Aug-13	15-Aug-13
CUP Building Work	**20**	**12-Jun-13**	**10-Jul-13**
Install New Heaters/Boilers	20	12-Jun-13	10-Jul-13
Install New Pumps/Chillers	6	12-Jun-13	19-Jun-13
Modify Existing Electrical Gear	5	12-Jun-13	18-Jun-13
Pull Wire/Terminate - Main Feeders to Building	5	19-Jun-13	25-Jun-13
Building Interior	**236**	**31-Dec-12**	**02-Dec-13**
Interior Phase 1A	**196**	**31-Dec-12**	**04-Oct-13**
Vertical Risers- MEP/Roof Drains	33	31-Dec-12	14-Feb-13
Elect. Room/Corridors MEP Rough-in	51	04-Jan-13	15-Mar-13
Spray Fireproofing	2	18-Feb-13	19-Feb-13
Install Elect. Room Equipment	10	25-Feb-13	08-Mar-13
Interior Partition Framing	14	04-Mar-13	21-Mar-13
Sprinkler Rough-in	5	04-Mar-13	08-Mar-13
MEP Rough-in (Rooms)	22	07-Mar-13	05-Apr-13
Drywall Ceiling Installation	24	22-Mar-13	24-Apr-13
Sheetrock Installation, Finish & Paint	71	28-Mar-13	08-Jul-13
Ceiling Grid Installation	38	16-May-13*	10-Jul-13

Legend: Actual Level of Effort; Actual Work; Remaining Work; Critical Remaining Work; Milestone; summary

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
Light Fixtures Installation	38	23-May-13	17-Jul-13
Install Registers & Diffusers	42	23-May-13	23-Jul-13
Pull Wire/Termintate - MEP Equip. & Elevator	41	30-May-13	26-Jul-13
ICRA Partition Erection	15	21-Jun-13	12-Jul-13
Pull Wire/Terminate - To Panels	9	26-Jun-13	09-Jul-13
MEP Tie-In to Phase I	9	26-Jun-13	09-Jul-13
Ceiling Tiles Installation	17	03-Jul-13	26-Jul-13
Coiling Doors/Fire Shutters	3	08-Jul-13	10-Jul-13
Interior Glass & Glazing Installation	6	08-Jul-13	15-Jul-13
Ceramic Tiles Installation	11	08-Jul-13	22-Jul-13
Install & Hookup Surgical/Scrub Sinks	5	15-Jul-13	19-Jul-13
Pull Wire/Terminate - Branch Power & Lighting	10	29-Jul-13	09-Aug-13
Elevator Installation	5	05-Aug-13	09-Aug-13
Resilient Flooring/Base	10	16-Aug-13	29-Aug-13
Device Installation - Fire Alarm, Nurse Call, PA, CATV, V&D, AT	10	16-Aug-13	29-Aug-13
Plumbing Fixtures Installation	4	30-Aug-13	05-Sep-13
MEP Trim-Out	10	30-Aug-13	13-Sep-13
Door/Hardware Installation	2	30-Aug-13	03-Sep-13
ICRA Partition Demolition	5	16-Sep-13	20-Sep-13
Restore Finishes after ICRA Removale	11	20-Sep-13	04-Oct-13
Subcontractor Installation Complete	0		04-Oct-13
Interior Phase 2A	**204**	**15-Jan-13**	**30-Oct-13**
Subcontractor Installation Start	0	15-Jan-13	
Subcontractor Installation Complete	0		30-Oct-13
Interior Phase 1B	**221**	**22-Jan-13**	**02-Dec-13**
Vertical Risers - MEP/Roof Drains	5	22-Jan-13	28-Jan-13
Spray Fireproofing	2	22-Feb-13	25-Feb-13
Electrical Rooms/Corridors MEP Rough-in	20	04-Mar-13	29-Mar-13
Interior Partition Framing	71	28-Mar-13	08-Jul-13
Sprinkler Rough-in	5	28-Mar-13	03-Apr-13
O.R. Light/Boom Support Steel	20	02-Apr-13	29-Apr-13
MEP Rough-in (Rooms)	42	02-Apr-13	30-May-
Sheetrock Installation, Finish & Paint	10	15-Apr-13	26-Apr-13
Drywall Ceiling Installation	15	28-Jun-13	19-Jul-13
Install & Hookup Surgical/Scrub Sinks	5	15-Jul-13	19-Jul-13
Ceiling Grid Installation	10	29-Jul-13	09-Aug-13
Interior Glass & Glazing	6	29-Jul-13	05-Aug-13
Light Fixtures Installation	15	05-Aug-13	23-Aug-13
Install Registers & Diffusers	15	05-Aug-13	23-Aug-13
Ceramic Tiles Installation	11	07-Aug-13	21-Aug-13
Pull Wire/Terminate - Branch Power & Lighting	10	26-Aug-13	09-Sep-13
Ceiling Tiles Installation	5	26-Aug-13	30-Aug-13
Device Installation - Fire Alarm, Nurse Call, PA, CATV, V&D, AT	10	24-Sep-13	07-Oct-13
MEP Trim-Out	8	08-Oct-13*	17-Oct-13
Resilient Flooring/Base	10	14-Oct-13*	25-Oct-13
Plumbing Fixtures Installation	19	28-Oct-13*	21-Nov-13
Door/Hardware Installation	25	28-Oct-13*	02-Dec-13



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

TASK filter: All Activities

Activity Name	Original Duration	Start	Finish
Subcontractor Installation Complete	0		08-Nov-13
Interior Phase 2B	191	29-Jan-13	25-Oct-13
Subcontractor Installation Start	0	29-Jan-13	
Subcontractor Installation Complete	0		25-Oct-13
Mechanical Yard Sitework	71	04-Apr-13	15-Jul-13
Install New Cooling Tower	3	04-Apr-13	08-Apr-13
Demolish/Replace Ductbank for Generator	15	24-Apr-13	14-May-
Install New Generator	7	16-May-13	24-May-
Oxygen Tank Foundations & Slab	5	03-Jul-13	10-Jul-13
Install Oxygen Bulk Storage Tank	1	15-Jul-13	15-Jul-13
Completion & Closeout	118	22-Aug-13	06-Feb-14
Testing & Balancing	20	22-Aug-13	19-Sep-13
MEP System testing	10	04-Oct-13	17-Oct-13
Final Commisioning	5	17-Oct-13*	23-Oct-13
Contractor Punchlist Inspection	20	16-Oct-13*	12-Nov-13
Install Booms & Medical Equipment	30	07-Nov-13*	19-Dec-13
Owner Punchlist Inspections	21	13-Nov-13*	12-Dec-13
Substantial Completion	0		02-Jan-14
Inspection - Centre Region Code Agency	11	18-Dec-13*	02-Jan-14
Inspection - Patton Township	11	18-Dec-13*	02-Jan-14
Inspection - Centre County Conservation District	11	18-Dec-13*	02-Jan-14
Inspection - University Area Joint Authority	11	18-Dec-13*	02-Jan-14
Inspection - SC Borough Water Authority	11	18-Dec-13*	02-Jan-14
Inspection -Department of health (DOH)	21	18-Dec-13*	16-Jan-14
Owner Move-In	0		06-Feb-14

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

TASK filter: All Activities

APPENDIX C

Detailed Project Costs

GEISINGER GRAY'S WOODS
AMBULATORY CARE CAMPUS PHASE II
PATTON TOWNSHIP
CENTRE COUNTY, PA

	GSS PTS CODE	ABC PHASE CODE	DESCRIPTION	Current Budget thru OCO#9	Current Subcontract / Committed Amounts	Current Allowances / Pending Sub CO's	Current Forecasted Savings
1	01A	01000	General Conditions	$ 2,080,506	$ 2,080,506	$ -	$ 174,202
2	01C	01030	Waste Management / Cleanup	$ 95,000	$ 4,846	$ 90,154	$ -
3	18B	01034	Engineering & Layout	$ 12,000	$ 8,699	$ 3,301	$ -
4	02A	02000	Site Excavation	$ 657,941	$ 583,103	$ 74,838	$ 63,500
5	02M	02329	Caissons	$ 48,800	$ 48,800	$ -	$ -
6	02A	02300	Structural Excavation	$ 796,021	$ 796,021	$ -	$ -
7	02B	02834	Paving	$ 313,230	$ 301,230	$ 12,000	$ -
8	02I	02840	Water Distribution	$ 55,511	$ 55,511	$ -	$ -
9	02J	02843	Storm Sewer	$ 340,314	$ 340,314	$ -	$ -
10	02H	02844	Sanitary Sewer	$ 14,880	$ 14,880	$ -	$ -
11	02R	02845	Fences/Gates/Bollards	$ 40,886	$ 40,886	$ -	$ -
12	02K	02852	Site Power & Communication	$ 167,590	$ 167,590	$ -	$ -
13	02C	02861	Site Concrete	$ 126,699	$ 126,699	$ -	$ -
14	02V	02863	Site Retaining Walls	$ 244,200	$ 244,200	$ -	$ -
15	02D	02900	Landscaping	$ 60,552	$ 60,552	$ -	$ -
16	03A	03000	Concrete Footings/Foundations	$ 935,421	$ 934,652	$ 769	$ 769
17	03B	03350	Concrete Slabs	$ 650,591	$ 650,591	$ -	$ -
18	03C	03400	Precast Concrete	$ 947,163	$ 947,163	$ -	$ -
19	04A	04000	Masonry	$ 674,093	$ 658,092	$ 16,001	$ 16,001
20	05A	05100	Structural Steel / Metal Decking	$ 1,213,187	$ 1,145,314	$ 67,873	$ 793
21	05A	05122	Steel Erection	$ 219,220	$ 219,220	$ -	$ -
22	05B	05500	Miscellaneous Metals	$ 126,481	$ 126,481	$ -	$ -
23	06A	06000	General Trades	$ 563,840	$ 410,463	$ 153,377	$ 27,732
24	07C	07100	Waterproofing / Dampproofing	$ 29,936	$ 29,936	$ -	$ -
25	07D	07500	Roofing & Sheetmetal	$ 444,616	$ 438,218	$ 6,398	$ -
26	09K	07522	Metal Panels	$ 312,250	$ 298,494	$ 13,756	$ -
27	07G	07730	Skylights	$ 97,597	$ 97,597	$ -	$ -
28	09J	07810	Fireproofing	$ 35,445	$ 35,445	$ -	$ -
29	07B	07900	Joint Protection / Sealants	$ 76,187	$ 76,187	$ -	$ -
30	08C	08000	Doors / Frames / Hardware	$ 505,597	$ 505,597	$ -	$ -
31	08G	08323	Coiling Doors	$ 90,160	$ 73,517	$ 16,643	$ 7,500
32	08D	08400	Entrances / Storefronts / Curtainwalls	$ 337,055	$ 337,055	$ -	$ -
33	08F	08821	Interior Glazing	$ 5,980	$ 5,980	$ -	$ -
34	09A	09250	Metal Studs / Drywall	$ 1,886,738	$ 1,886,738	$ -	$ -
35	09G	09321	Ceramic Tile	$ 157,748	$ 142,748	$ 15,000	$ -
36	09E	09510	Acoustical Ceilings	$ 217,285	$ 217,285	$ -	$ -
37	09F	09600	Flooring	$ 455,161	$ 375,161	$ 80,000	$ 25,000
38	09C	09900	Painting	$ 190,860	$ 175,860	$ 15,000	$ -
39	10D	10023	Cubicle Curtain Tracks	$ 42,051	$ 42,051	$ -	$ -
40	10F	10024	Louvers	$ 2,005	$ 2,005	$ -	$ -
41	10G	10025	Wall & Corner Guards	$ 271,572	$ 271,572	$ -	$ -
42	10E	10029	Lockers	$ 37,611	$ 37,611	$ -	$ -
43	10C	10030	Fire Extinguishers	$ 7,558	$ 7,558	$ -	$ -
44	10A	10800	Toilet Partitions & Accessories	$ 43,080	$ 43,080	$ -	$ -
45	10E	11027	Loading Dock Equipment	$ -	$ -	$ -	$ -
46	12C	12490	Window Treatments	$ 56,710	$ 36,548	$ 20,162	$ 15,000
47	15C	15300	Fire Protection	$ 200,041	$ 200,041	$ -	$ -
48	15B	15400	Plumbing	$ 1,515,591	$ 1,492,411	$ 23,180	$ 13,180
49	15E	15430	Medical Gas	$ 563,421	$ 563,421	$ -	$ -
50	15A	15700	HVAC	$ 3,648,511	$ 3,616,112	$ 32,399	$ 7,399
51	16A	16000	Electrical Power / Lighting	$ 3,044,829	$ 3,014,829	$ 30,000	$ 10,000
52	16B	16030	Site Lighting	$ 29,123	$ 29,123	$ -	$ -
53	16C	16600	Fire Alarm	$ 56,017	$ 56,017	$ -	$ -

GEISINGER GRAY'S WOODS
AMBULATORY CARE CAMPUS PHASE II
PATTON TOWNSHIP
CENTRE COUNTY, PA

	GSS PTS CODE	ABC PHASE CODE	DESCRIPTION	Current Budget thru OCO#9	Current Subcontract / Committed Amounts	Current Allowances / Pending Sub CO's	Current Forecasted Savings
54	16D	16002	Nurse Call	$ 128,849	$ 128,849	$ -	$ -
55	16F	16721	Public Address System	$ 54,991	$ 54,991	$ -	$ -
56	17A	16700	Communications	$ 230,648	$ 230,648	$ -	$ -
57	01A	19200	General Liability	$ 192,920	$ 192,920	$ -	$ -
58	18C	20000	CM Fee	$ 437,371	$ 437,371	$ -	$ -
				$ 25,789,640	**$ 25,118,789**	**$ 670,851**	**$ 361,076**

Contingency Update:

Design / Estimating Contingency thru OCO#9	$ -	
Owner Contingency thru OCO#9	$ -	
Construction Contingency thru OCO#9	$ 951,834	
Subtotal	**$ 951,834**	

Estimated Final Construction Cost:

Current Budget thru OCO#9	$ 25,789,640	
Current Anticpated GC and Allowance Savings	$ (361,076)	
Cost Events submitted	$ 15,339	
Estimate for identified Cost Events not submitted	$ 110,000	
Estimated Contingency required for balance of project	$ 400,000	
Total Estimate Final Construction Cost	**$ 25,953,903**	

Overall Project Summary:

Estimated Final Construction Cost	$ 25,953,903	
Backfill Budget for Scenery Park and Gray's Woods	$ 2,000,000	Per 5-31-13 GSS budget
GSS Costs	$ 6,224,157	Per 5-31-13 GSS budget
Furnishings and Equipment Budget	$ 5,220,500	Per 5-31-13 GSS budget
Total Current Overall Project Budget	**$ 39,398,560**	
Approved Project Budget	**$ 40,221,300**	
Delta	**$ (822,740)**	Budget Savings

APPENDIX D

General Conditions Estimate

General Conditions Estimate					
Cost Code*	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
	Project Team				
13113200200	Project Executive (Inflate 20% to PM)	7.2	Week	$3,096.00	$22,291.20
13113200200	Sr. Project Manager (Inflate 20% to PM)	23.76	Week	$2,580.00	$61,300.80
13113200200	Project Manager	72	Week	$2,150.00	$154,800.00
13113200200	MEP Project Manager	56	Week	$2,150.00	$120,400.00
13113200260	Site Superintendent	72	Week	$2,000.00	$144,000.00
13113200260	Ass. Site Superintendent (Deflate 20%)	55	Week	$1,600.00	$88,000.00
13113200120	Project Engineer	46	Week	$1,325.00	$60,950.00
13113200160	Corporate Safety Director	36	Week	$1,425.00	$51,300.00
13113200160	Senior Estimator	36	Week	$1,425.00	$51,300.00
13113200160	Accounting	36	Week	$1,425.00	$51,300.00
	Field Office				
15213200550	(4) Trailer Office Rental, Furnished, 50'x10'	72	Month	$340.00	$24,480.00
15213400100	Office Equipment & Supplies	18	Month	$200.00	$3,600.00
15213400140	Office Telephone, Avg.	18	Month	$81.00	$1,458.00
15213400160	Office Lights/HVAC, Avg.	18	Month	$152.00	$2,736.00
Avg. Mileage Cost	Vehicle Milage	2000	Miles	$0.57	$1,130.00
	Field Operations				
15113500130	Temporary Power, 400A	1	EA	$2,625.00	$2,625
15113800700	Temporary Water, Avg.	18	Month	$63.00	$1,134
15626500020	Temporary Fencing	3500	LF	$4.01	$14,035
15433406410	Temporary Toilets (3)	18	Month	549	$9,882
15613900110	Safety/Protection	18	Month	1200	$21,600
15613900100	Winter Protection	77560	SF	$1.53	$118,667
15813500020	Signage	500	SF	$34.00	$17,000
17123131100	Survey, 3 Person Crew	3	Day	$1,252.50	$3,758
Alexander Building	*Waste Management/Cleanup	$95,000	Ea	-	$95,000
	Insurance				
13113300050	Builder's Risk, Max.	0.64%	%	-	$167,680
Alexander Building	*General Liability	$192,920	Total	-	$192,920
13113900020	Performance Bonds, Max.	0.60%	%	-	$157,200
	Building Closeout				
14523500050	Testing Steel Building, Max.	1	Ea	$5,200.00	$5,200.00
19113500100	Basic Commisioning, Max.	0.5%	%	-	$131,000
*Testimates Based off Alexander Building Construction				**GRAND TOTAL**	**$1,776,746.30**

APPENDIX E

LEED Scorecard

LEED 2009 for Healthcare: New Construction & Major Renovations

Project Checklist

Geisinger Gray's Woods-Phase 2

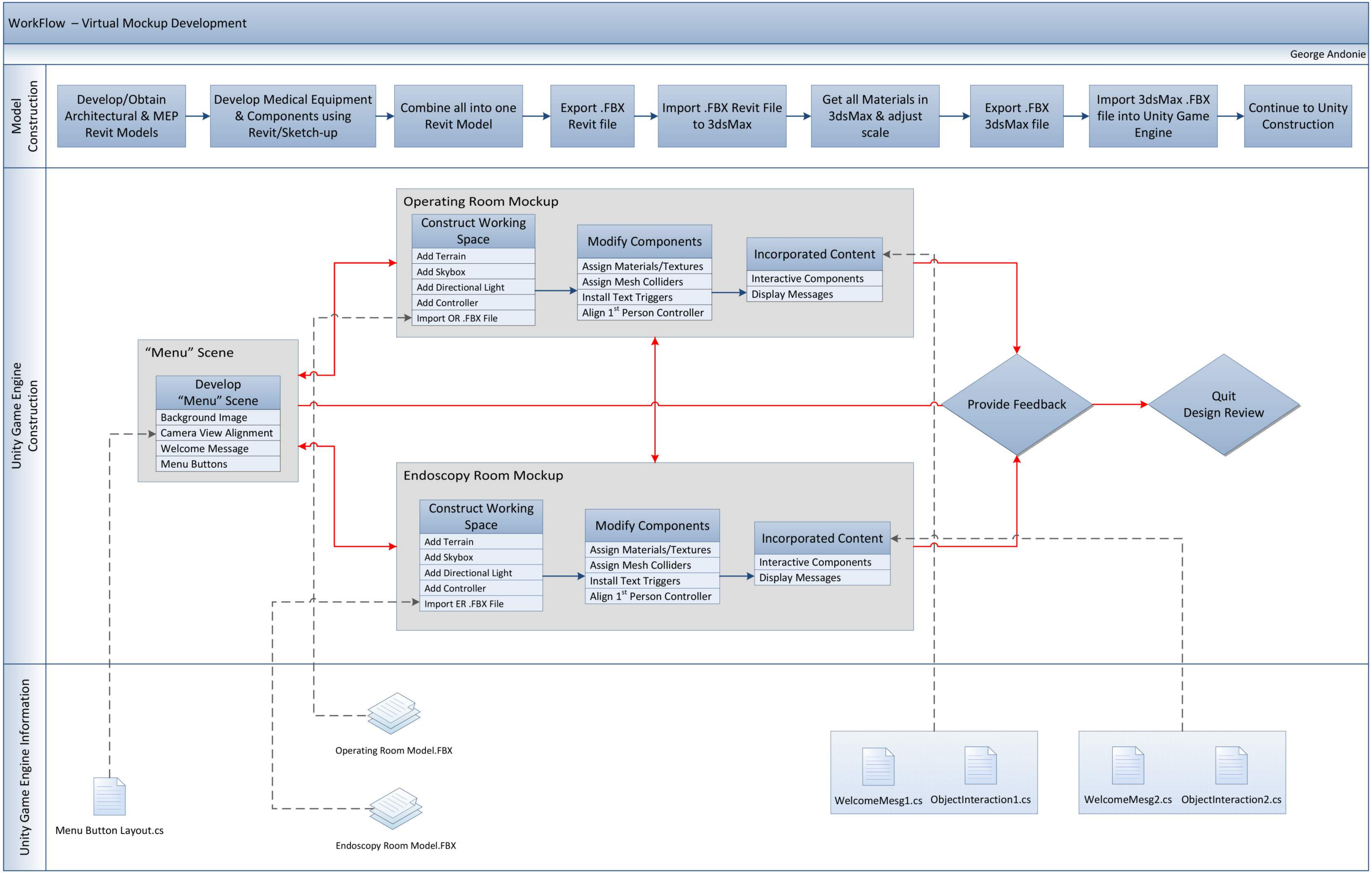
Addendum #8 Revised 7/27/2012

Y	?	N			
8	2	8	**Sustainable Sites**	**Possible Points:**	**18**
Y			Prereq 1	Construction Activity Pollution Prevention	
Y			Prereq 2	Environmental Site Assessment	
1			Credit 1	Site Selection	1
		1	Credit 2	Development Density and Community Connectivity	1
		1	Credit 3	Brownfield Redevelopment	1
3			Credit 4.1	Alternative Transportation—Public Transportation Access	3
		1	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
		1	Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	1
	1		Credit 4.4	Alternative Transportation—Parking Capacity	1
	1		Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
1			Credit 6.2	Stormwater Design—Quality Control	1
		1	Credit 7.1	Heat Island Effect—Non-roof	1
		1	Credit 7.2	Heat Island Effect—Roof	1
1			Credit 8	Light Pollution Reduction	1
		1	Credit 9.1	Connection to the Natural World—Places of Respite	1
		1	Credit 9.2	Connection to the Natural World—Direct Exterior Access for Patients	1
2	3	4	**Water Efficiency**	**Possible Points:**	**9**
Y			Prereq 1	Water Use Reduction—20% Reduction	
Y			Prereq 2	Minimize Potable Water Use for Medical Equipment Cooling	
1			Credit 1	Water Efficient Landscaping—No Potable Water Use or No Irrigation	1
	2		Credit 2	Water Use Reduction: Measurement & Verification	1 to 2
		3	Credit 3	Water Use Reduction	1 to 3
1			Credit 4.1	Water Use Reduction—Building Equipment	1
	1		Credit 4.2	Water Use Reduction—Cooling Towers	1
		1	Credit 4.3	Water Use Reduction— Food Waste Systems	1
9	9	21	**Energy and Atmosphere**	**Possible Points:**	**39**
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
7	4	13	Credit 1	Optimize Energy Performance	1 to 24
		8	Credit 2	On-Site Renewable Energy	1 to 8
1	1		Credit 3	Enhanced Commissioning	1 to 2
1			Credit 4	Enhanced Refrigerant Management	1
	2		Credit 5	Measurement and Verification	2
	1		Credit 6	Green Power	1
	1		Credit 7	Community Contaminant Prevention—Airborne Releases	1
12	0	4	**Materials and Resources**	**Possible Points:**	**16**
Y			Prereq 1	Storage and Collection of Recyclables	
Y			Prereq 2	PBT Source Reduction—Mercury	
		3	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
		1	Credit 1.2	Building Reuse—Maintain Interior Non-Structural Elements	1
2			Credit 2	Construction Waste Management	1 to 2
4			Credit 3	Sustainably Sourced Materials and Products	1 to 4
1			Credit 4.1	PBT Source Reduction—Mercury in Lamps	1
2			Credit 4.2	PBT Source Reduction—Lead, Cadmium, and Copper	2
2			Credit 5	Furniture and Medical Furnishings	1 to 2
1			Credit 6	Resource Use—Design for Flexibility	1
8	8	2	**Indoor Environmental Quality**	**Possible Points:**	**18**
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
Y			Prereq 3	Hazardous Material Removal or Encapsulation	
1			Credit 1	Outdoor Air Delivery Monitoring	1
	2		Credit 2	Acoustic Environment	1 to 2
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
1			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
4			Credit 4	Low-Emitting Materials	1 to 4
		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	Thermal Comfort—Design and Verification	1
	2		Credit 8.1	Daylight and Views—Daylight	2
	3		Credit 8.2	Daylight and Views—Views	1 to 3
4	2	0	**Innovation in Design**	**Possible Points:**	**6**
Y			Prereq 1	Integrative Project Planning and Design	
	1		Credit 1.1	Innovation in Design: Green Advantage Training	1
1			Credit 1.2	Innovation in Design: Green Kiosk Education & Booklet	1
	1		Credit 1.3	Innovation in Design: Green Power 100%, Green Power 200%	1
1			Credit 1.4	Innovation in Design: Smart Certification, Green Housekeeping	1
1			Credit 2	LEED Accredited Professional	1
1			Credit 3	Integrative Project Planning and Design	1
2	2	0	**Regional Priority Credits**	**Possible Points:**	**4**
1			Credit 1.1	Regional Priority: WEc1	1
	1		Credit 1.2	Regional Priority: SSc4.4	1
1			Credit 1.3	Regional Priority: SSc6.1	1
	1		Credit 1.4	Regional Priority: WEc2	1
45	26	39	**Total**	**Possible Points:**	**110**

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

APPENDIX F

Virtual Mockup Workflow Diagram

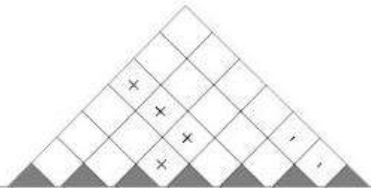


WorkFlow – Virtual Mockup Development
George Andonie
Model Construction
Develop/Obtain Architectural & MEP Revit Models
Develop Medical Equipment & Components using Revit/Sketch-up
Combine all into one Revit Model
Export .FBX Revit file
Import .FBX Revit File to 3dsMax
Get all Materials in 3dsMax & adjust scale
Export .FBX 3dsMax file
Import 3dsMax .FBX file into Unity Game Engine
Continue to Unity Construction
Unity Game Engine Construction
Operating Room Mockup
Construct Working Space
Add Terrain
Add Skybox
Add Directional Light
Add Controller
Import OR .FBX File
Modify Components
Assign Materials/Textures
Assign Mesh Colliders
Install Text Triggers
Align 1st Person Controller
Incorporated Content
Interactive Components
Display Messages
"Menu" Scene
Develop "Menu" Scene
Background Image
Camera View Alignment
Welcome Message
Menu Buttons
Provide Feedback
Quit Design Review
Endoscopy Room Mockup
Construct Working Space
Add Terrain
Add Skybox
Add Directional Light
Add Controller
Import ER .FBX File
Modify Components
Assign Materials/Textures
Assign Mesh Colliders
Install Text Triggers
Align 1st Person Controller
Incorporated Content
Interactive Components
Display Messages
Unity Game Engine Information
Operating Room Model.FBX
Endoscopy Room Model.FBX
Menu Button Layout.cs
WelcomeMesg1.cs
ObjectInteraction1.cs
WelcomeMesg2.cs
ObjectInteraction2.cs

APPENDIX G

House of Quality Diagram

Interrelationship matrix



Owner Requirements / Design Requirements	Assembly Location (Miles)	Insulation Properties (R-Value)	Impact Resistant (Relative)	Face Material Aesthetic (Relative)	Cost of Panel ($)	Installation Time (SF/Hr)	Component Weight (Lbs/SF)	Customer Rating (1-6)	Weighted Importance (%)
Exterior Matches Existing			△ 30	◎ 270				1	30%
Low Construction Cost	○ 60	△ 20	△ 20	△ 20	◎ 180			2	20%
Short Installation Schedule	○ 48					◎ 144	○ 48	3	16%
Good Insulation Performance		◎ 126					△ 14	4	14%
Durable Wall Exterior		○ 36	◎ 108		△ 12			5	12%
Maintenance Free Wall Assemblies		△ 8	○ 24		△ 8			6	8%
Total (Σ *Column*)	108	190	182	290	200	144	62	1176	
Total (% Column)	9.2	16.2	15.5	24.7	17.0	12.2	5.3	100%	
Existing Wall Performance (Units)	0	25.1	-	-	40.3	103	54		
HighConcrete Performance (Units)	160	20	-	-	38.4	560	100		
NitterHouse Performance (Units)	100	31.2	-	-	48.2	600	87.5		
PBVS Performance (Units)	20	25	-	-	52	300	54		
HighConcrete Panel Ranking	0.6	0.6	0.6	0.6	1	0.8	0.6	814.4	
NitterHouse Panel Ranking	0.8	1	0.8	0.8	0.8	1	0.8	**1007.6**	
PBVS Wall Assembly Ranking	1	0.8	1	1	0.6	0.6	1	1000.4	

TOTAL VALUE:
$\Sigma(\Sigma\, Column^{*}\, Rank)$
Highest Value = Most Suitable Panel

***Correlation Matrix:**
+ Positive Correlation
- Negative Correlation

***Weighting Factors:**
◎ Strong (9)
○ Moderate (3)
△ Weak (1)

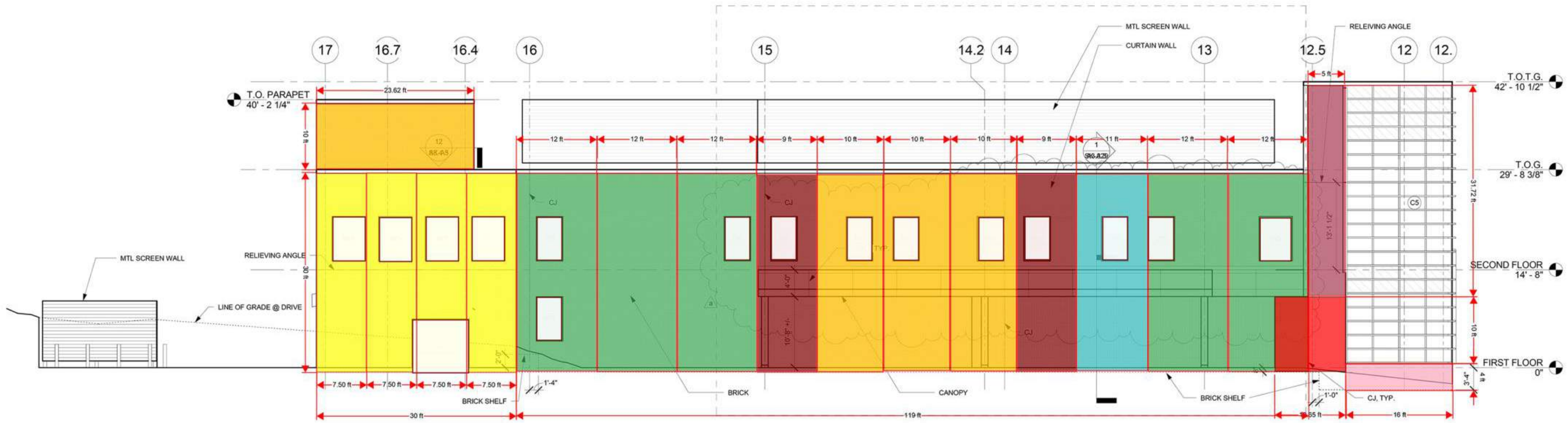
***Customer Rating:**
6 High, 1 Low

***Panel Rank Weights:**
1.0 = Best
0.8 = Second Best
0.6 = Third Best

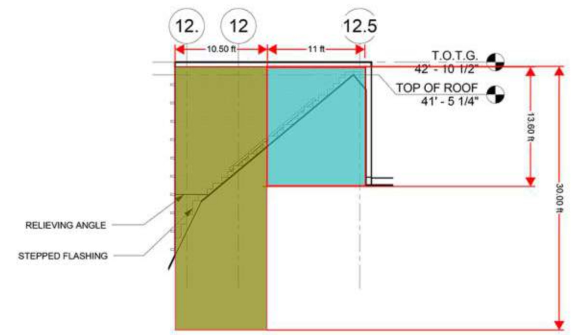
*Note: Values for panel costs, duration, and weight are relative and are used for performance comparison purposes only.

APPENDIX H

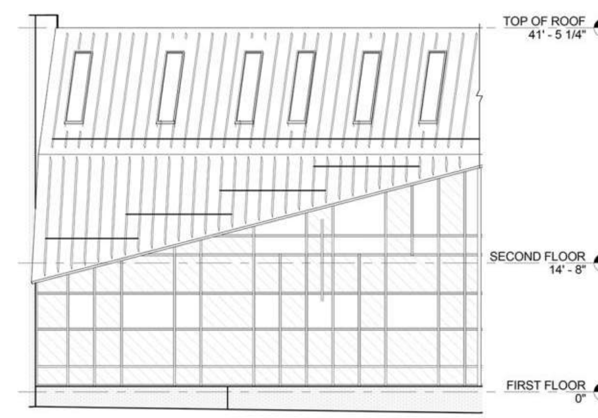
Panel Breakdown Layout



4 EAST ELEVATION
SCALE: 1/8" = 1'-0"



3 TOWER WEST ELEVATION
SCALE: 1/8" = 1'-0"



2 FLATTENED NORTH ELEVATION
SCALE: 1/8" = 1'-0"

1 NORTH ELEVATION
SCALE: 1/8" = 1'-0"

EWING COLE

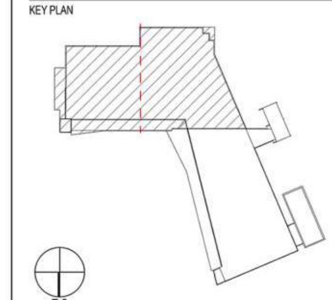
Federal Reserve Bank Building
100 North 6th Street
Philadelphia, PA 19106-1590
Tel: 215-923-2020 Fax: 215-574-0952

CONSULTANTS

GENERAL NOTES

1. ALIGN TOP OF RIDGE OF STANDING SEAM ROOF W/ EXISTING TOP OF RIDGE, U.N.O.
2. ALIGN TOP OF GRAVEL STOP W/ EXISTING TOP OF GRAVEL STOP, U.N.O.
3. ALIGN HORIZONTAL MULLION OF CURTAIN WALL WITH EXISTING CURTAIN WALL MULLIONS, U.N.O.
4. PROVIDE BRICK RELIEVING ANGLE @ 2ND FLR. WHERE F.O. BRICK IS LESS THAN 2'-0" FROM GRID. (a)

KEY PLAN



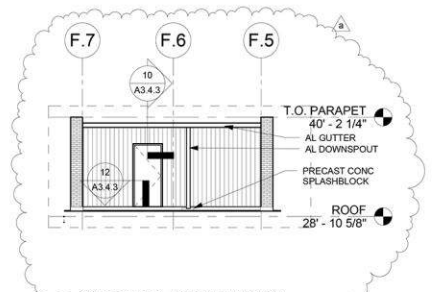
PROJECT MANAGER
Patrick Brunner
PROJECT ARCHITECT
Ramon Santos
PROJECT DESIGNER
John Chase
HEALTHCARE PLANNER
Natalie Miovski

REVISIONS

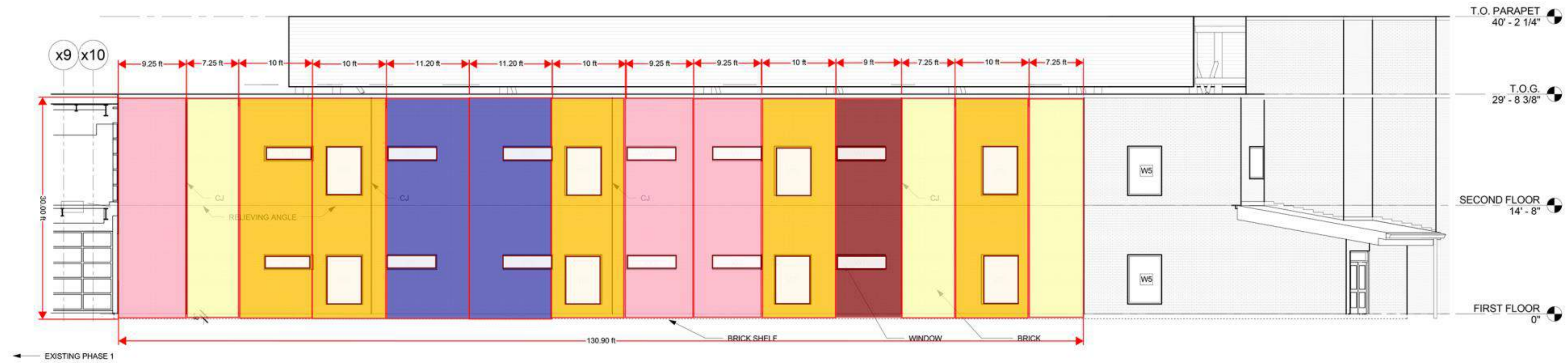
NO.	BY	DESCRIPTION	DATE
a		ADDENDUM 2	03/09/2012

GEISINGER
GRAY'S WOODS
AMBULATORY CARE CAMPUS PHASE II
CONSTRUCTION DOCUMENTS
CORE AND SHELL

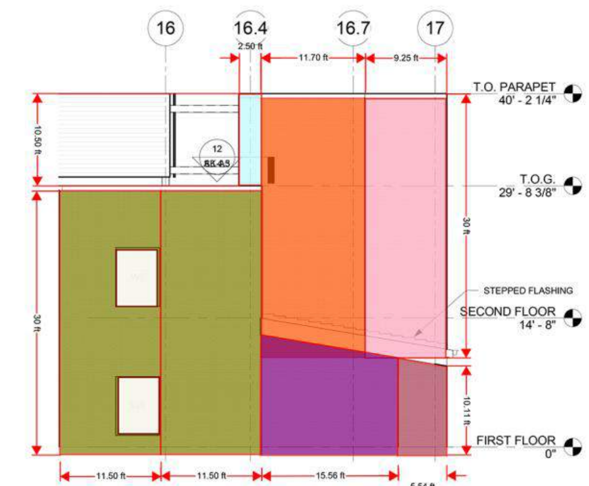
DRAWN BY DC DATE 02/08/2012
PROJECT NO. EC 20110397 SCALE 1/8" = 1'-0"
DRAWING NAME
ELEVATIONS
FLOOR/SECTION PHASE CD DRAWING NO. A3.1.1



4 SOUTH STAIR - NORTH ELEVATION
SCALE: 1/8" = 1'-0"



3 WEST ELEVATION
SCALE: 1/8" = 1'-0"



2 ANGLED WEST ELEVATION
SCALE: 1/8" = 1'-0"

1 SOUTH ELEVATION
SCALE: 1/8" = 1'-0"

C:\Revit Local Files\GGW2_CENTRAL_acliffiord.rvt
3/9/2012 11:55:52 AM

EWING COLE

Federal Reserve Bank Building
100 North 6th Street
Philadelphia, PA 19106-1590
Tel: 215-923-2020 Fax: 215-574-0952

CONSULTANTS

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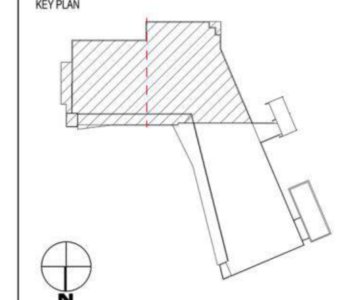
4. PROVIDE BRICK RELIEVING ANGLE @ 2ND FLR. WHERE F.O. BRICK IS LESS THAN 2'-0" FROM GRID.

KEY PLAN



PROJECT MANAGER
Patrick Brunner
PROJECT ARCHITECT
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PROJECT DESIGNER
John Chase
HEALTHCARE PLANNER
Natalie Miovski

REVISIONS

NO.	BY	DESCRIPTION	DATE
2		ADDENDUM 2	03/09/2012
1		ADDENDUM 1	02/08/2012

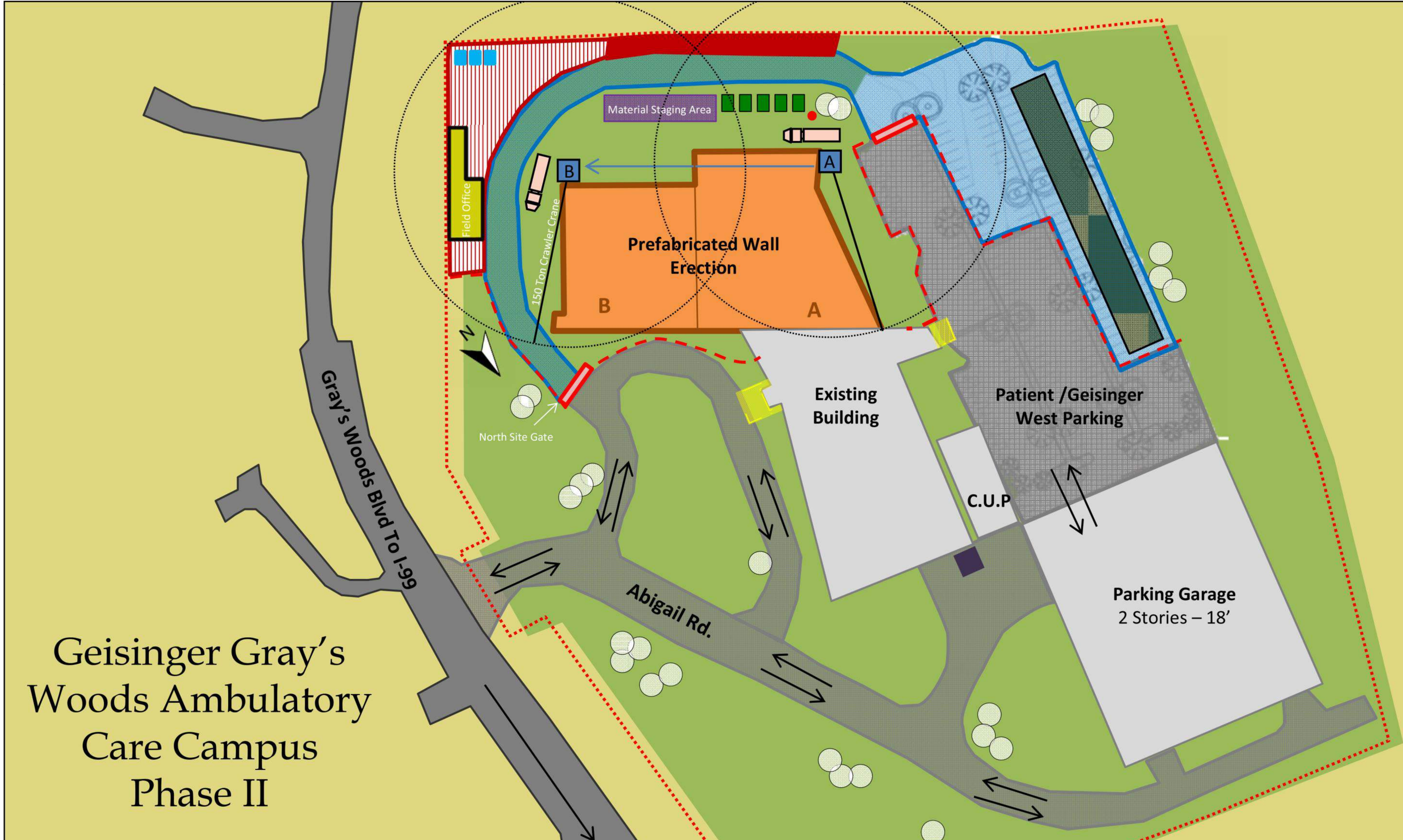
GEISINGER
GRAY'S WOODS

AMBULATORY CARE CAMPUS PHASE II
CONSTRUCTION DOCUMENTS
CORE AND SHELL

DRAWN BY DC DATE 02/08/2012
PROJECT NO. EC 20110397 SCALE 1/8" = 1'-0"
DRAWING NAME
ELEVATIONS
FLOOR/SECTION PHASE CD DRAWING NO. A3.1.2

APPENDIX I

Panel Erection Site Layout



Site Layout:

Structural Steel Erection

George Andonie

April 16, 2014

Legend:

- Property Line
- Site Fence
- Existing Transformer
- Existing Trees
- New Construction
- Existing Structure
- Site Gate
- Patient Access Roads
- Patient Access
- Material Staging Area
- Alexander Field Office
- Subcontractor Field Offices
- Construction Access Only
- Construction Personnel Parking
- Material Storage Trailers
- Portable Toilets
- Recycle Bins/ Dumpster
- 150 Ton Crawler Crane

APPENDIX J

Panel Thermal Properties Specification

DATE 02/19/14	DESIGN MTT	NITTERHOUSE CONCRETE PRODUCTS, INC. P.O. BOX N, CHAMBERSBURG, PA 17201		SHEET 1
REVISED	CHECK	JOB	FOR	JOB NO. -

Thermal Properties For Composite Sandwich Wall Panels

		"R"
	Exterior Air Film (Winter)	0.17
4.00 in	Exterior Concrete Wythe (0.075 per inch)	0.30
2.00 in	Polyisocyanurate	13.00
3.00 in	Interior Concrete Wythe (0.075 per inch)	0.23
	Interior Air Film	0.68
	Σ	14.38

Expanded Polystyrene (2 pcf) =	4.35/in
Extruded Polystyrene (2 pcf) =	5.00/in
Polyisocyanurate =	6.50/in

Nominal "R" Value For Panels Is 14

Calculation of "R" Value due to Thermal Bridging

Per the *PCI Design Handbook* (6th Edition), Section 9.1.8:

The net effect of metal ties is to increase the U value by 10 to 15%, depending on size and spacing:

Metal ties @ 4'-0" o.c., increase U by 14%

Nominal U = 1/R = 0.06957

Increase U by 14 %

Modified U Value = 0.0793

Modified R Value due to thermal bridging through metal ties: 12.6

Note: NCP has provided thermal calculations for the precast panels to assist the design team in determining the overall thermal envelope of the exterior walls as comprised of precast panels, panel joints, windows, doors, etc…

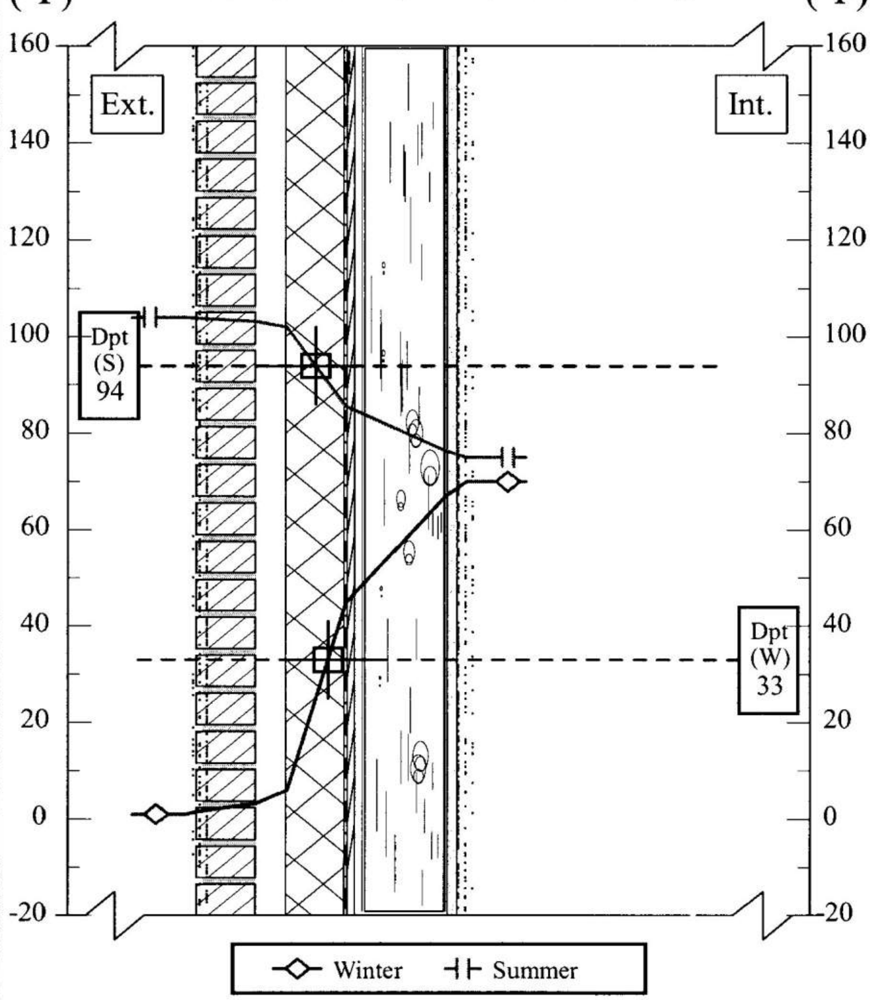
APPENDIX K

H.A.M. Analyses Results

R VALUE ANALYSIS

The Heat, Air and Moisture Building Science Toolbox - V.1B-E/U (11)

WALL SECTION AND TEMPERATURE GRADIENTS



PROJECT

Name	Geisinger Grays Woods
Number	001
City	Port Matilda, PA
Date	2/20/2014
Analysis by:	George Andonie
Wall Type	
Option	

CLIMATIC CONDITIONS

	Winter		Summer	
	Int.	Ext.	Int.	Ext.
Temp (°F)	70	1	75	104
RH (%)	25	67	50	72
DPT (°F)	33	-6	56	94

PENNSYLVANIA STATE UNIVERSITY

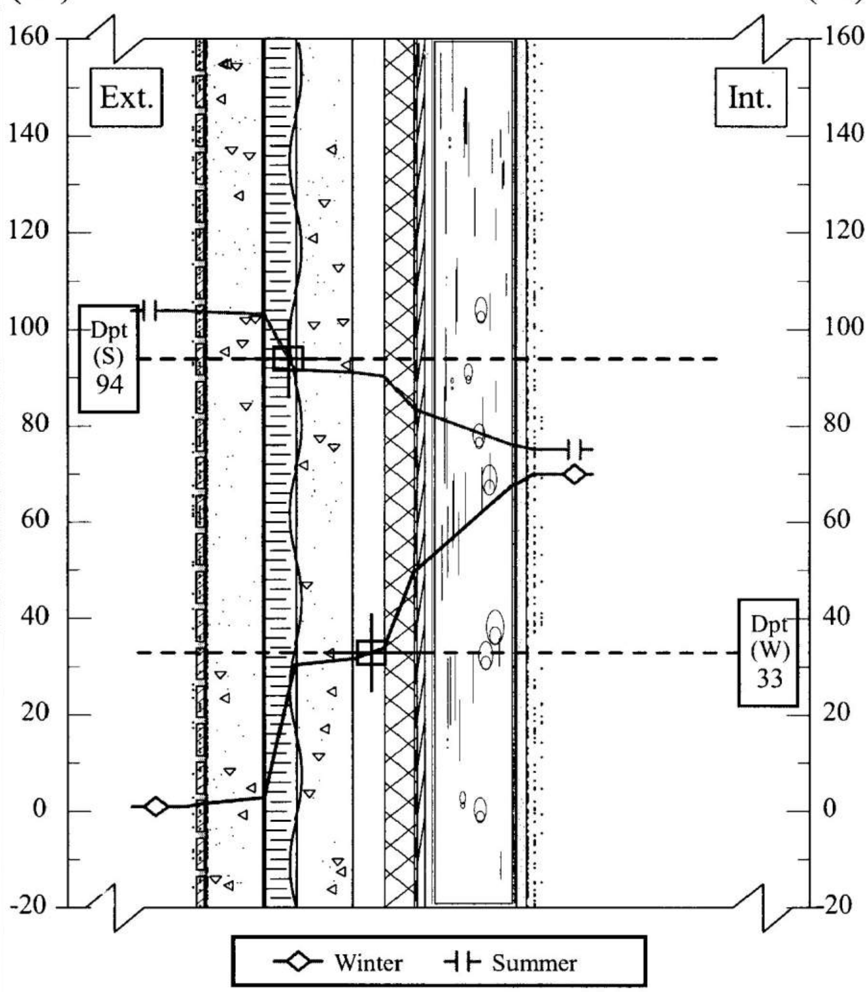
104 ENGINEERING, UNIT A
UNIVERSITY PARK, PA, USA, 16802

	Generic Material	Manufacturer	Model No.	Thick (in.)	RVal (R)	W.Temp. (°F)	S.Temp. (°F)
1	air film (ext), 3/4 in.	No Recor...	Generic...	0.75	0.17	1.5	103.8
2	brick (TTW), 4 in.	No Recor...	Generic...	4.00	0.64	3.2	103.1
3	cavity, 2 in.	No Recor...	Generic...	2.00	0.98	5.9	101.9
4	semi-rigid ins., 4 in.	No Recor...	Generic...	4.00	14.24	45.0	85.5
5	membrane (#1), .080 in.	No Recor...	Generic...	0.08	0.07	45.2	85.4
6	plywood shtg., 1/2 in.	No Recor...	Generic...	0.50	0.64	47.0	84.7
7	framing, 2x6s, 6 in.	No Recor...	Generic...	6.02	7.28	67.0	76.3
8	gypsum bd., 5/8 in., (#1)	No Recor...	Generic...	0.63	0.46	68.3	75.7
9	air film (int), 3/4 in.	No Recor...	Generic...	0.75	0.64	70.0	75.0
	Total or (Layer 0)			17.23	25.11	(1.0)	(104.0)

R VALUE ANALYSIS

The Heat, Air and Moisture Building Science Toolbox - V.1B-E/U (11)

WALL SECTION AND TEMPERATURE GRADIENTS



PROJECT

Name	Geisinger Grays Woods
Number	001
City	Port Matilda, PA
Date	2/20/2014
Analysis by:	George Andonie
Wall Type	
Option	

CLIMATIC CONDITIONS

	Winter		Summer	
	Int.	Ext.	Int.	Ext.
Temp (°F)	70	1	75	104
RH (%)	25	67	50	72
DPT (°F)	33	-6	56	94

PENNSYLVANIA STATE UNIVERSITY

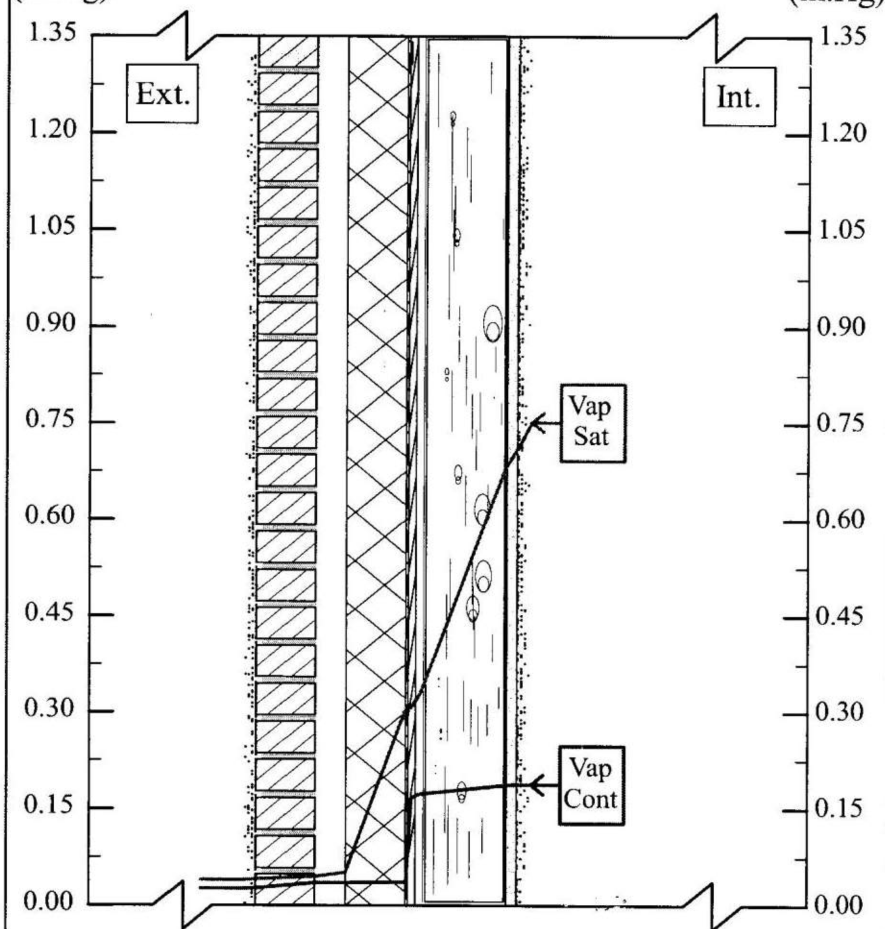
104 ENGINEERING, UNIT A
UNIVERSITY PARK, PA, USA, 16802

	Generic Material	Manufacturer	Model No.	Thick (in.)	RVal (R)	W.Temp. (°F)	S.Temp. (°F)
1	air film (ext), 3/4 in.	No Recor...	Generic...	0.75	0.17	1.4	103.8
2	brick, facing, 1/2 in.	No Recor...	Generic...	0.50	0.12	1.6	103.7
3	concrete wall, 4 in.	No Recor...	Generic...	4.00	0.58	2.9	103.2
4	ureth.(int.) insul., 2 in.	No Recor...	Generic...	2.00	12.34	30.4	91.6
5	concrete wall, 4 in.	No Recor...	Generic...	4.00	0.58	31.7	91.1
6	cavity, 2 in.	No Recor...	Generic...	2.00	0.98	33.9	90.2
7	semi-rigid ins., 2 in.	No Recor...	Generic...	2.00	7.12	49.8	83.5
8	membrane (#1), .080 in.	No Recor...	Generic...	0.08	0.07	49.9	83.4
9	plywood shtg., 1/2 in.	No Recor...	Generic...	0.50	0.64	51.3	82.8
10	framing, 2x6s, 6 in.	No Recor...	Generic...	6.02	7.28	67.6	76.0
11	gypsum bd., 5/8 in., (#1)	No Recor...	Generic...	0.63	0.46	68.6	75.6
12	air film (int), 3/4 in.	No Recor...	Generic...	0.75	0.64	70.0	75.0
	Total or (Layer 0)			21.73	30.97	(1.0)	(104.0)

CONDENSATION ANALYSIS

The Heat, Air and Moisture Building Science Toolbox - V.1B-E/U (11a)

WALL SECTION AND VAPOUR PRESSURE GRADIENTS



** NO CONDENSATION **

PROJECT

Name	Geisinger Grays Woods
Number	001
City	Port Matilda, PA
Date	2/20/2014
Analysis by:	George Andonie
Wall Type	
Option	

CLIMATIC CONDITIONS

	Winter		Summer	
	Int.	Ext.	Int.	Ext.
Temp (°F)	70	1	—	—
RH (%)	25	67	—	—
DPT (°F)	33	-6	—	—

PENNSYLVANIA STATE UNIVERSITY

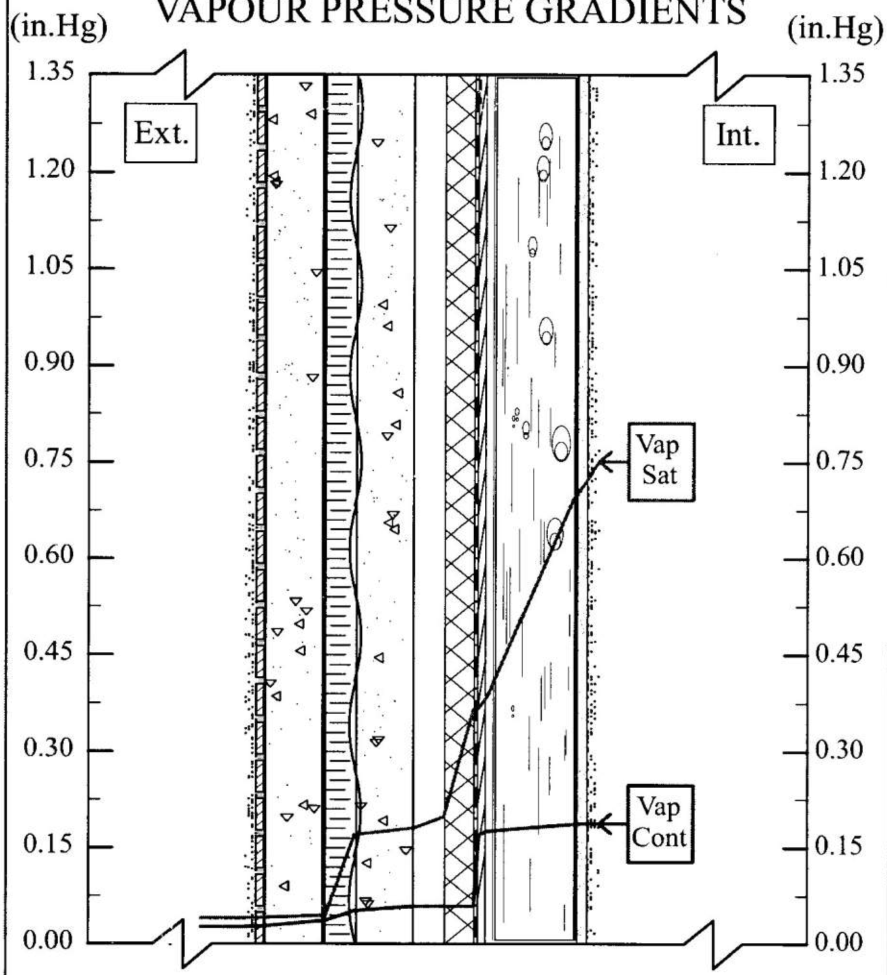
104 ENGINEERING, UNIT A
UNIVERSITY PARK, PA, USA, 16802

	Material	Manufacturer	Model No.	Rvap (1/M)	Temp (°F)	VapSat (in.Hg)	VapCont (in.Hg)
1	air film (ext), 3/4 in.	No Recor...	Generic...	0.001	1.5	0.041	0.027
2	brick (TTW), 4 in.	No Recor...	Generic...	1.430	3.2	0.045	0.035
3	cavity, 2 in.	No Recor...	Generic...	0.016	5.9	0.051	0.035
4	semi-rigid ins., 4 in.	No Recor...	Generic...	0.057	45.0	0.301	0.036
5	membrane (#1), .080 in.	No Recor...	Generic...	21.190	45.2	0.303	0.165
6	plywood shtg., 1/2 in.	No Recor...	Generic...	1.054	47.0	0.324	0.171
7	framing, 2x6s, 6 in.	No Recor...	Generic...	2.043	67.0	0.667	0.184
8	gypsum bd., 5/8 in., (#1)	No Recor...	Generic...	0.229	68.3	0.697	0.185
9	air film (int), 3/4 in.	No Recor...	Generic...	0.006	70.0	0.740	0.185
10							
11							
12							
	TOTAL or (Layer 0)			26.135	(1.0)	(0.040)	(0.027)

CONDENSATION ANALYSIS

The Heat, Air and Moisture Building Science Toolbox - V.1B-E/U (11a)

WALL SECTION AND VAPOUR PRESSURE GRADIENTS



** NO CONDENSATION **

PROJECT

Name	Geisinger Grays Woods
Number	001
City	Port Matilda, PA
Date	2/20/2014
Analysis by:	George Andonie
Wall Type	
Option	

CLIMATIC CONDITIONS

	Winter		Summer	
	Int.	Ext.	Int.	Ext.
Temp (°F)	70	1	—	—
RH (%)	25	67	—	—
DPT (°F)	33	-6	—	—

PENNSYLVANIA STATE UNIVERSITY

104 ENGINEERING, UNIT A
UNIVERSITY PARK, PA, USA, 16802

	Material	Manufacturer	Model No.	Rvap (1/M)	Temp (°F)	VapSat (in.Hg)	VapCont (in.Hg)
1	air film (ext), 3/4 in.	No Recor...	Generic...	0.001	1.4	0.041	0.027
2	brick, facing, 1/2 in.	No Recor...	Generic...	0.358	1.6	0.041	0.028
3	concrete wall, 4 in.	No Recor...	Generic...	1.430	2.9	0.044	0.036
4	ureth.(int.) insul., 2 in.	No Recor...	Generic...	2.861	30.4	0.168	0.051
5	concrete wall, 4 in.	No Recor...	Generic...	1.430	31.7	0.178	0.058
6	cavity, 2 in.	No Recor...	Generic...	0.016	33.9	0.195	0.058
7	semi-rigid ins., 2 in.	No Recor...	Generic...	0.029	49.8	0.360	0.058
8	membrane (#1), .080 in.	No Recor...	Generic...	21.190	49.9	0.362	0.168
9	plywood shtg., 1/2 in.	No Recor...	Generic...	1.054	51.3	0.381	0.173
10	framing, 2x6s, 6 in.	No Recor...	Generic...	2.043	67.6	0.680	0.184
11	gypsum bd., 5/8 in., (#1)	No Recor...	Generic...	0.229	68.6	0.705	0.185
12	air film (int), 3/4 in.	No Recor...	Generic...	0.006	70.0	0.740	0.185
	TOTAL or (Layer 0)			30.774	(1.0)	(0.040)	(0.027)

APPENDIX L

Precast Panel Takeoff

Precast Panel Takeoffs														
Panel Orientation	Panel Designation	Panel Width (Ft.)	Panel Height (Ft.)	Openings (Qty. & Type)	Total Opening Area (SF)	Joint Sealant (LF)	East Façade	South Façade	West Façade	North Façade	Total Quantity	Total Panel Area (SF)	Average Cost/SF	Total Cost
VERTICAL	A-1	2.5	10.5	-	0	26	-	-	1	-	1	26.25	$25.00	$656.25
	B-1	5	31.72	-	0	73.44	1	-	-	-	1	158.6	$25.00	$3,965.00
	B-2	5	41.7	-	0	93.4	-	-	-	1	1	208.5	$25.00	$5,212.50
	C-1	7.25	30	-	0	74.5	-	-	3	-	3	652.5	$25.00	$16,312.50
	D-1	7.5	30	1 x W5	33	75	3	-	-	-	3	576	$25.00	$14,400.00
	D-2	7.5	21.85	1 x W5	33	58.7	1	-	-	-	1	130.875	$25.00	$3,271.88
	E-1	8	15	1 x W4	20.5	46	-	1	-	-	1	99.5	$25.00	$2,487.50
	E-2	8	9.77	1 x D1	55.66	35.54	-	1	-	-	1	22.5	$25.00	$562.50
	E-3	8	30	1 x W5	33	76	-	1	-	-	1	207	$25.00	$5,175.00
	F-1	9	30	1 x W6	26	78	2	-	-	-	2	488	$25.00	$12,200.00
	F-2	9	30	2 x W1	25.6	78	-	-	1	-	1	244.4	$25.00	$6,110.00
	F-3	9	30	1 x W7	14	78	-	6	-	-	6	1536	$25.00	$38,400.00
	G-1	9.25	30	-	0	78.5	-	-	2	-	2	555	$25.00	$13,875.00
	G-2	9.25	30	2 x W1	25.6	78.5	-	-	2	-	2	503.8	$25.00	$12,595.00
	G-3	9.25	30	1 x W7	14	78.5	-	1	-	-	1	263.5	$25.00	$6,587.50
	H-1	10	30	2 x W1	25.6	80	-	-	1	-	1	274.4	$25.00	$6,860.00
	H-2	10	30	2 x W5	66	80	-	-	3	-	3	702	$25.00	$17,550.00
	H-3	10	30	1 x W5	33	80	-	1	-	-	1	267	$25.00	$6,675.00
	H-4	10	30	1 x W6	26	80	3	-	-	-	3	822	$25.00	$20,550.00
	H-5	10	27	-	0	74	-	1	-	-	1	270	$25.00	$6,750.00
	H-6	10	9.77	-	0	39.54	-	1	-	-	1	97.7	$25.00	$2,442.50
	I-1	10.5	30	-	0	81	-	-	1	-	1	315	$25.00	$7,875.00
	I-2	10.5	30	1 x W5	33	81	-	1	-	-	1	282	$25.00	$7,050.00
	J-1	11	13.6	-	0	49.2	-	-	1	-	1	149.6	$25.00	$3,740.00
	J-2	11	30	1 x W6	26	82	1	-	-	-	1	304	$25.00	$7,600.00
	K-1	11.2	30	2 x W1	25.6	82.4	-	-	2	-	2	620.8	$25.00	$15,520.00
	L-1	11.5	30	-	0	83	-	-	1	-	1	345	$25.00	$8,625.00
	L-2	11.5	30	2 x W5	66	83	-	-	1	-	1	279	$25.00	$6,975.00
	M-1	11.7	30	-	0	83.4	-	2	1	-	3	1053	$25.00	$26,325.00
	M-2	11.7	30	L1 , L2	22	83.4	-	1	-	-	1	329	$25.00	$8,225.00
	M-3	11.7	30	L3, L4	12	83.4	-	1	-	-	1	339	$25.00	$8,475.00
	M-4	11.7	30	1 x L5	11	83.4	-	2	-	-	2	680	$25.00	$17,000.00
	M-5	11.7	30	1 x W1	12.8	83.4	-	1	-	-	1	338.2	$25.00	$8,455.00
	N-1	12	30	-	0	84	1	-	-	-	1	360	$25.00	$9,000.00
	N-2	12	30	2 x W3	51.2	84	1	-	-	-	1	308.8	$25.00	$7,720.00
	N-3	12	30	1 x W5	33	84	1	3	-	-	4	1308	$25.00	$32,700.00
	N-4	12	30	1 x W6	26	84	2	-	-	-	2	668	$25.00	$16,700.00
	N-5	12	40	-	0	104	-	1	-	-	1	480	$25.00	$12,000.00
HORIZONTAL	O-1	13.3	2.5	-	0	31.6	-	-	-	1	1	33.25	$25.00	$831.25
	P-1	30	3.25	-	0	66.5	-	-	-	2	2	195	$25.00	$4,875.00
	Q-1	16	4	-	0	40	1	-	-	-	1	64	$25.00	$1,600.00
	R-1	19	4	-	0	46	-	-	-	1	1	76	$25.00	$1,900.00
	S-1	21.25	4	-	0	50.5	-	-	-	1	1	85	$25.00	$2,125.00
	T-1	30	4	-	0	68	-	-	-	2	2	240	$25.00	$6,000.00
	U-1	23.62	10	-	0	67.24	1	-	-	-	1	236.2	$25.00	$5,905.00
	V-1	10.65	10	-	0	41.3	1	-	-	-	1	106.5	$25.00	$2,662.50
	W-1	5.54	-	-	0	32.9	-	-	1	-	1	57.9	$25.00	$1,447.50
	X-1	15.56	-	-	0	56.1	-	-	1	-	1	192.5	$25.00	$4,812.50
TOTAL						**3,360 LF**	**19**	**25**	**22**	**8**	**74**	**17,551 SF**	**$25.00**	**$438,782**
***Anticipated Schedule Durations (Days)**							**1.19**	**1.56**	**1.38**	**0.50**	**4.63**			

- Costs and Productivity Rates provided by Nitterhouse Concrete
- Quantity Takeoffs taken from…..
*Assuming Productivity of 15 Panels/Day

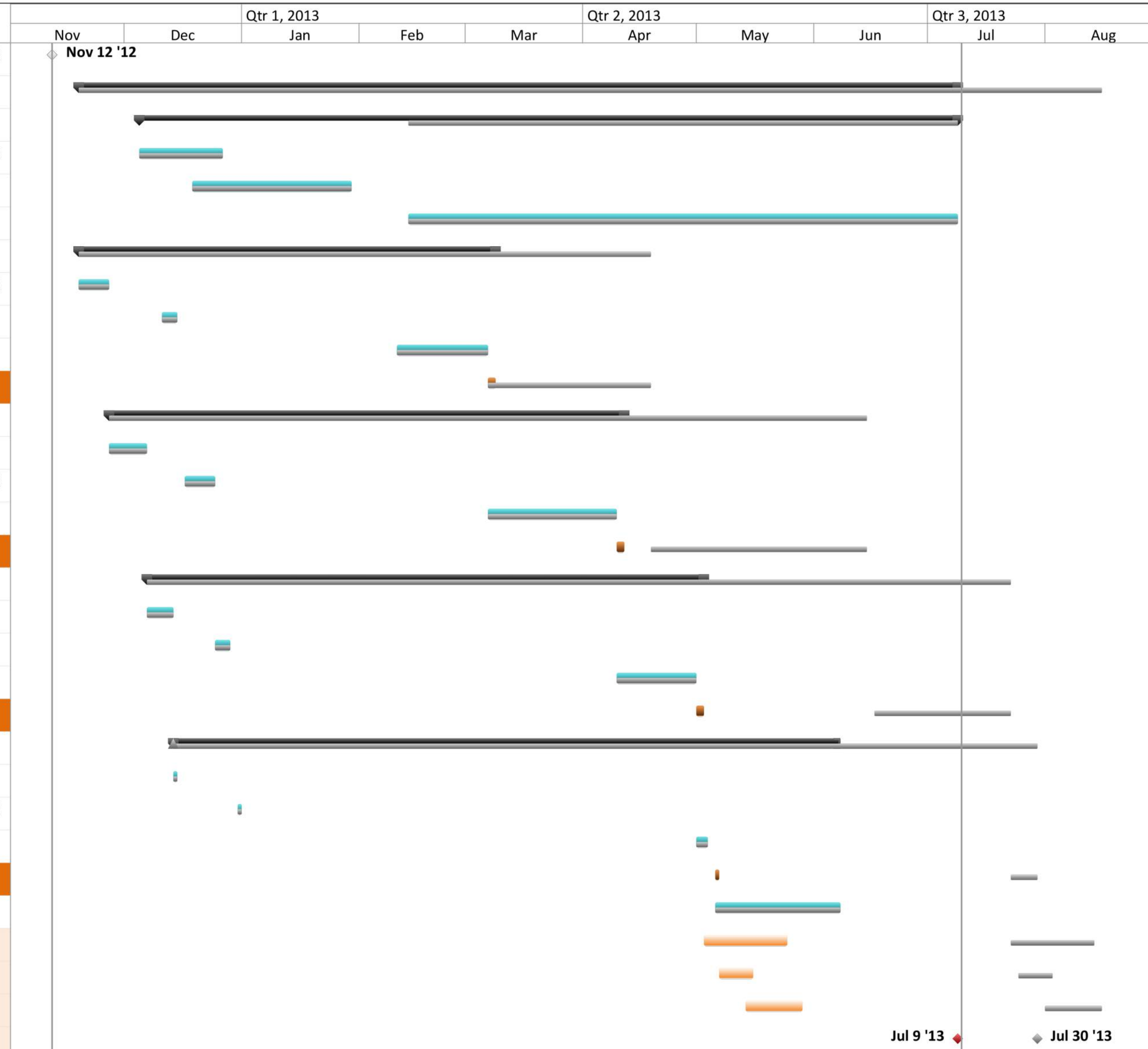
Opening	D1	W1	W3	W4	W5	W6	W7	L1 & L2	L3 & L4	L5
Area (SF)	55.66	12.8	25.6	20.5	33	26	14	11	6	11

APPENDIX M

Proposed Schedule for Building Enclosure

Prefabricated Panel Schedule - Geisinger Grays Woods Project

ID	Task Name	Duration	Start	Finish
1	**Structural Steel Top-Out**	**0 days**	Mon 11/12/12	Mon 11/12/12
2	**Building Envelope**	**166 days**	**Mon 11/19/12**	**Tue 7/9/13**
3	**Roofing**	**154 days**	**Wed 12/5/12**	**Mon 7/8/13**
4	Install Roof Blocking, Parapet & Drain	16 days	**Wed 12/5/12**	Wed 12/26/12
5	Membrane Roofing	30 days	Wed 12/19/12	Tue 1/29/13
6	Metal Panel Roofing	103 days	**Thu 2/14/13**	Mon 7/8/13
7	**West Façade**	**80 days**	**Mon 11/19/12**	**Fri 3/8/13**
8	Exterior Wall Framing	6 days	**Mon 11/19/12**	Mon 11/26/12
9	Exterior Wall Sheathing	4 days	Tue 12/11/12	Fri 12/14/12
10	Air Vapor Barrier & Insulation	18 days	**Mon 2/11/13**	Wed 3/6/13
11	Brick Veneer/Flashing	2 days	**Thu 3/7/13**	Fri 3/8/13
12	**South Façade**	**98 days**	**Tue 11/27/12**	**Thu 4/11/13**
13	Exterior Wall Framing	8 days	Tue 11/27/12	Thu 12/6/12
14	Exterior Wall Sheathing	6 days	Mon 12/17/12	Mon 12/24/12
15	Air Vapor Barrier & Insulation	24 days	Thu 3/7/13	Tue 4/9/13
16	Brick Veneer/Flashing	2 days	Wed 4/10/13	Thu 4/11/13
17	**East Façade**	**105 days**	**Fri 12/7/12**	**Thu 5/2/13**
18	Exterior Wall Framing	5 days	Fri 12/7/12	Thu 12/13/12
19	Exterior Wall Sheathing	4 days	Tue 12/25/12	Fri 12/28/12
20	Air Vapor Barrier & Insulation	15 days	Wed 4/10/13	Tue 4/30/13
21	Brick Veneer/Flashing	2 days	Wed 5/1/13	Thu 5/2/13
22	**North Façade**	**126 days**	**Fri 12/14/12**	**Fri 6/7/13**
23	Exterior Wall Framing	1 day	Fri 12/14/12	Fri 12/14/12
24	Exterior Wall Sheathing	1 day	Mon 12/31/12	Mon 12/31/12
25	Air Vapor Barrier & Insulation	3 days	Wed 5/1/13	Fri 5/3/13
26	Brick Veneer/Flashing	1 day	Mon 5/6/13	Mon 5/6/13
27	Curtain Wall	25 days	Mon 5/6/13	Fri 6/7/13
28	Install Windows/Doors	16 days	Fri 5/3/13	Fri 5/24/13
29	Exterior Painting	7 days	Tue 5/7/13	Wed 5/15/13
30	Façade Joint Sealant	11 days	Tue 5/14/13	Tue 5/28/13
31	Building Dried-in & Conditioned	0 days	Tue 7/9/13	Tue 7/9/13



APPENDIX N

Vulcraft Decking Catalogs

FLOOR-CEILING ASSEMBLIES WITH COMPOSITE DECK

Vulcraft Decks have been tested by Underwriters Laboratories Inc. for their Fire Resistance Ratings. In as much as new listings are continually being added, please contact the factory if your required design is not listed below. The cellular decks listed comply with U.L. 209 for use as Electrical Raceways.

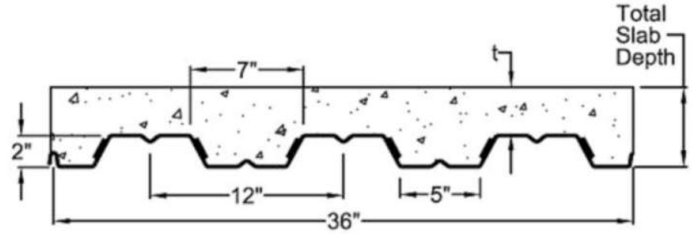
Restrained Assembly Rating	Type of Protection	Concrete Thickness & Type (1)	U.L. Design No. (2,3,4)	Classified Deck Type: Fluted Deck	Classified Deck Type: Cellular Deck (5)	Unrestrained Beam Rating
3/4 Hr.	Unprotected Deck	2 1/2" LW	D914 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
1 Hr.	Exposed Grid	2 1/2" NW	D216 +	1.5VL,1.5VLI,2VLI,3VLI	2VLP, 3VLP	2,3 Hr.
	Cementitious	2" NW&LW	D743 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D703 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1.5 Hr.
			D712 *	3VLI	3VLP	2 Hr.
			D722 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D739 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3,4 Hr.
			D759	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
	Sprayed Fiber	2" NW&LW	D859 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D832 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D847 *	2VLI,3VLI	3VLP	1,1.5,3 Hr.
			D858 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
			D871 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
	Unprotected Deck	2 1/2" LW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D914 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
		3 1/2" NW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
1 1/2 Hr.	Gypsum Board	2 1/2" NW	D502 *	1.5VL,1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5,2 Hr.
	Cementitious	2" NW&LW	D743 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D703 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1.5 Hr.
			D712 *	3VLI	3VLP	2 Hr.
			D722 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D739 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3,4 Hr.
			D759	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
	Sprayed Fiber	2" NW&LW	D859 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D832 *	1.5VLI,2VLI,3VLI	3VLP	1,1.5,2,3 Hr.
			D847 *	2VLI,3VLI	3VLP	1,1.5,3 Hr.
			D858 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
			D871 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
	Unprotected Deck	3" LW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
		4" NW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
2 Hr.	Exposed Grid	2 1/2" NW	D216 +	1.5VL,1.5VLI,2VLI,3VLI	2VLP, 3VLP	2,3 Hr.
	Gypsum Board	2 1/2" NW	D502 +	1.5VL,1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5,2 Hr.
	Cementitious	2" NW&LW	D743 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" LW	D746 *	1.5VLI		1,1.5,2,3 Hr.
			D752 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2, Hr.
		2 1/2" NW&LW	D703 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1.5 Hr.
			D712 *	3VLI	3VLP	2 Hr.
			D716 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5,2 Hr.
			D722 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D739 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3,4 Hr.
			D745 *	2VLI,3VLI		1,1.5,2, Hr.
			D750 *	1.5VLI,2VLI,3VLI		1.5,2 Hr.
			D755	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D759	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D760 *	2VLI,3VLI		1,1.5,2,3,4 Hr.
		2 1/2" NW	D730 *	2VLI,3VLI	2VLP, 3VLP	1.5,2 Hr.
			D742 *	1.5VLI,2VLI,3VLI		1,1.5 Hr.

Restrained Assembly Rating	Type of Protection	Concrete Thickness & Type (1)	U.L. Design No. (2,3,4)	Classified Deck Type		Unrestrained Beam Rating
				Fluted Deck	Cellular Deck (5)	
2 Hr. (continued)	Sprayed Fiber	2" NW&LW	D859 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D822 *	2VLI,3VLI	2VLP, 3VLP	1 Hr.
			D825 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D831 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D832 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D833 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5 Hr.
			D847 *	2VLI,3VLI	3VLP	1,1.5,3 Hr.
			D858 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
			D861 *	12VLI,3VLI		1,1.5 Hr.
			D870 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,2 Hr.
			D871 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" LW	D862 *	2VLI,3VLI		1 Hr.
		2 1/2" NW	D864 *	3VLI	3VLP	1.5 Hr.
		3 1/4" LW	D860 *	2VLI,3VLI		1,1.5,2 Hr.
	Unprotected Deck	3 1/4" LW	D733 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5Hr.
			D826 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2 Hr.
			D840 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D907 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,2 Hr.
			D913 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D920 #	2VLI,3VLI	2VLP, 3VLP	1.5 Hr.
		4 1/2" NW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
3 Hr.	Exposed Grid	3 1/4" NW	D216 +	1.5VL,1.5VLI,2VLI,3VLI	2VLP, 3VLP	2,3 Hr.
	Cementitious	2" NW&LW	D743 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" LW	D746 *	1.5VLI		1,1.5,2,3 Hr.
		2 1/2" NW&LW	D703 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1.5 Hr.
			D708 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1.5,3 Hr.
			D739 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3,4 Hr.
			D755	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D759	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D760 *	2VLI,3VLI		1,1.5,2,3,4 Hr.
		3 1/4" LW	D754 *	1.5VLI,2VLI,3VLI		1.5,2 Hr.
		3 1/4" NW	D742 *	1.5VLI,2VLI,3VLI		1,1.5 Hr.
	Sprayed Fiber	2" NW&LW	D859 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW&LW	D816 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5,2 Hr.
			D831 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D832 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D833 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5 Hr.
			D858	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
			D871 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 1/2" NW	D864	3VLI	3VLP	1.5 Hr.
		3 1/4" LW	D860 *	2VLI,3VLI		1,1.5,2 Hr.
	Unprotected Deck	4 3/16" LW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
		5 1/4" NW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
4 Hr.	Cementitious	2 1/2" NW&LW	D760	2VLI,3VLI		1,1.5,2,3,4 Hr.
			D739	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3,4 Hr.
		3 1/4" LW	D754	1.5VLI,2VLI,3VLI		1.5,2 Hr.
	Sprayed Fiber	2 1/2" NW&LW	D858	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
		3 1/4" LW	D860	2VLI,3VLI		1,1.5,2 Hr.

NOTES:
1. Concrete thickness is thickness of slab above deck, in.
2. Refer to the U.L. "Fire Resistance Directory" for the necessary construction details.
3. Cellular deck finish shall be galvanized.
4. Fluted deck finish shall be galvanized unless noted otherwise.
   + Denotes fluted deck finish is not critical when used in D2-- & D5-- Series designs. Deck finish shall be galvanized or phosphatized/painted.
   * Fluted deck finish is critical for fire resistance. Fluted deck finish shall be galvanized or phosphatized/painted. This paint is a special type of paint and is compatible with the spray-applied fire protection and is U.L. approved for use in the denoted D7-- & D8-- Series designs.
   # Denotes fluted deck finish is not critical for fire resistance. Fluted deck finish shall be galvanized or phosphatized/painted.
5. Vulcraft cellular deck units are approved by U.L. for use as electrical raceways under U.L Standard 209.

2 VLI

Maximum Sheet Length 42'-0
Extra Charge for Lengths Under 6'-0
ICBO Approved (No. 3415)



Interlocking side lap is not drawn to show actual detail.

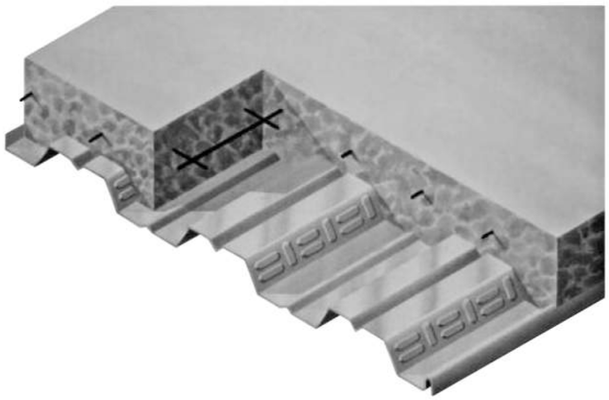
STEEL SECTION PROPERTIES

Deck Type	Design Thickness in	Deck Weight psf	Section Properties I_p in^4/ft	S_p in^3/ft	I_n in^4/ft	S_n in^3/ft	V_a lbs/ft	F_y ksi
2VLI22	0.0295	1.62	0.324	0.263	0.321	0.266	1832	50
2VLI20	0.0358	1.97	0.409	0.341	0.406	0.346	2698	50
2VLI19	0.0418	2.30	0.492	0.420	0.489	0.426	3190	50
2VLI18	0.0474	2.61	0.559	0.495	0.558	0.504	3608	50
2VLI16	0.0598	3.29	0.704	0.653	0.704	0.653	3618	40

(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span 1 SPAN	2 SPAN	3 SPAN	Superimposed Live Load, PSF Clear Span (ft.-in.) 5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6
	2VLI22	7'-4	9'-6	9'-9	274	239	211	188	145	129	115	104	94	85	78	71	65	59	54
4.00	2VLI20	8'-7	10'-10	11'-2	310	269	236	210	188	170	155	117	106	96	87	80	73	67	61
(t=2.00)	2VLI19	9'-9	11'-11	12'-4	344	298	261	231	207	186	169	155	142	106	97	88	81	74	68
39 PSF	2VLI18	10'-9	12'-9	12'-9	373	324	285	253	228	206	188	172	159	147	137	103	95	87	81
	2VLI16	11'-1	13'-2	13'-5	400	376	330	292	261	235	214	195	180	166	154	143	109	100	93
	2VLI22	6'-11	9'-0	9'-4	319	278	245	190	168	150	134	121	109	99	90	83	76	69	63
4.50	2VLI20	8'-2	10'-3	10'-7	361	313	275	244	219	198	152	136	123	112	102	93	85	78	72
(t=2.50)	2VLI19	9'-2	11'-5	11'-9	400	346	303	268	240	216	196	180	136	124	113	103	94	86	79
45 PSF	2VLI18	10'-2	12'-4	12'-4	400	376	331	295	264	239	218	200	184	171	130	119	110	102	94
	2VLI16	10'-5	12'-6	12'-11	400	400	383	339	303	274	248	227	209	193	150	137	126	117	108
	2VLI22	6'-7	8'-7	8'-11	364	317	279	217	192	171	153	138	125	113	103	94	86	79	72
5.00	2VLI20	7'-9	9'-10	10'-2	400	356	313	278	249	193	173	156	141	128	116	106	97	89	82
(t=3.00)	2VLI19	8'-9	10'-11	11'-3	400	394	345	306	273	247	224	172	156	141	128	117	107	99	91
51 PSF	2VLI18	9'-7	11'-10	11'-11	400	400	377	336	301	273	249	228	210	162	148	136	126	116	107
	2VLI16	9'-11	12'-0	12'-4	400	400	400	386	346	312	283	259	238	187	171	157	144	133	123
	2VLI22	6'-4	8'-0	8'-6	400	355	278	244	216	192	172	155	140	127	116	106	97	89	81
5.50	2VLI20	7'-5	9'-5	9'-9	400	400	351	312	244	217	194	175	158	143	131	119	109	100	92
(t=3.50)	2VLI19	8'-4	10'-5	10'-9	400	400	388	343	307	277	215	193	175	159	144	132	121	111	102
57 PSF	2VLI18	9'-2	11'-4	11'-7	400	400	400	377	338	306	279	256	199	182	167	153	141	130	121
	2VLI16	9'-5	11'-6	11'-10	400	400	400	400	388	350	318	290	230	210	192	176	162	150	138
	2VLI22	6'-1	7'-5	8'-2	400	394	308	270	239	213	191	172	156	141	129	118	108	99	90
6.00	2VLI20	7'-1	9'-1	9'-4	400	400	390	346	271	241	215	194	175	159	145	132	121	111	102
(t=4.00)	2VLI19	8'-0	10'-1	10'-5	400	400	400	381	340	307	239	215	194	176	160	146	134	123	113
63 PSF	2VLI18	8'-10	10'-11	11'-3	400	400	400	400	375	339	309	243	221	202	185	170	157	145	134
	2VLI16	9'-1	11'-1	11'-5	400	400	400	400	400	388	352	322	255	233	213	195	180	166	154
	2VLI22	5'-11	6'-11	7'-11	400	390	339	297	263	234	210	189	171	155	141	129	118	108	99
6.50	2VLI20	6'-11	8'-9	9'-0	400	400	400	337	297	264	237	213	193	175	159	145	133	122	112
(t=4.50)	2VLI19	7'-10	9'-8	10'-0	400	400	400	400	374	293	262	236	213	193	176	161	147	135	124
69 PSF	2VLI18	8'-7	10'-6	10'-11	400	400	400	400	400	373	340	268	243	222	203	187	172	159	147
	2VLI16	8'-10	10'-8	11'-0	400	400	400	400	400	400	387	309	280	256	234	215	198	183	169

Notes:
1. Minimum exterior bearing length required is 2.00 inches. Minimum interior bearing length required is 4.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. Always contact Vulcraft when using loads in excess of 200 psf. Such loads often result from concentrated, dynamic, or long term load cases for which reductions due to bond breakage, concrete creep, etc. should be evaluated.
3. All fire rated assemblies are subject to an upper live load limit of 250 psf.



SLAB INFORMATION

Total Slab Depth, in.	Theo. Concrete Volume Yd³ / 100 ft²	ft³ / ft²	Recommended Welded Wire Fabric
4	0.93	0.250	6x6 - W1.4xW1.4
4 1/2	1.08	0.292	6x6 - W1.4xW1.4
5	1.23	0.333	6x6 - W1.4xW1.4
5 1/4	1.31	0.354	6x6 - W1.4xW1.4
5 1/2	1.39	0.375	6x6 - W2.1xW2.1
6	1.54	0.417	6x6 - W2.1xW2.1
6 1/4	1.62	0.438	6x6 - W2.1xW2.1
6 1/2	1.70	0.458	6x6 - W2.1xW2.1

(N=14.15) LIGHTWEIGHT CONCRETE (110 PCF)

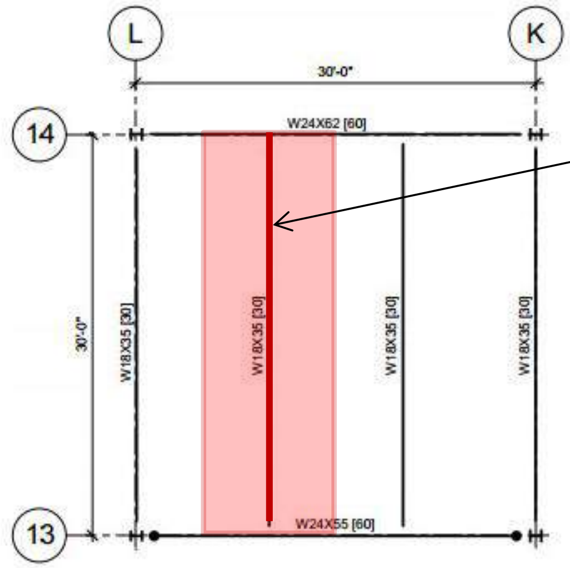
TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 SPAN	2 SPAN	3 SPAN	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6	13'-0
	2VLI22	8'-1	10'-3	10'-7	238	209	186	167	152	120	108	98	90	82	75	69	64	59	55
4.00	2VLI20	9'-6	11'-8	12'-1	268	235	209	187	169	153	140	129	101	92	84	78	72	66	61
(t=2.00)	2VLI19	10'-10	13'-0	13'-2	297	260	230	206	185	168	153	141	130	121	93	86	79	73	68
30 PSF	2VLI18	11'-7	13'-7	13'-7	324	285	253	227	205	187	171	158	146	136	127	119	92	86	80
	2VLI16	12'-3	14'-3	14'-4	377	330	292	261	235	214	195	179	165	153	143	133	118	98	91
	2VLI22	7'-8	9'-10	10'-2	276	243	216	194	155	139	126	114	104	96	88	81	75	69	64
4.50	2VLI20	9'-0	11'-3	11'-7	312	273	243	217	196	178	163	128	117	107	98	90	83	77	72
(t=2.50)	2VLI19	10'-3	12'-5	12'-9	346	302	268	239	215	195	178	164	151	118	108	100	92	85	79
35 PSF	2VLI18	11'-2	13'-1	13'-1	376	331	294	264	238	217	199	183	170	158	147	116	107	100	93
	2VLI16	11'-7	13'-8	13'-10	400	384	340	303	273	248	227	208	192	178	166	155	123	114	106
	2VLI22	7'-4	9'-5	9'-9	315	277	247	197	176	159	143	130	119	109	100	92	85	79	73
5.00	2VLI20	8'-7	10'-9	11'-2	355	312	276	248	224	203	161	146	133	122	112	103	95	88	82
(t=3.00)	2VLI19	9'-9	11'-11	12'-4	394	345	305	272	245	223	203	187	147	135	124	114	105	97	90
39 PSF	2VLI18	10'-9	12'-9	12'-9	400	377	335	300	272	247	227	209	193	180	143	132	122	114	106
	2VLI16	11'-0	13'-1	13'-5	400	400	387	346	311	283	258	237	219	203	189	151	140	130	121
	2VLI22	7'-2	9'-3	9'-7	334	294	262	209	187	168	152	138	126	116	106	98	90	84	78
5.25	2VLI20	8'-5	10'-7	10'-11	377	331	293	263	237	190	171	155	142	130	119	110	101	94	87
(t=3.25)	2VLI19	9'-6	11'-8	12'-1	400	366	324	289	260	236	216	198	156	143	131	121	111	103	95
42 PSF	2VLI18	10'-6	12'-7	12'-7	400	400	355	319	288	263	241	222	205	191	151	140	130	121	113
	2VLI16	10'-9	12'-10	13'-3	400	400	400	367	330	300	274	252	232	215	173	160	148	138	128
	2VLI22	7'-0	9'-1	9'-5	353	311	277	222	198	178	161	147	134	122	113	104	96	89	82
5.50	2VLI20	8'-3	10'-4	10'-9	399	350	310	278	251	201	181	165	150	137	126	116	107	99	92
(t=3.50)	2VLI19	9'-4	11'-6	11'-10	400	387	342	306	275	250	228	182	165	151	139	128	118	109	101
44 PSF	2VLI18	10'-3	12'-5	12'-5	400	400	376	337	305	278	254	234	217	174	160	148	138	128	119
	2VLI16	10'-6	12'-7	13'-0	400	400	400	388	350	317	290	266	246	228	184	170	157	146	136
	2VLI22	6'-8	8'-7	8'-11	400	362	291	258	231	208	188	171	156	143	131	121	112	103	96
6.25	2VLI20	7'-9	9'-10	10'-2	400	400	361	323	260	234	211	192	175	160	147	135	125	115	107
(t=4.25)	2VLI19	8'-9	10'-11	11'-3	400	400	398	356	320	291	233	212	193	176	162	149	137	127	118
51 PSF	2VLI18	9'-8	11'-10	11'-11	400	400	400	392	355	323	296	273	220	202	187	173	160	149	139
	2VLI16	9'-11	12'-0	12'-5	400	400	400	400	400	369	337	310	253	232	214	198	183	170	158

Notes:
1. Minimum exterior bearing length required is 2.00 inches. Minimum interior bearing length required is 4.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. Always contact Vulcraft when using loads in excess of 200 psf. Such loads often result from concentrated, dynamic, or long term load cases for which reductions due to bond breakage, concrete creep, etc. should be evaluated.
3. All fire rated assemblies are subject to an upper live load limit of 250 psf.

APPENDIX O

Structural Breadth Calculations

Calculating Beam Size:



Assumptions:

Tributary Width:

$W_T = 10'$

Influence Area:

$K_{LL}A_T = 20' * 30'$

$K_{LL}A_T = 600SF$

$600SF \geq 400SF$ $\quad \therefore$ *Reducible LL*

Live Loads:

Hospital = 60psf

Wall Partitions = 20psf

Calculations:

$$\mathbf{LL_0 = 80psf * \left(0.25 + \frac{15}{\sqrt{600}}\right)}$$

$$\mathbf{LL_0 = 80psf * 0.86}$$

$$\mathbf{\underline{LL_0 = 69psf}}$$

$$\mathbf{DL = (Comp.\,Deck) + (Super.) + (Beam\,)}$$

$$\mathbf{DL = 69psf + 10psf + 5psf}$$

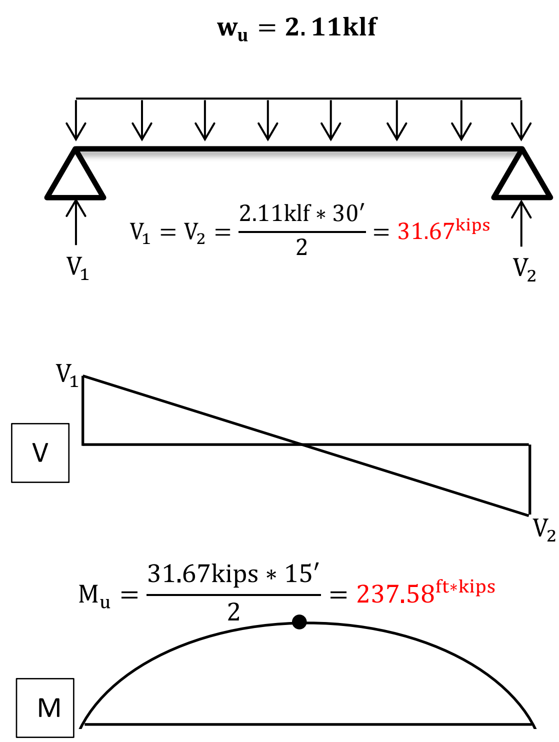
$$\mathbf{\underline{DL = 84psf}}$$

$$\mathbf{W_u = 1.2D + 1.6L}$$

$$\mathbf{W_u = 1.2(84) + 1.6(51.6)}$$

$$\mathbf{W_u = 211.18psf}$$

Graphs:



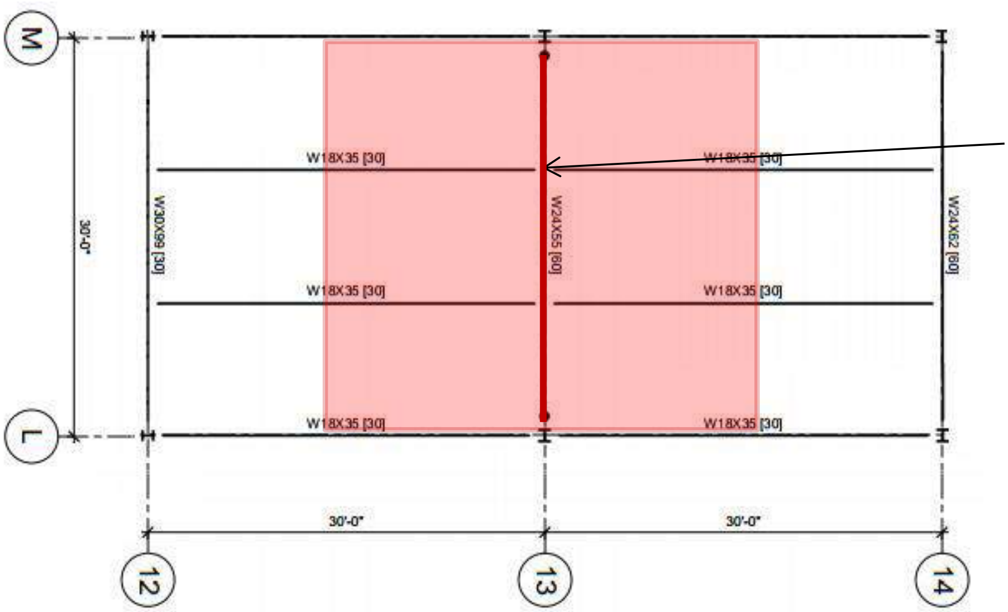
Check W18x35:

$\phi M_n = 249'^k \geq 237.58'^k$ $\quad \therefore Ok$

$\phi V_n = 159^k \geq 31.67^k$ $\quad \therefore Ok$

$\Delta = \frac{5wl^4}{384EI} = .631" \leq \frac{L*12}{240} = 1.5"$ $\quad \therefore Ok$

Calculating Girder Size:



Assumptions:

Girder Tributary Width:
$W_T = 30'$

Girder Self-Weight::
$W_U = 2\text{psf}$

Calculations:

$\mathbf{P_u = 2 \text{ x } 31.67}$

$\mathbf{P_{u,1} = P_{u,2} = 63.34^{kips}}$

$\mathbf{w_u = W_u * A_T}$

$\mathbf{w_u = 2^{psf} * 30'}$

$\mathbf{w_u = 60^{plf} = .06^{klf}}$

$\mathbf{P_{u,3} = w_u * W_T}$

$\mathbf{P_{u,3} = .06^{klf} * 30' = 1.8^{kips}}$

$\mathbf{\sum M = 0}$

$\mathbf{0 = 10 * (-P_{u,1}) + 15'(-P_{u,3}) + 20'(-P_{u,2}) + 30' * V_1}$

$\mathbf{0 = 10 * (63.34^k) + 15'(1.8^k) + 20'(63.34^k) + 30' * V_1}$

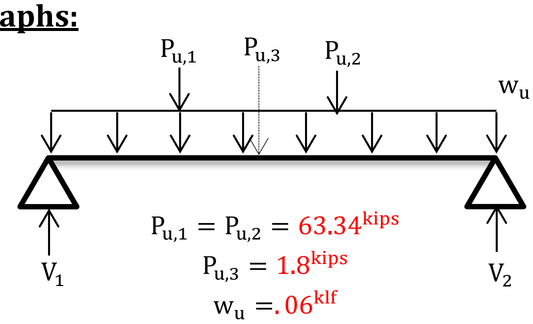
$\mathbf{V_1 = V_2 = 64.24^{kips}}$

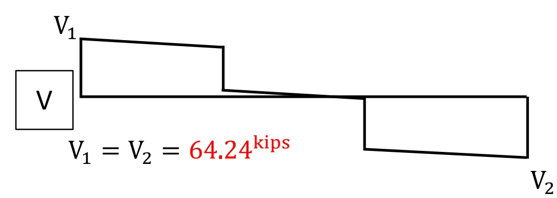
$$\mathbf{M_{u,Max} = (V_1 * 10') - \frac{1}{2}(1.8 * 15 * 0.5)}$$

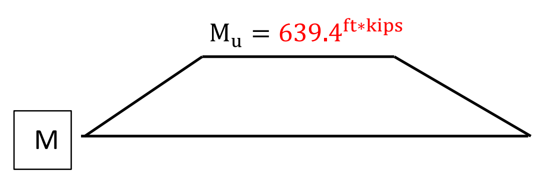
$$\mathbf{M_{u,Max} = (64.24^k * 10') - \frac{1}{2}(6)}$$

$\mathbf{M_{u,Max} = 639.4^{ft*kips}}$

Graphs:

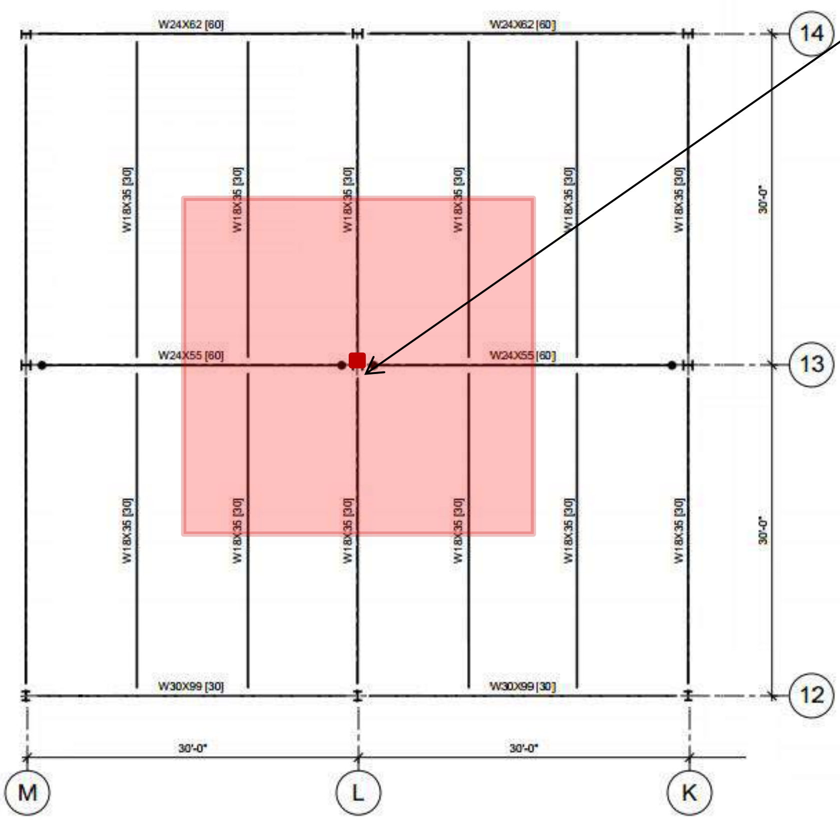






Check W24x68:	$\phi M_n = 664'^k \geq 639.4'^k$	$\therefore Ok$
	$\phi V_n = 295^k \geq 64.24^k$	$\therefore Ok$
	$\Delta = \frac{5wl^4}{384EI} = .911" \leq \frac{L*12}{240} = 1.5"$	$\therefore Ok$

Calculating Column Size:



Assumptions:

Tributary Area:

$$A_T = \frac{(30' + 30')}{2} + \frac{(30' + 30')}{2}$$
$$A_T = 30' * 30'$$
$$A_T = 900SF$$

Influence Area:

$$K_{LL}A_T = 60' * 60'$$ ∴ *Reducible LL*
$$K_{LL}A_T = 3{,}600SF$$
$$3{,}600SF \geq 400SF$$

Roof Loads:

$$\mathbf{LL = SL = 30psf}$$

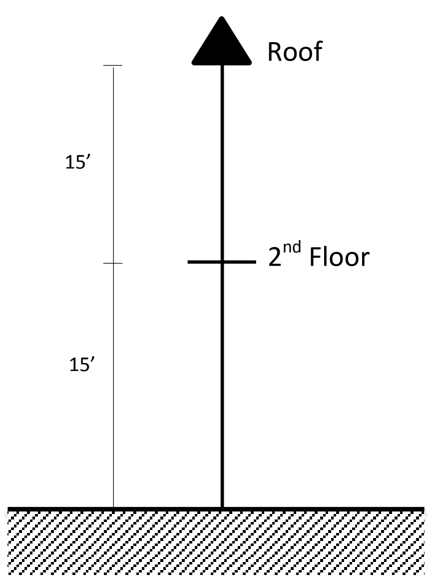
$$\mathbf{DL = (Roof) + (Deck) + (FP) + (Super.) + (Beams)}$$
$$\mathbf{DL = 30psf + 3psf + 3psf + 10psf + 5psf + 2psf}$$
$$\mathbf{DL = 53psf}$$

Effective Column Length (KL):

K= 1 (Pin-Pin Connection)

L= 15'

KL = 15'



Calculations:

a) First Floor:

$$\mathbf{P_{u,a} = (2 * V_{u,Girder}) + (2 * V_{u,Beams})}$$
$$\mathbf{P_{u,a} = (2 * 64.2^{kips}) + (2 * 31.67^{kips})}$$
$$\mathbf{P_{u,a} = (128.4^{kips}) + (63.34^{kips})}$$
$$\mathbf{P_{u,a} = 191.74^{kips}}$$

b) Roof:

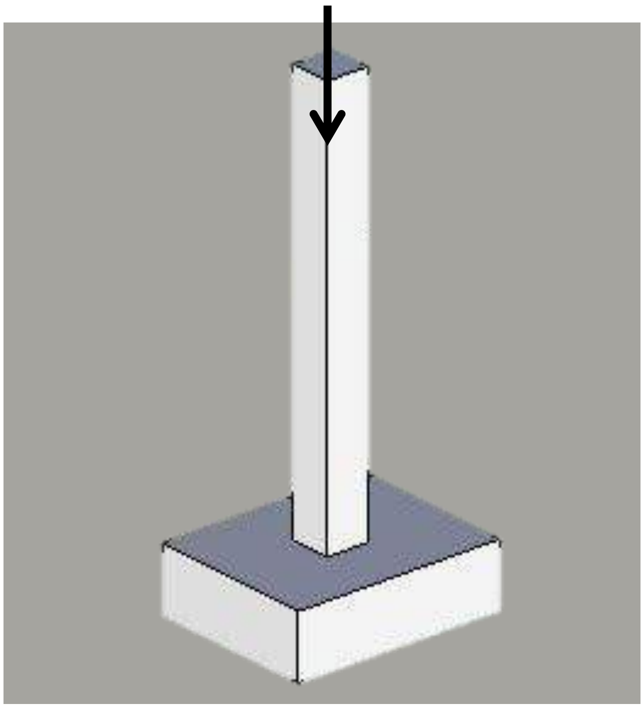
$$\mathbf{P_{u,b} = [1.2D + 1.6S]}$$
$$\mathbf{P_u = [1.2(53^k) + 1.6(30^k)]}$$
$$\mathbf{P_u = [63.6^k + 48^k]}$$
$$\mathbf{P_{u,b} = 111.6^{kips}}$$

$$\sum P_u = 191.74^k + 111.6^k = 303.34^k$$

Check W10x49: $\phi P_n = 449^k \geq 303.34^k$ ∴ *Ok*

Calculating Footing Size:

$P_u = 262.34^k$



Assumptions:

Column (13-L) Size:

$\text{Width} = 9'$

$\text{Length} = 9'$

Allowable Bearing Capacity:

$q_a = 4{,}000^{\text{psf}} = 4^{\text{ksf}}$

Calculations:

$$q_u = \frac{P_u}{\text{Area}} = \frac{262.34^k}{9'x9'} = \frac{262.34^k}{81\text{ft}^2} = 3.238^{\text{ksf}}$$

Check 9'x9' Footing:

$$q_u < q_{\text{allowable}}$$

$$3.238^{\text{ksf}} < 4^{\text{ksf}} \qquad \therefore Ok$$

APPENDIX P

ASCE Reference Data

TABLE 4-1 MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lb (kN)
Apartments (see *Residential*)		
Access floor systems		
Office use	50 (2.4)	2,000 (8.9)
Computer use	100 (4.79)	2,000 (8.9)
Armories and drill rooms	150 (7.18)	
Assembly areas and theaters		
Fixed seats (fastened to floor)	60 (2.87)	
Lobbies	100 (4.79)	
Movable seats	100 (4.79)	
Platforms (assembly)	100 (4.79)	
Stage floors	150 (7.18)	
Balconies (exterior)	100 (4.79)	
On one- and two-family residences only, and not exceeding 100 ft^2 (9.3 m^2)	60 (2.87)	
Bowling alleys, poolrooms, and similar recreational areas	75 (3.59)	
Catwalks for maintenance access	40 (1.92)	300 (1.33)
Corridors		
First floor	100 (4.79)	
Other floors, same as occupancy served except as indicated		
Dance halls and ballrooms	100 (4.79)	
Decks (patio and roof)		
Same as area served, or for the type of occupancy accommodated		
Dining rooms and restaurants	100 (4.79)	
Dwellings (see *Residential*)		
Elevator machine room grating (on area of 4 in.^{2} [2,580 mm^2])		300 (1.33)
Finish light floor plate construction (on area of 1 in.^{2} [645 mm^2])		200 (0.89)
Fire escapes	100 (4.79)	
On single-family dwellings only	40 (1.92)	
Fixed ladders	See Section 4.4	
Garages (passenger vehicles only)	40 (1.92)^{a,b}	
Trucks and buses		
Grandstands (see *Stadiums and arenas, Bleachers*)		
Gymnasiums—main floors and balconies	100 (4.79)	
Handrails, guardrails, and grab bars	See Section 4.4	
Hospitals		
Operating rooms, laboratories	60 (2.87)	1,000 (4.45)
Patient rooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
Hotels (see *Residential*)		
Libraries		
Reading rooms	60 (2.87)	1,000 (4.45)
Stack rooms	150 (7.18)^c	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
Manufacturing		
Light	125 (6.00)	2,000 (8.90)
Heavy	250 (11.97)	3,000 (13.40)
Marquees	75 (3.59)	
Office Buildings		
File and computer rooms shall be designed for heavier loads based on anticipated occupancy		
Lobbies and first-floor corridors	100 (4.79)	2,000 (8.90)
Offices	50 (2.40)	2,000 (8.90)
Corridors above first floor	80 (3.83)	2,000 (8.90)
Penal Institutions		
Cell blocks	40 (1.92)	
Corridors	100 (4.79)	
Residential		
Dwellings (one- and two-family)		
Uninhabitable attics without storage	10 (0.48)	
Uninhabitable attics with storage	20 (0.96)	
Habitable attics and sleeping areas	30 (1.44)	
All other areas except stairs and balconies	40 (1.92)	
Hotels and multifamily houses		
Private rooms and corridors serving them	40 (1.92)	
Public rooms and corridors serving them	100 (4.79)	
Reviewing stands, grandstands, and bleachers	100 (4.79)^d	

APPENDIX Q

AISC Steel Construction Manual Reference Data

Z_x

Table 3-2 (continued)
W-Shapes
Selection by Z_x

F_y = 50 ksi

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W24×84	**224**	**559**	**840**	**342**	**515**	**16.2**	**24.2**	**6.89**	**20.3**	**2370**	**227**	**340**
W21×93	221	551	829	335	504	14.6	22.0	6.50	21.3	2070	251	376
W12×136	214	534	803	325	488	4.02	6.06	11.2	63.2	1240	212	318
W14×120	212	529	795	332	499	5.09	7.65	13.2	51.9	1380	171	257
W18×97	211	526	791	328	494	9.41	14.1	9.36	30.4	1750	199	299
W24×76	**200**	**499**	**750**	**307**	**462**	**15.1**	**22.6**	**6.78**	**19.5**	**2100**	**210**	**315**
W16×100	198	494	743	306	459	7.86	11.9	8.87	32.8	1490	199	298
W21×83	196	489	735	299	449	13.8	20.8	6.46	20.2	1830	220	331
W14×109	192	479	720	302	454	5.01	7.54	13.2	48.5	1240	150	225
W18×86	186	464	698	290	436	9.01	13.6	9.29	28.6	1530	177	265
W12×120	186	464	698	285	428	3.94	5.95	11.1	56.5	1070	186	279
W24×68	**177**	**442**	**664**	**269**	**404**	**14.1**	**21.2**	**6.61**	**18.9**	**1830**	**197**	**295**
W16×89	175	437	656	271	407	7.76	11.6	8.80	30.2	1300	176	265
W14×99[f]	173	430	646	274	412	4.91	7.36	13.5	45.3	1110	138	207
W21×73	172	429	645	264	396	12.9	19.4	6.39	19.2	1600	193	289
W12×106	164	409	615	253	381	3.93	5.89	11.0	50.7	933	157	236
W18×76	163	407	611	255	383	8.50	12.8	9.22	27.1	1330	155	232
W21×68	**160**	**399**	**600**	**245**	**368**	**12.5**	**18.8**	**6.36**	**18.7**	**1480**	**181**	**272**
W14×90[f]	157	382	574	250	375	4.82	7.26	15.1	42.5	999	123	185
W24x62	**153**	**382**	**574**	**229**	**344**	**16.1**	**24.1**	**4.87**	**14.4**	**1550**	**204**	**306**
W16×77	150	374	563	234	352	7.34	11.1	8.72	27.8	1110	150	225
W12×96	147	367	551	229	344	3.85	5.78	10.9	46.7	833	140	210
W10×112	147	367	551	220	331	2.69	4.03	9.47	64.1	716	172	258
W18×71	146	364	548	222	333	10.4	15.8	6.00	19.6	1170	183	275
W21×62	**144**	**359**	**540**	**222**	**333**	**11.6**	**17.5**	**6.25**	**18.1**	**1330**	**168**	**252**
W14×82	139	347	521	215	323	5.40	8.10	8.76	33.2	881	146	219
W24×55[v]	**134**	**334**	**503**	**199**	**299**	**14.7**	**22.2**	**4.73**	**13.9**	**1350**	**167**	**252**
W18×65	133	332	499	204	307	9.98	15.0	5.97	18.8	1070	166	248
W12×87	132	329	495	206	310	3.81	5.73	10.8	43.1	740	129	193
W16×67	130	324	488	204	307	6.89	10.4	8.69	26.1	954	129	193
W10×100	130	324	488	196	294	2.64	4.00	9.36	57.9	623	151	226
W21×57	129	322	484	194	291	13.4	20.3	4.77	14.3	1170	171	256

ASD	LRFD
$\Omega_b = 1.67$	$\phi_b = 0.90$
$\Omega_v = 1.50$	$\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.
[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with F_y = 50 ksi; therefore, ϕ_v = 0.90 and Ω_v = 1.67.

Z_x

Table 3-2 (continued)
W-Shapes
Selection by Z_x

F_y = 50 ksi

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W18×35	66.5	166	249	101	151	8.14	12.3	4.31	12.3	510	106	159
W12×45	64.2	160	241	101	151	3.80	5.80	6.89	22.4	348	81.1	122
W16×36	64.0	160	240	98.7	148	6.24	9.36	5.37	15.2	448	93.8	141
W14×38	61.5	153	231	95.4	143	5.37	8.20	5.47	16.2	385	87.4	131
W10×49	60.4	151	227	95.4	143	2.46	3.71	8.97	31.6	272	68.0	102
W8×58	59.8	149	224	90.8	137	1.70	2.55	7.42	41.6	228	89.3	134
W12×40	57.0	142	214	89.9	135	3.66	5.54	6.85	21.1	307	70.2	105
W10×45	54.9	137	206	85.8	129	2.59	3.89	7.10	26.9	248	70.7	106
W14×34	**54.6**	**136**	**205**	**84.9**	**128**	**5.01**	**7.55**	**5.40**	**15.6**	**340**	**79.8**	**120**
W16×31	**54.0**	**135**	**203**	**82.4**	**124**	**6.86**	**10.3**	**4.13**	**11.8**	**375**	**87.5**	**131**
W12×35	51.2	128	192	79.6	120	4.34	6.45	5.44	16.6	285	75.0	113
W8×48	49.0	122	184	75.4	113	1.67	2.55	7.35	35.2	184	68.0	102
W14×30	**47.3**	**118**	**177**	**73.4**	**110**	**4.63**	**6.95**	**5.26**	**14.9**	**291**	**74.5**	**112**
W10×39	46.8	117	176	73.5	111	2.53	3.78	6.99	24.2	209	62.5	93.7
W16×26[v]	**44.2**	**110**	**166**	**67.1**	**101**	**5.93**	**8.98**	**3.96**	**11.2**	**301**	**70.5**	**106**
W12×30	43.1	108	162	67.4	101	3.97	5.96	5.37	15.6	238	64.0	95.9
W14×26	**40.2**	**100**	**151**	**61.7**	**92.7**	**5.33**	**8.11**	**3.81**	**11.0**	**245**	**70.9**	**106**
W8×40	39.8	99.3	149	62.0	93.2	1.64	2.46	7.21	29.9	146	59.4	89.1
W10×33	38.8	96.8	146	61.1	91.9	2.39	3.62	6.85	21.8	171	56.4	84.7
W12×26	**37.2**	**92.8**	**140**	**58.3**	**87.7**	**3.61**	**5.46**	**5.33**	**14.9**	**204**	**56.1**	**84.2**
W10×30	36.6	91.3	137	56.6	85.1	3.08	4.61	4.84	16.1	170	63.0	94.5
W8×35	34.7	86.6	130	54.5	81.9	1.62	2.43	7.17	27.0	127	50.3	75.5
W14×22	**33.2**	**82.8**	**125**	**50.6**	**76.1**	**4.78**	**7.27**	**3.67**	**10.4**	**199**	**63.0**	**94.5**
W10×26	31.3	78.1	117	48.7	73.2	2.91	4.34	4.80	14.9	144	53.6	80.3
W8×31[f]	30.4	75.8	114	48.0	72.2	1.58	2.37	7.18	24.8	110	45.6	68.4
W12×22	**29.3**	**73.1**	**110**	**44.4**	**66.7**	**4.68**	**7.06**	**3.00**	**9.13**	**156**	**64.0**	**95.9**
W8×28	27.2	67.9	102	42.4	63.8	1.67	2.50	5.72	21.0	98.0	45.9	68.9
W10×22	**26.0**	**64.9**	**97.5**	**40.5**	**60.9**	**2.68**	**4.02**	**4.70**	**13.8**	**118**	**49.0**	**73.4**
W12×19	**24.7**	**61.6**	**92.6**	**37.2**	**55.9**	**4.27**	**6.43**	**2.90**	**8.61**	**130**	**57.3**	**86.0**
W8×24	23.1	57.6	86.6	36.5	54.9	1.60	2.40	5.69	18.9	82.7	38.9	58.3
W10×19	**21.6**	**53.9**	**81.0**	**32.8**	**49.4**	**3.18**	**4.76**	**3.09**	**9.73**	**96.3**	**51.0**	**76.5**
W8×21	20.4	50.9	76.5	31.8	47.8	1.85	2.77	4.45	14.8	75.3	41.4	62.1

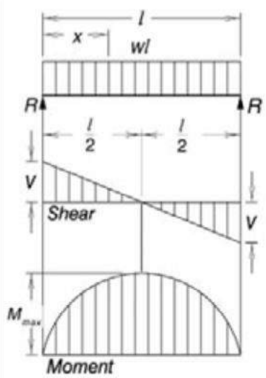
ASD	LRFD
$\Omega_b = 1.67$ $\Omega_v = 1.50$	$\phi_b = 0.90$ $\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.

[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with F_y = 50 ksi; therefore, ϕ_v = 0.90 and Ω_v = 1.67.

Table 3-23
Shears, Moments and Deflections

1. SIMPLE BEAM — UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load .... $= wl$

$R = V$ .... $= \frac{wl}{2}$

V_x .... $= w\left(\frac{l}{2} - x\right)$

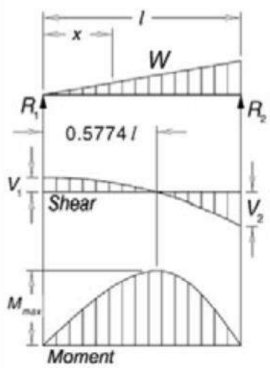
M_{max} (at center) .... $= \frac{wl^2}{8}$

M_x .... $= \frac{wx}{2}(l - x)$

Δ_{max} (at center) .... $= \frac{5wl^4}{384EI}$

Δ_x .... $= \frac{wx}{24EI}\left(l^3 - 2lx^2 + x^3\right)$

2. SIMPLE BEAM — LOAD INCREASING UNIFORMLY TO ONE END



Total Equiv. Uniform Load .... $= \frac{16W}{9\sqrt{3}} = 1.03W$

$R_1 = V_1$ .... $= \frac{W}{3}$

$R_2 = V_2 = V_{max}$ .... $= \frac{2W}{3}$

V_x .... $= \frac{W}{3} - \frac{Wx^2}{l^2}$

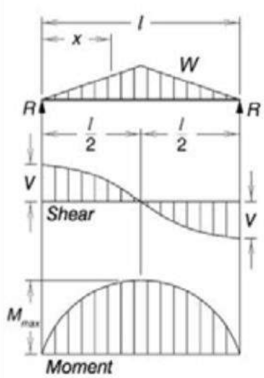
M_{max} $\left(\text{at } x = \frac{l}{\sqrt{3}} = 0.557\,l\right)$ .... $= \frac{2Wl}{9\sqrt{3}} = 0.128\,Wl$

M_x .... $= \frac{Wx}{3l^2}(l^2 - x^2)$

Δ_{max} $\left(\text{at } x = l\sqrt{1 - \sqrt{\frac{8}{15}}} = 0.519\,l\right)$ .... $= 0.0130\frac{Wl^3}{EI}$

Δ_x .... $= \frac{Wx}{180EIl^2}\left(3x^4 - 10l^2x^2 + 7l^4\right)$

3. SIMPLE BEAM — LOAD INCREASING UNIFORMLY TO CENTER



Total Equiv. Uniform Load .... $= \frac{4W}{3}$

$R = V$ .... $= \frac{W}{2}$

V_x (when $x < \frac{l}{2}$) .... $= \frac{W}{2l^2}\left(l^2 - 4x^2\right)$

M_{max} (at center) .... $= \frac{Wl}{6}$

M_x (when $x < \frac{l}{2}$) .... $= Wx\left(\frac{1}{2} - \frac{2x^2}{3l^2}\right)$

Δ_{max} (at center) .... $= \frac{Wl^3}{60EI}$

Δ_x (when $x < \frac{l}{2}$) .... $= \frac{Wx}{480EIl^2}\left(5l^2 - 4x^2\right)^2$

W10

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

F_y = 50 ksi

Shape		W10×									
lb/ft		54		49		45		39		33	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	473	711	431	648	398	598	344	517	291	437
	6	446	671	407	611	363	545	313	470	263	395
	7	437	657	398	598	350	527	302	454	253	381
	8	427	642	388	584	337	507	290	436	243	365
	9	415	624	378	568	322	485	277	416	232	348
	10	403	605	366	550	307	461	263	396	220	330
	11	389	585	354	532	291	437	249	374	207	311
	12	375	564	341	512	274	411	234	352	194	292
	13	361	542	327	492	256	385	219	329	181	272
	14	345	519	313	471	239	359	203	306	168	253
	15	330	495	299	449	222	333	188	283	155	233
	16	314	471	284	427	204	307	173	260	142	214
	17	297	447	269	404	188	282	158	238	130	195
	18	281	422	254	382	171	257	144	217	117	177
	19	265	398	239	360	155	234	130	196	106	159
	20	249	374	224	337	140	211	118	177	95.4	143
	22	217	327	196	294	116	174	97.2	146	78.8	118
	24	188	282	168	253	97.4	146	81.7	123	66.2	99.5
	26	160	240	143	216	83.0	125	69.6	105	56.4	84.8
	28	138	207	124	186	71.5	108	60.0	90.2	48.7	73.1
	30	120	180	108	162	62.3	93.7	52.3	78.6	42.4	63.7
	32	106	159	94.7	142	54.8	82.3	46.0	69.1	37.3	56.0
	34	93.5	141	83.9	126						
	36	83.4	125	74.8	112						
	38	74.8	112	67.2	101						
	40	67.6	102	60.6	91.1						

Properties

	54 ASD	54 LRFD	49 ASD	49 LRFD	45 ASD	45 LRFD	39 ASD	39 LRFD	33 ASD	33 LRFD
P_{wo}, kips	69.1	104	60.1	90.1	65.3	98.0	54.1	81.1	45.2	67.8
P_{wi}, kips/in.	12.3	18.5	11.3	17.0	11.7	17.5	10.5	15.8	9.67	14.5
P_{wb}, kips	112	168	86.6	130	94.2	142	68.7	103	53.7	80.7
P_{fb}, kips	70.8	106	58.7	88.2	71.9	108	52.6	79.0	35.4	53.2
L_p, ft	9.04		8.97		7.10		6.99		6.85	
L_r, ft	33.6		31.6		26.9		24.2		21.8	
A_g, in.^{2}	15.8		14.4		13.3		11.5		9.71	
I_x, in.^{4}	303		272		248		209		171	
I_y, in.^{4}	103		93.4		53.4		45.0		36.6	
r_y, in.	2.56		2.54		2.01		1.98		1.94	
r_x/r_y	1.71		1.71		2.15		2.16		2.16	
$P_{ex}(KL)^2/10^4$, k-in.^{2}	8670		7790		7100		5980		4890	
$P_{ey}(KL)^2/10^4$, k-in.^{2}	2950		2670		1530		1290		1050	

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

Note: Heavy line indicates KL/r_y equal to or greater than 200.

Table 17–13
Weights of Building Materials

Materials	Weight lb per sq ft	Materials	Weight lb per sq ft
CEILINGS		**PARTITIONS**	
Channel suspended system	1	Wood Studs, 2 × 4	
Lathing and plastering	See Partitions	12-16 in. o. c.	2
Acoustical fiber tile	1	Steel Studs	
		12-16 in. o. c.	1
FLOORS		Drywall, 1/2 in.	2
Steel Deck	See Manufacturer	Drywall, 5/8-in.	2 1/2
Concrete-Reinforced, 1 in.		Plaster, 1 in.	
Stone	12 1/2	Cement	10
Structural Lightweight	9 1/2	Gypsum	5
Concrete-Plain, 1 in.		Lathing	
Stone	12	Metal	1/2
Structural Lightweight	9	Gypsum board, 1/2 in.	2
Non-Structural Lightweight	3 to 9		
Finishes		**WALLS**	
Terrazzo, 1 in.	13	Brick	
Ceramic or Quarry Tile 3/4-in.	10	4 in.	40
Linoleum 1/4-in.	1	8 in.	80
Mastic 3/4-in.	9	12 in.	120
Hardwood 7/8-in.	4	Hollow Concrete Block	
Softwood 3/4-in.	2 1/2	(135 pcf-No Grout/Full Grout)	
		4 in.	29/-
ROOFS		6 in.	30/62
Copper	1	8 in.	39/83
Corrugated steel	See Manufacturer	10 in.	47/105
3-ply ready roofing	1	12 in.	54/127
3-ply felt and gravel	5 1/2	Hollow Concrete Block	
5-ply felt and gravel	6	(125 pcf-No Grout/Full Grout)	
Shingles		4 in.	26/-
Wood	2	6 in.	28/59
Asphalt	3	8 in.	36/81
Clay tile	9 to 14	10 in.	44/102
Slate, 1/4 in.	10	12 in.	50/123
Sheathing		Hollow Concrete Block	
Wood, 3/4 in.	3	(105 pcf-No Grout/Full Grout)	
Gypsum, 1 in.	4	4 in.	22/-
Insulation, 1 in.		6 in.	24/55
Loose	1/2	8 in.	31/75
Poured	2	10 in.	37/95
Rigid	1 1/2	12 in.	43/115
		Stone, 4 in.	55
		Glass Block, 4 in.	18
		Curtain Walls	See Manufacturer
		Structural Glass, 1 in.	15

For weights of other materials used in building construction, see Table 17-12.
See ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures for additional design dead loads.