HUB Renovations & Addition

The Pennsylvania State University
University Park, PA

Final Report

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Construction Management
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HUB RENOVATIONS & ADDITION

THE PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA

PROJECT OVERVIEW

Building Function: Student Union Center
Overall Project Cost: $44.6 Million
Size: 40,000 GSF Renovation
64,000 GSF New Construction
Project Delivery Method: CM at Risk
Contract Type: GMP Contract

PROJECT TEAM

Owner: The Pennsylvania State University
Construction Manager: Gilbane Building Company
Architect: GUND Partnership
Structural Engineer: LeMessurier Consultants
M/E/P Engineer: Vanderweil Engineers
Civil Engineer: Sweetland Engineering & Assoc.

ARCHITECTURE

Renovated Book Store / New THON Merchandise Store
New Seating/Lounge Space
Habitable Green Roof
Brick Veneer & Glazed Aluminum Curtain Wall System

PENNSTATE

1855

STRUCTURAL

Foundation: Spread Footings & Micropiles
Canopy Truss Roofing System
Laterally Braced Structural Steel Framing
18 GA Composite Steel Decking

ELECTRICAL

New 480/277V Transformer
Low Voltage MDS - 1600A, 3ϕ, 4W, 480Y/277V
4 Switchboards: 3 New, 1 Existing
Lighting: Mixture of fluorescents and LED's

MECHANICAL

VAV and Single Zone Systems
Automatic Wet Pipe Sprinkler System
Finned Tube Radiators
Fan Coil Units

ROBERT JUSTIN BARLOW | CONSTRUCTION OPTION

http://www.engr.psu.edu/ae/thesis/portfolios/2014/rjb5258/index.html

Executive Summary

Over the fall 2013 and spring 2014 academic year, the HUB Renovations and Addition Project of The Pennsylvania State University was analyzed in order to identify areas that had potential to enhance the project overall. Through countless hours of research, feedback from academic members, the project team, multiple site visits, and construction professionals, four main areas were focused on for further analysis. The following report presents the four analyses performed as part of The Pennsylvania State University Architectural Engineering Senior Capstone Project. The purpose of this thesis project is strictly educational and is not intended to critique the work performed by the project team in any way.

Analysis # 1: Schedule Resequence

The first analysis addressed the feasibility of resequencing the interior bookstore phase of the original schedule. Analyzing the schedule by decreasing unnecessary float, sequencing improvements, and schedule overlap the schedule was looked to be improved. Areas of the project were looked at in order to accelerate the schedule which later analyses touch on. In addition, the lean principle of Last Planner was investigated for implementation on a project such as the HUB. The project team is encouraged to use the suggested acceleration techniques as well as the idea of Last Planner to make up for schedule delay.

Analysis # 2: Terra Cotta Rain Screen Redesign

Nearly half of the renovations and addition on the HUB façade is comprised of a complex terra cotta rain screen. This analysis addresses the need for schedule acceleration by providing an alternative brick veneer design. By switching the rain screen to brick veneer the project was able to save over a week of work days on the exterior façade of the bookstore alone, while saving $64,143.18. With similar thermal properties analysis and acceptable structural loading, the project team is encouraged to use the alternative design to provide schedule and cost savings.

Analysis # 3: GPS Material Tracking System – Structural Steel

Topics discussed during The 22nd Annual PACE Roundtable by construction professionals led to the research portion provided in the third analysis. With a Just-In-Time delivery system for the structural steel a GPS tag tracking system will help ensure quality control by preventing schedule delays. The cost of the tracking system is roughly $88,150 and the schedule would not see any savings. Although the technology to track the steel pieces will promote quality control, implementation would not benefit the project team due to the cost impact on a project of this size.

Analysis # 4: Removal of Habitable Green Roof Design

The final analysis looks at the current design of the habitable green roof to be constructed on the existing bookstore roof. Providing an alternative cool roof design will further address the need for schedule acceleration due to unforeseen issues. The alternative design provides a cost savings of $154,896.00 and a schedule savings of 40 work days. The project team is encouraged to use the alternative design due to the cost and schedule savings of switching the design of an already existing roof structure.

Acknowledgments

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Gilbane

GUND PARTNERSHIP

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Gilbane Project Team

Derek Stoecklein

Devon Saunders

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Project Information

Background

The proposal for the HUB Renovations and Addition was made public over three years ago when the need for expansion of one of the most popular buildings on The Penn State University's campus arose. The HUB-Robeson Center was first constructed in 1955 as the student union center for the university and with the increase in student enrollment and the university itself the building has been renovated and expanded multiple times. With the amount of student and public traffic through the HUB daily the need for further expansion was required with the new proposal.

Drawing funds from Student Facilities, Barnes & Nobles, HUB Reserves, and Food Services the HUB Renovations and Addition will involve the following key improvements to the student union building: new seating, new lounge space, a new THON merchandise store, renovated bookstore, renovated food court, and relocation of various retail venues. Once the bids were made public the project team of the architect, GUND Partnership and the Construction Management Firm, Gilbane Construction Company emerged. The project was presented in front of Penn State's Board of Trustees and once approved; construction began in May of 2013.

The focus of this report is the HUB Renovation and Addition Project. The project has a LEED Silver Certification and is slated for 64,000 GSF of new construction and 40,000 GSF of renovation. Figure 1 displays the architect's rendering of the project.

Figure 1: Rendering of HUB-Robeson Building East Entrance | Image courtesy of Penn State

Existing Conditions

The HUB-Robeson Building is located on East Pollock Road in the heart of The Penn State University's campus in University Park, PA. With annual enrollment of more than 45,000 graduate and undergraduate students The Penn State University is one of the largest universities in the United States. The amount of student and pedestrian traffic around and through the HUB itself raises safety and logistical issues. In order to ensure the safety of those around the site multiple access maps were developed and posted. The maps provide access points for the public due to the east entrance being closed during construction. Construction fence surrounds the entire site and access to the site is carefully monitored due to the large amount of traffic around the site. Major access to the site for materials, equipment and are limited to main gate at East Pollock Road to eliminate congestion on campus.

The construction trailers for project team offices will be located offsite across East Pollock Road in the parking lot behind The Ritenour Building. These trailers are located off the construction site due to the limited amount of space around the HUB. Throughout the lifetime of the project multiple areas around the HUB will have temporary partitions in order to direct pedestrian traffic flow through and around the building. A main aspect of the project is the transfer of the bookstore into a temporary location on the HUB lawn. The temporary bookstore is comprised of 22 trailers and provides the same amenities as the current bookstore in order to supply books and retail items to students and the community. Figure 2 depicts the location of the HUB Project on campus.

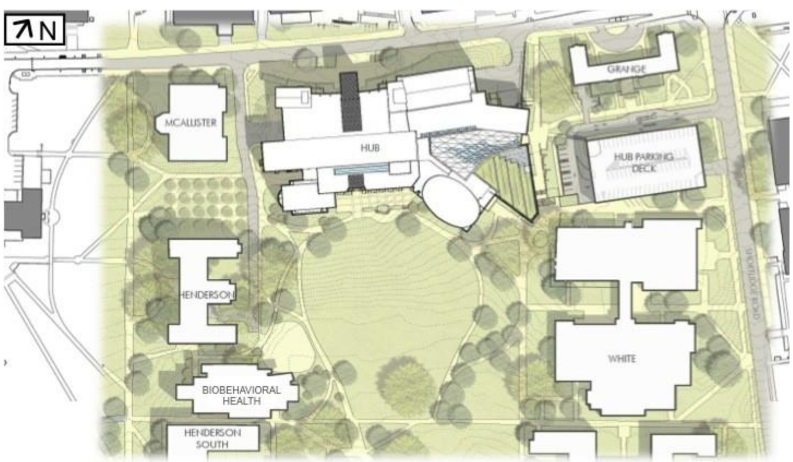

Figure 2: HUB Location on Campus | Image courtesy of Penn State

Delivery Method

Gilbane is the single prime contractor working on the HUB Renovation and Addition. A Guaranteed Max Price contract is held between Penn State and Gilbane. Penn State has a separate contract with GUND Partnership who is serving as the lead Architect for the project. Subcontractors needed to be prequalified with Gilbane and then bids were formally submitted through Penn State.

Project Schedule

The project schedule incorporates a summary of major construction activities occurring at the HUB. This includes the design phase, procurement, preconstruction and construction activities. Due to parts of the project being turned over to Penn State before the entire project is complete, the construction has been split into phases. As previously stated construction began in May of 2013 and the project has a planned turnover date of March 2015. Figure 3 breaks down the start dates of the major construction activities.

Concerns of the existing structural foundation of the building and contractual issues have delayed the project. The analyses for the report focus on promoting schedule acceleration in order to make up for these potential delays. For the following report all duration and dates are based of the original baseline schedule used during bidding.

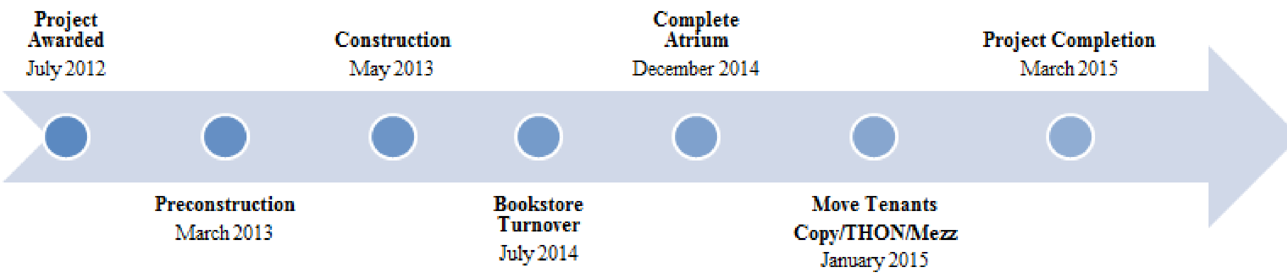

Figure 3: Project Timeline | RJB

Project Cost

The total building construction cost of the HUB Renovations and Addition is $30 Million. The overall project cost is set at $44.6 Million; Table 1 provides a cost breakdown.

Table 1: Project Cost Breakdown | RJB

Project Cost Breakdown	
Description	**Cost**
Building Cost	**$30,000,000**
Project Cost	**$44,600,000**
HVAC Cost	$4,000,000
Plumbing Cost	$550,000
Electrical Cost	$2,800,000
Structural Cost	$3,500,000

Building System Overview

Structural Steel

The structural system for the HUB project consists of concrete fill on steel deck and composite that bears on structural steel framing. The structure is framed with both, non-composite and composite beams connected with a blend of shear and moment connections. All the bracing for the frame utilizes HSS shapes, where all other structural steel is mostly W shaped steel. During the project duration one tower crane will be used located towards the HUB parking deck.

Mechanical System

The new work set on the project consists of seven AHU units supplying air to the bookstore, the atrium, multipurpose areas and to other existing areas. All the units will be Trane, M Series model ranging in supply 6,600 CFM to 22,000 CFM. These units will consist of both variable-air-volume (VAV) and single-zone air-handling units.

The fire suppression for the entire renovation/addition will comprise of a hydraulically-calculated automatic wet-pipe sprinkler system. All valves shall be equipped with supervisory switches and be provided with lockout covers to prevent tampering.

Electrical System

A new transformer rated at 480/277V will run primary feeder from PSU distribution to a new low-voltage main distribution switchgear that has a rating of 1600A, 3ϕ, 4W, 480Y/277V. This MDS runs to four switchboards, two rated at 208Y/120V, 3ϕ, 4W, 800A, one rated at 480Y/277Y, 3ϕ, 4W, 800A and an existing one rated at 480Y/277Y, 3ϕ, 4W, 2000A. These four switchboards feed panel boards which supply certain areas of the building.

Terra Cotta Rain Screen System

Similar to other newer buildings on campus the HUB Renovations and Addition incorporates newer architectural features with the more traditional aesthetics of the university. Nearly half of the HUB Project's façade is comprised of terra cotta rain screen with another quarter made up of aluminum curtain wall. The terra cotta is a unitized panel system with panels anchored to an aluminum track support in order to allow for thermal movements.

Aluminum Curtain Wall System

The enclosure for the atrium/courtyard area of the addition is aluminum glazed curtain wall. A pressure equalization design has been chosen with all components silicon compatible to provide durability. The curtain wall is aesthetically pleasing with concealed fasteners to create an unbroken line and an unchanging look. The curtain wall is also incorporated along with the terra cotta rain screen system throughout the exterior of the building.

Habitable Green Roof

The HUB Project introduces the first habitable green roof to a university which strives to learn, live, and lead in sustainability practices. The green roof will help advance sustainable architecture and design on campus and will provide several environmental benefits. The extensive green roof design will cover nearly 8,000 SF of the bookstore existing roof structure. The rendering of the east entrance in Figure 4 shows the habitable green roof, aluminum curtain wall system, and the terra cotta rain scree system.

Figure 4: Rendering of HUB-Robeson Building East Façade | Image courtesy of Penn State

Analysis #1: Schedule Resequence

Problem

The structural conditions of the existing portion of the HUB created a potential delay in the project schedule. This creates multiple scenarios for potential schedule acceleration in order to make up a large portion of the time that could be lost due to the structural issue. With the original schedule focusing on specific turn over dates for each phase of the project, the potential acceleration will focus around each one of these crucial phases.

Research Goal

The goal of this analysis is to establish the best schedule sequence for the overall project in order to keep the original turn over dates in tack. The original schedule constraints will be analyzed in order to figure out which phases have areas of flexibility and which phases have the largest areas for issues. Once the main areas are uncovered one phase will be analyzed in order to focus on areas of concern. Possible schedule techniques for these areas include the following; crashing, shifting work, and working on concurrent activities at once. After analyzing multiple options, the most efficient process will be suggested in order for the project team to create a more efficient schedule sequence.

Methodology

- Analyze the original schedule
  - Discover the schedule constraints
- Evaluate the areas with potential flexibility - (Issue Areas)
  - Review areas with Gilbane Project Team & AE Faculty - (Advisor: Robert Leicht)
- Develop potential option(s) for the project sequence – (Focused around Issue areas)
- Evaluate the potential option(s)
  - Review the option(s) with Gilbane Project Team & AE Faculty – (Advisor)
- Suggest the most efficient option to implement
- Research Lean Construction Practices (The Lean Construction Institute)

Resources

- Gilbane Project Team - (Project Manager: Randy Holman, Project Engineer(s): Derek & Devin)
- AE Faculty - (Advisor: Robert Leicht)
- Other Industry Professional(s) – (OPP Staff Members)
- Schedule Software (P6)
- The Lean Construction Institute

Expected Outcome

The potential for delay of the initial schedule allows for the option of resequencing multiple phases of the project. The delay occurred during the demolish phase of the project creating many opportunities to improve upon the schedule. Through a sequencing analysis the schedule is to provide the project team with the best techniques to help maintain the original deadlines. Through the investigation of Lean Construction principles a more efficient way of reducing the schedule will be presented.

Original Schedule

In order to complete a project resequencing analysis the first step is to study the existing schedule to identify areas that can be resequenced or adjusted. The overall schedule was broken down into 9 different construction sections shown in Table 2. Each phase was evaluated separately for sequencing improvements and the potential for actives to overlap. After studying the multiple phases focus for major schedule resequencing shifted towards the Bookstore Interior.

Table 2: Detailed Schedule Summary | RJB

Detailed Schedule Summary			
Description	**Start Date**	**End Date**	**Total Duration**
Sitework	26 February 2014	24 December 2014	43 Weeks
Lobby	16 May 2013	05 September 2014	68 Weeks
Atrium/Courtyard	16 July 2013	09 April 2014	38 Weeks
Courtyard Interiors	09 April 2014	24 December 2014	37 Weeks
Bookstore Interior	16 May 2013	18 July 2014	61 Weeks
Bookstore Exterior	02 December 2013	14 February 2014	10 Weeks
MPR Volume	25 October 2013	29 May 2014	30 Weeks
Overbuild	25 September 2013	26 February 2014	22 Weeks
Food Service Renovation	05 May 2014	15 August 2014	14 Weeks

The HUB Roberson Center is home to The Pennsylvania State University, University Park's Official Bookstore. The bookstore supplies textbooks, supplies, electronics, Penn State apparel and much more to nearly 45,000 students and the residents of the surrounding community. The turnover of the bookstore back to the University was originally set for mid-July of 2014 however due to unforeseen structural issues the new date for the basement area of the bookstore is September 2014. During the renovation and addition of the HUB a temporary bookstore was set up outside the building in 22 trailers. Although Penn State owns the land and trailers not having the permanent bookstore in the student union center of one of the largest universities in the nation causes some concerns. Focusing on the turnover of the bookstore will help deal with unforeseen issues while ensuring a pleased owner.

Bookstore Interior

The activities in the Bookstore Interior Phase are the focus of the study for this analysis. Focusing on one phase of the project will help to find areas of improvement that may be able to be used in other phases of the project. Figure 5 below shows the original bid schedule for the Bookstore Interiors.

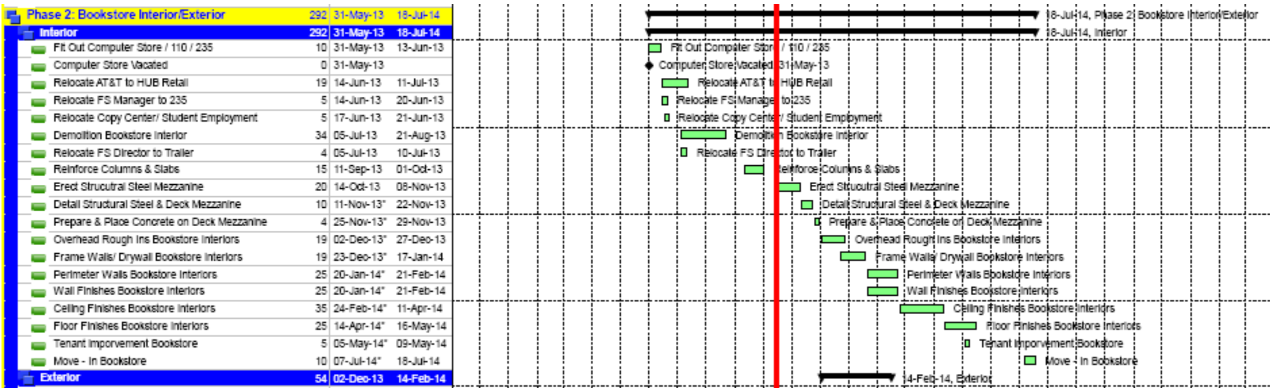

Figure 5: Bookstore Interior Schedule | RJB

The first step in the evaluation process was to assess the activities for any unnecessary float or days where no work was scheduled. An example of unnecessary float is evident between relocation of copy center and the start of interior demolition. There is a 10 day work gap between the first activity ending and the other beginning. After discovering gaps similar to this one, each needed to be analyzed individually in order to identify the purpose of the gap and if there was room for improvement. Once each gap was analyzed if the gap was not required, i.e. the start of interior demolition, it has potential to be removed or reduced from the schedule.

After analyzing the gaps between line items, the schedule was studied for potential sequencing improvements. Once the foundation work is complete in the lower levels of the bookstore, the remaining work is on the main floor of the bookstore and new mezzanine level. The basement level of the bookstore holds the entire inventory for the bookstore retail items. Allowing the bookstore occupants to move the large amount of inventory into the basement will help save time instead of turning the bookstore over as a whole. Partial occupation does involve certain regulations that would have to be looked into. New egress plans would have to be created as well as occupant permitting to allow spaces to be occupied while others are under construction. The bookstore itself has always been scheduled to be turned over before the entire project completion date. Along with the bookstore area, the lobby outside the bookstore contains the only accessible entrance during construction so finishing the lobby would be another crucial area of acceleration in order for turnover to occur.

The final way the bookstore interior phase was analyzed in order to be altered was through the study of potential scheduling overlaps. After studying the bookstore phase itself, there were no areas for overlapping activities. When looking to save time by schedule overlapping multiple phases of the project needed to be looked at. For example moving the start of the overbuild up to start the foundation work while demolition in the bookstore is in progress could have potential to accelerate the overall project schedule.

Areas of Schedule Acceleration: Building System

While studying the project schedule for areas of schedule resequencing scenarios the possibility of changing the current Terra Cotta façade system came up. This has potential for major schedule savings and potential cost savings. Analysis 2 provides an in-depth investigation into switching the Terra Cotta façade. It details the potential schedule acceleration of switching to an alternative façade of the exterior of the bookstore. Another area of schedule acceleration is the design of the roof for the bookstore.

Analysis 4 details the removal of the Green Roof proposed for the roof over top of the existing bookstore. The analysis breaks down the potential schedule savings of changing the Green Roof to an alternative design. For the results of changing the façade system and developing an alternative bookstore roofing design refer to the schedule impact section in each relevant analysis. Table 3 displays the current schedule for the bookstore exterior.

Table 3: Schedule Bookstore Exterior | RJB

Schedule Breakdown – Bookstore Exterior			
Description	**Start Date**	**End Date**	**Total Duration**
Roof Membrane	02 December 2013	13 December 2013	10 Days
Exterior Façade Terra Cotta	02 December 2013	17 January 2014	35 Days
Green Roof / Accessories	16 December 2013	24 January 2014	30 Days
Install Green Roof - Planting	27 January 2014	14 February 2014	15 Days

Last Planner System

The Last Planner System (LPS) developed in association with the Lean Construction Institute is a "production planning system designed to produce predictable work flow and rapid learning in programming, design, construction and commissioning of projects" (The Last Planner, 2014). Examples of the lean process have been presented through case studies and industrial experiences throughout the Architectural Engineering curriculum. Las Planner is a short-term project planning system used in engineering construction for over 20 years in order to make improvements in project and program safety, predictability, productivity, speed of delivery, profit and feeling of wellbeing among project staff. Similar to issues that arise on the HUB Project, much of construction management is dealing with issues that have gone wrong in an effort to get back on track.

LPS uses five key conversations that each brings its own benefits, and are listed below

1. **Collaborative Programming** – creating and agreeing the production sequence
2. **MakeReady** – Making tasks in the look ahead period ready so that they can be done when needed
3. **Production Planning** – collaboratively agreeing production tasks for the next day or week
4. **Production Management** – collaboratively monitoring production to keep activities on track
5. **Measurement, learning and continual improvements** – learning together

LPS is a production control system designed to ensure the achievement of agreed goals. A collaborative programming process is used to set these goals as a way to engage the entire team from the start. Involving all major players early in the process helps to ensure the critical interdependencies and risks are discussed. There are multiple benefits of collaborative programming which include the following: preparing team members for action together, discuss details much sooner, sort out sequencing and other issues that would be difficult to change later, enable teams to test options while improving workflow, identifies unclear design details, and builds commitment to program and reduces overall schedule period. LPS promotes the use of the important words, "I don't know" which are important in all conversations and some people will do anything to avoid saying them. Promoting the use of these words will help other members of the team help one another to be successful. The second conversation helps to look ahead in the project schedule.

The MakeReady process systematically checks that everything is in place for each of the tasks in the look ahead. The MakeReady process has benefits such as tasks are ready for production when required, safer working/planning, and a greater certainty of time, materials and equipment with less waste. The third conversation deals with production tasks for the upcoming days or week. Production evaluation and planning (PEP) meetings are incorporating in all last planners. Depending on the length of a project, shorter daily work planning may be required but generally PEP meeting occur weekly. The purposes of these meetings are to review and learn from the work done in the previous periods. This allows planning the work that will be done in the next period. The benefits of PEP meeting as it pertains to Last Planner are as follows: maintains commitment to the intention of the project and current client concerns, suppliers prepare better because they know what's expected of them, builds relationships between supplier team leaders, focuses attention on what can really be done, and facilitates learning from experiences. The fifth conversation in LPS helps improve promise reliability and the predictability of production plans.

The Collaborative Programming and Production Planning conversations help to develop the social process in construction promoting a shared sense of responsibility for project delivery. Implementing daily stand-up meetings on site or by phone detailing the work completed the day before. This allows detecting early warning of any late deliveries and enables the team to renew deadlines based on last minute adjustments. Depending on the project, production planning and production management are combined in a daily meeting. The sixth and final conversation promotes learning together about and improving project, planning and production processes. Measurement, learning and continual improvement is the basis for evaluation process in a PEP meeting. Continual improvement elements contribute to more predictable and reliable workflow. When all these conversations are working together they reinforce each other and the overall benefits are greater.

The effect of implementing Last Planner on the HUB Project could result in major schedule savings. This could help benefit the perimeter enclosure as well as the project as a whole. According to the Lean Construction Institute not only does schedule duration and costs decrease but accident frequency decrease as well when LPS is used. Last Planner is a registered trademark by The Lean Construction Institute. The Lean Construction Institute requires their consent before implementing Last Planner in order to ensure the system is being properly used.

Conclusion

This analysis has evaluated the possibility of removing gaps in construction activities, looking at the schedule for sequencing improvements and overlaps, alternative design for schedule acceleration, and a look into project management methods for more lean construction practices. The project team is encouraged to analyze the schedule for gaps in activities and the ability to overlap phases in order to meet the turn over deadlines set by the university. It is strongly recommended that the project team implement Last Planner System as a lean building tactic due to its capability of reducing schedules. The schedule effect of the alternative design for the exterior façade and Green Roof are provided in Analysis 2 and Analysis 4.

Analysis #2: Terra Cotta Rain Screen Redesign

Problem

The current façade of the existing building consists of mainly brick veneer and the new design implements multiple new facades types. Roughly half of the surface area of the building façade is comprised of a complex terra cotta rain screen. The step-by-step installation process for each fragile piece of terra cotta is labor intensive and time consuming. With the structural concerns leading to potential delays in schedule this analysis will provide a further area for schedule acceleration.

Research Goal

The purpose of this analysis is to look into an alternate system for the terra cotta rain screen that will allow for schedule acceleration. The total square footage of each type of exterior façade will be analyzed based on the cost and time required for each system. With the new design an updated schedule will be produced and a comparison between the original schedule will be developed. An estimate and cost comparison between the original and re-design will provide further analysis of the two systems.

Methodology

- Establish the Square Footage of each façade type
- Establish the scope & production rates for each façade type
- Develop a schedule comparison between original & new design
- Develop an estimate and cost comparison between the original & new design
- Develop Energy Study based off Thermal properties of façade components
- Develop Structural Study – Check to ensure new loading is acceptable

Resources

- Gilbane Project Team - (Project Manager: Randy Holman, Project Engineer(s): Derek & Devin)
- Design Team (GUND Partnership)
- AE Faculty - (Advisor: Robert Leicht, Moses Ling)
- Other Industry Professional(s) – (OPP Staff Members)
- Material Specifications
- Construction Drawings
- Mechanical Software
- Structural Software

Expected Outcome

The expected outcome of this analysis is to provide a new system that will accelerate the schedule without taking away from the overall architectural vision of the design team and owner. Ultimately this will save time and money with a reduced labor and equipment requirement to install the new system. Along with the resequencing of the phases this will allow the project to make up for potential delays.

Building Façade Study

In order to develop an alternative façade choice to implement into the project the current design for the addition and renovation was analyzed to determine the overall square footage of each. Terra cotta rain screen covers nearly 50 percent of the exterior of the building with the remainder consisting of the following: Aluminum Glazed Curtain Wall (25%), Brick Veneer (14%), and Metal Paneling (10%). The aluminum glazed curtain wall encloses the atrium/courtyard area of the addition and includes a complex canopy roofing system. Although the brick veneer is the third most commonly used façade type on the new design, due to the amount of brick on the current building and surrounding campus, using brick veneer as a substitute for the terra cotta rain screen was chosen. Table 4 breaks down the façade types further.

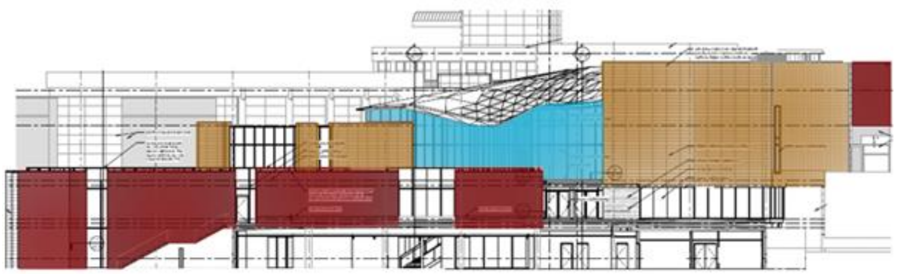

Figure 6.1: East Building Facade | RJB

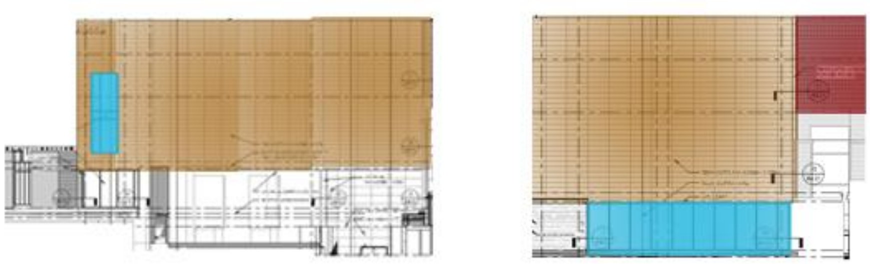

Figure 6.2: North Building Facade | RJB

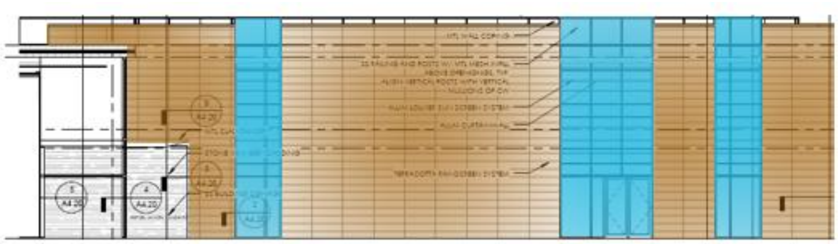

Figure 6.3: West Building Façade | RJB

Terra Cotta Rain Screen **Brick Veneer** **Curtain Wall**

Table 4: Facade Breakdown | RJB

Façade Description				
Description	**Area (SF)**	**Percentage**	**Cost / SF**	**Weight (PSF)**
Terra Cotta Rain Screen	13812.03	51%	$38.00	25
Aluminum Glazed Curtain Wall	6811.56	25%	--	--
Brick Veneer	3776.4	14%	$5.00	65
Metal Paneling	2658.22	10%	--	--
Total:	27058.21	100%	--	--

Switch to Brick Veneer

The current terra cotta rain screen system is by Shildan Inc. and features Alphaton terra cotta panels that rest onto aluminum frames by means of a support grid with hooks that the panels rest onto. Figure 7 below shows the process of installing such a system with exterior sheathing attached first. Horizontal substructure aluminum extrusion or metal braces, are then attached to the exterior structure before two and half inches of insulation can be installed. The horizontal extrusions are what provide structural support. Once the vertical spacers are installed, the Alphaton terra cotta panels can be hung from them to complete the rain screen system. All of these steps must be completed in a subsequent order with the use of lifts which is very time-consuming.

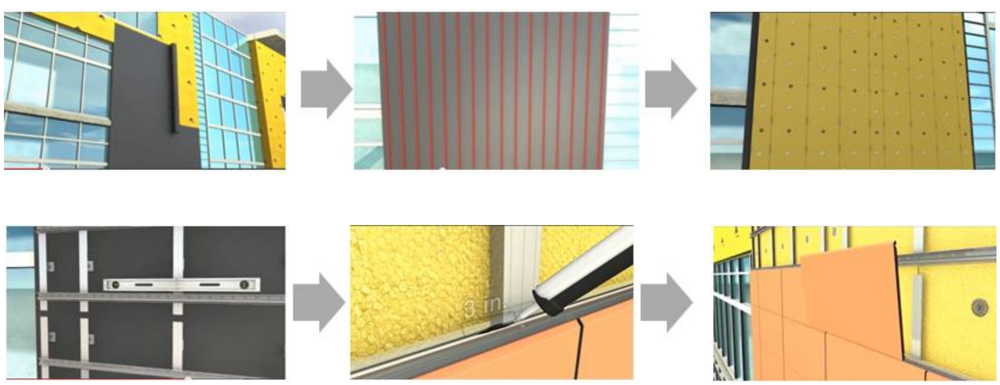

Figure 7: Terra Cotta System Installation Steps - Pictures Courtesy of Cladding Corp. (www.claddingcorp.com)

Although the terra cotta system is time-consuming there are advantages to the system which factored into the decision to use it in the design. The following are long term benefits which will help the owner in the long run. Since the insulation is outside of the air/vapor barrier the contestation is continually evaporating due to air movement, providing a higher insulation value which reduces the energy consumption of the building. This will help with provide better comfort and productivity from the occupants. The terra cotta panels do not have calcium leakage or efflorescence effect and can simply be cleaned with water unlike that of a brick façade. The natural ventilation prevents the growth of mold or mildew from occurring in the walls of the building. This allows the terra cotta system to provide a 100-year façade to the building.

A large portion of Penn State's buildings consist of brick façade including the existing structure of the HUB-Robeson building. Introducing such a large square footage of new façade to a building may add character to the campus but does not benefit the University as much as it would another owner. Maintenance on campus is used to dealing with brick veneer and understands how to deal with such issues as calcium leakage or efflorescence effect. Although issues do come up in buildings as they age overtime however the knowledge at Penn State keep the issue of mold and mildew from becoming an issue. Switching the original design from terra cotta rain screen to brick veneer will allow Penn State to continue the continuity of red brick across the campus as well as keep the maintenance work constant from building to building.

Terra Cotta Rain Screen System vs. Brick Veneer: Physical Components

The physical components of the terra cotta rain screen system and brick veneer are similar however the location of the vapor barrier differs in the make-up of the wall. Each façade type utilizes a continuous AVB membrane and 2.5" Mineral Wool Insulation. The terra cotta rain screen system from exterior inwards consists of the following: Terra Cotta Panel (Alphaton Panel), 2.5" Mineral Wool, Continuous AVB Membrane, ½" Sheathing, and a 6" Metal Stud. Similarly the brick veneer from exterior inwards consists of the following: Brick Façade (8" Brick), Brick Ties (as required), Airspace, 2.5" Mineral Wool Insulation, and a Continuous AVB Membrane. The components within each system were looked at in order to define the scope of work for each system.

The overall dimensions difference of each wall system is 1.125" with the terra cotta rain screen and brick veneer totaling 1' – 4 3/8" and 1' – 5 1/2" respectively. Figure 8.1 shows a dimensioned detail of both the terra cotta rain screen system and Figure 8.2 shows the brick veneer detail. The overall difference in the components of the each system is due to the amount of time spent installing each component.

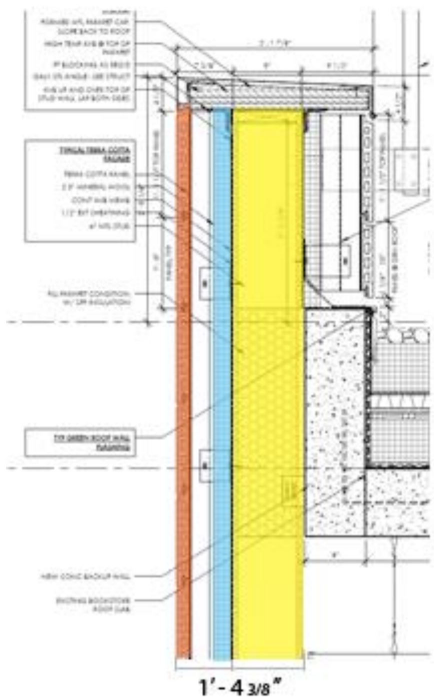

Figure 8.1: Terra Cotta Detail | RJB

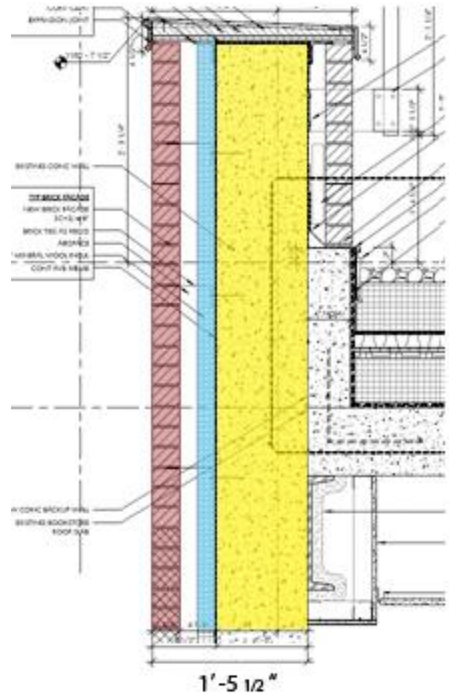

Figure 8.2: Brick Veneer Detail | RJB

The terra cotta rain screen system requires a great deal of time spent installing the horizontal and vertical metal grid system that the Alphaton Panel will attach to. Once the exterior sheathing is installed the anchors and vertical metal grids are installed. Next the insulation is installed before the horizontal grid is put in place and this takes some time due to the requirements for it to be level in order to have the Alphaton Panel connect to one another correctly. Once the panels are ready to be installed the remaining process goes by quickly. Each panel requires fasteners which will help connect it to the horizontal grid and one by one each panel will connect to one another completing the terra cotta rain screen system. Unlike the rain screen system most of the time spent installing the brick veneer occurs in laying the brick itself.

Similar to the terra cotta rain screen system the brick veneer requires the installation of and AVB membrane, insulation and the outside layer of masonry. However, more time is spent in the exterior of the system than the interior; it takes much longer to lay bricks than it does to connect the terra cotta panels to the building. Brick veneer is a common façade type and trades are used to laying brick compared to installation of terra cotta panels. This will allow for the brick veneer to be completed without a learning curve which may occur when installing an unfamiliar system like the terra cotta rain screen system.

Mechanical Breadth

The change in façade type from the terra cotta to the brick veneer will not only affect the buildings aesthetics but will also affect the overall energy performance of the building. Through this Mechanical Breadth the thermal properties of both the existing and new façade systems will be looked at and used to perform a simple energy model of the bookstore.

R-Values

With the change in façade systems the overall thermal properties of the systems are different and will therefore affect the building. Each system is constructed of materials which have a unique R-Value. Depending on the location and combination of the materials, the systems will have different thermal properties. Using the HAM Toolbox both the terra cotta system and the brick veneer system were analyzed to determine the overall R-Value of each one. The overall R-Values are shown below, the terra cotta values are in Table 5 and the brick veneer values are in Table 6. The calculations from the HAM Toolbox are provided in Appendix C.1-C.2.

Table 5: Terra Cotta R-Values

Terra Cotta Façade Assembly – R Values	
Construction Material	**R-Value (per thickness hr.*ft2*F/BTU)**
Terra Cotta Block	0.54
Mineral Wool	8.90
AVB Membrane	0.12
Exterior Sheathing	0.64
Metal Stud	0.12
Total:	**10.32**

Table 6: Brick Veneer R-Values

Brick Veneer Façade Assembly – R Values	
Construction Material	**R Value (per thickness hr.*ft2*F/BTU)**
Brick	0.64
Air Cavity	0.98
Mineral Wool	8.90
AVB Membrane	0.12
Exterior Sheathing	0.64
Metal Stud	0.12
Total:	**11.40**

The brick veneer assembly contains an air cavity which accounts for one more layer than the terra cotta assembly. Also, the brick provides a higher R-Value than the terra cotta helping the brick veneer assembly to obtain a slightly higher overall R-Value. When comparing the two façade assemblies, the new façade assembly has a higher R-Value than the original façade assembly. The brick veneer provides an R-Value of 11.40 hr*ft^2*F/BTU compared to 10.32 hr*ft^2*F/BTU provided by the terra cotta. The R-Values of the original and new assembly can only provide so much information, so in order to obtain a more in-depth understanding of the thermal properties a simple energy model was developed.

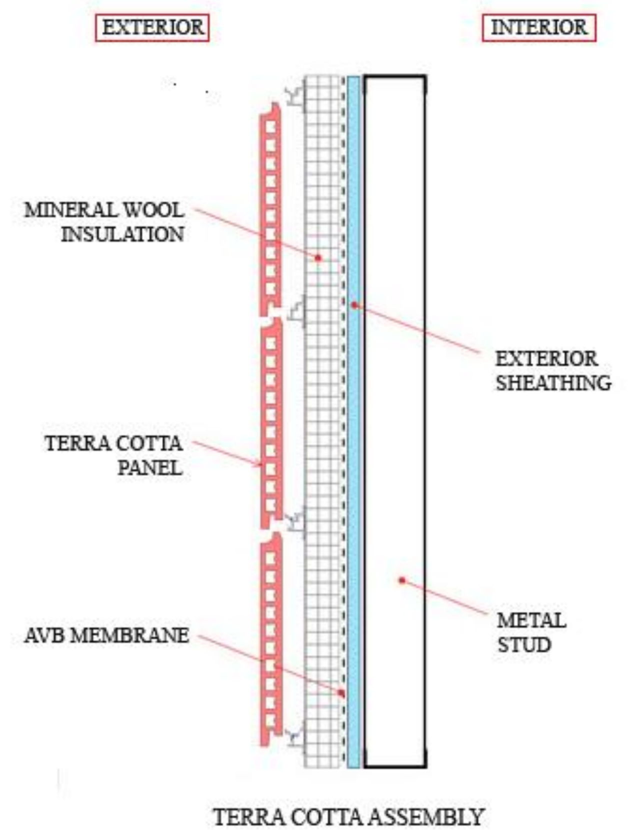

Figure 10.1: Terra Cotta Assembly | RJB

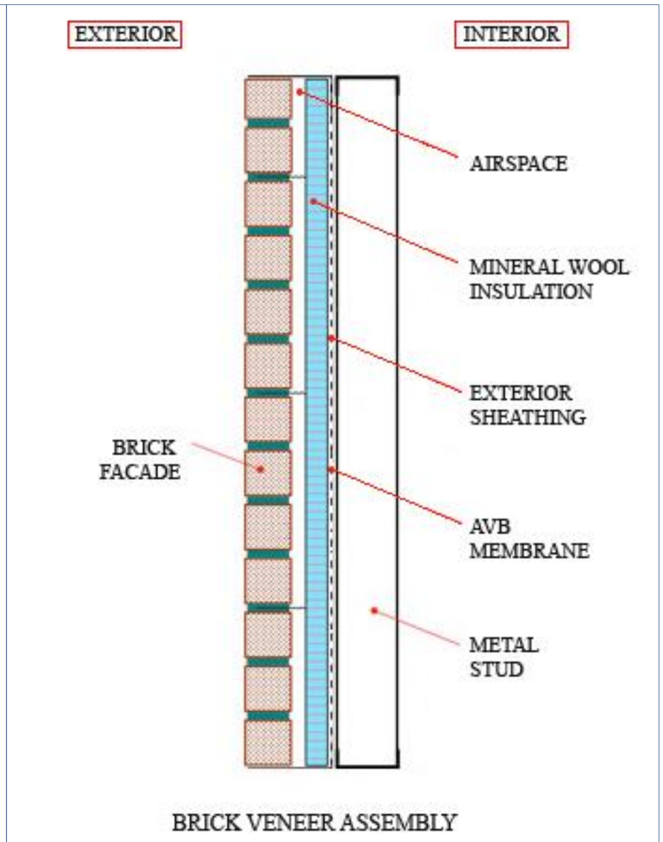

Figure 10.2: Brick Veneer Assembly | RJB

Analytic Software: DesignBuilder

DesignBuilder is a design modeling and simulation program providing information on building energy consumption, CO_2 emissions, occupant comfort, LEED compliance, and much more. Once the building features and location is inputted in the program, the simulator will provide information such as heating/cooling loads and allows users to check effects of alternative designs broken down in a range of comprehensive simulation data. Inputting the different façade systems into the simulator will allow for a comparison between the monthly heat gain values of each system.

Building Energy Model: Terra Cotta vs. Brick Veneer

A simple model of the bookstore of the HUB Project was created within the DesignBuilder in order to compare the two façade systems. The model was developed by creating assemblies for the walls and roofs. The results from each model can be compared to one another since other than the façade assemblies themselves, no other features of the building are changing. Two types of reports were generated, an annual ventilation report and a monthly ventilation report.

The effectiveness of the thermal properties of each façade systems were analyzed in each report. Targeting the effective heat gain for the building would help provide which of the two systems would provide better insulation for the building. The monthly heat loss comparison showed that the difference in overall heat loss was less than a percent difference. A month by month break down of the annual heat loss for each system is shown below in Table 7.

Table 7: DesignBuilder Data | RJB

Monthly Heat Loss Comparison (kBTU)												
Description	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Terra Cotta	40812	37224	32648	20913	15063	9355	6902	9500	13583	19298	26098	38967
Brick Veneer	40806	37206	32597	20884	15011	9259	6808	9415	13549	19304	26096	38953

The annual heat gain values that the original façade design experienced is a net loss of nearly 42948 kBTU. The new brick façade design experiences a net loss of 42708 kBTU. When comparing the two values of the original and new façade designs, the brick façade was less than 1 percent more effective in terms of thermal properties. The slight increase in both R-Value and effectiveness of the thermal properties of materials will come along with the change from terra cotta to brick. Graphs produced by DesignBuilder are provided in Appendix D.2 for the internal heat gains of the bookstore.

Mechanical Breadth: Conclusion

Based on the information provided by the HAM Toolbox and the DesignBuilder Software it is clear that new façade design will perform similarly to the current façade design. The R-Values of the systems overall were both similar and will perform well in the environment in University Park. The data output for the monthly heat loss for the brick veneer was slightly more efficient; however it was an insignificant increase. Overall through this mechanical breadth it was determined that the change from the terra cotta rain screen system to the brick veneer will not have a significant factor on the overall thermal performance of the bookstore.

Terra Cotta Rain Screen System vs. Brick Veneer: Component Weight

One of the advantages of implementing a rain screen system into a design is the reduction in the overall building dead load because of the light weight of the cladding options versus traditional building materials. The terra cotta rain screen system consists of similar components of the brick veneer however the light weight of the framing system and panels themselves make the rain screen system considerably lighter.

The terra cotta rain screen system is nearly 62 percent less in overall unit weight per square foot. The terra cotta rain screen system is 25 PSF where the more traditional brick veneer is 65 PSF. The difference is due to the weight of the brick and terra cotta materials themselves since the remaining components of the systems are practically identical. The Structural Breadth deals with the increase in component weight of the brick veneer system.

Structural Breadth

Changing the terra cotta façade to brick veneer brought up an investigation into the existing structural system. The weight of the brick veneer needed to be supported by the structural system. Through this structural breadth, the two systems were compared and the results will help determine whether any changes need to be made to the existing structural system.

One specific beam will be analyzed located on the second floor of the overbuild located between column lines HH and JJ and column line 37. This beam will carry the load of one of the larger spans of exterior façade due to the change in façade type. This beam is a W21x83 at 34' – 10" in length and is on the exterior of the building. The allowable limits for a typical W21x83 beam are shown below in Table 8. Figure XX shows the location of the specific beam chosen to be analyzed.

Table 8: Beam Allowance | RJB

Allowable Limits – Steel Beam				
Beam Type	**Length**	**ϕ Mn**	**ϕ Vn**	**Deflection**
W21x83	34' – 10"	529.20 kip-ft.	238.05 kip	0.663" – 1.097"

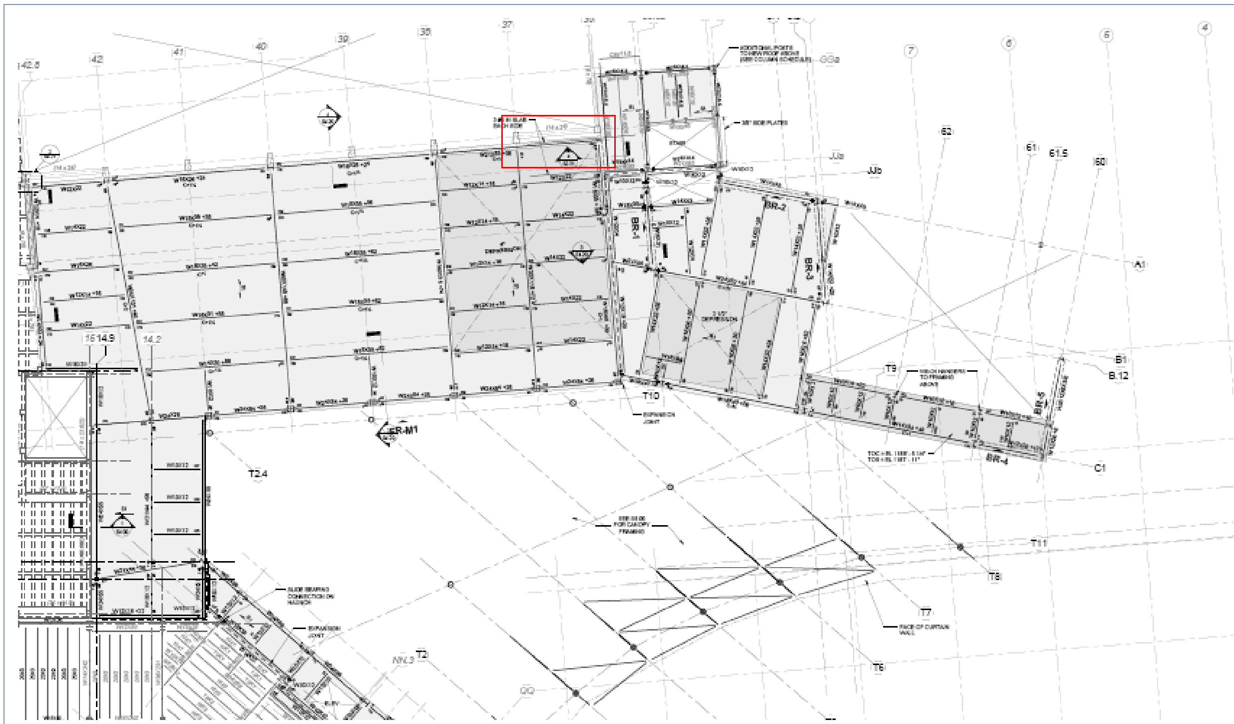

Figure 11: Specific Beam Location | RJB

Analytic Software: WebStructural

WebStructural is a newer structural engineering software that has the ability to design beams, columns, connections and more. It was designed by a practicing structural engineer and a software developer who created the program to provide an elegant and powerful structural engineering software. In order to calculate a design a steel beam the program follows 6 essential steps to design a steel beam:

1. Material – Choose the appropriate grade of steel for the beam you will be designing
2. Shape – Select the shape of steel beam you would like to design.
3. Span – Enter the distance you are trying to span.
4. Bracing – Not to be overlooked! Bracing is critical in determining the capacity of a beam.
5. Load – Enter loads base on their type and load case
6. Design- (ASD and LFRD)

After inputting the essential information required by the program, the results are provided to determine if the beam design is acceptable. The program uses the allowable capacity for bending (ϕ M_n), shear (ϕ V_n), and deflection (Max D_y) and compares the demand for each due to the loading inputted. Both the terra cotta façade and the brick veneer façade were inputted into the system to check each design.

Loading: Terra Cotta Façade

The original terra cotta façade system was used to calculate loading allowances to compare the new design to. Using the WebStructural Beam Design software the terra cotta system loading was plugged into the system to check for bending, shear, and deflection. The information obtained from the terra cotta results are shown below in Table 9.

Table 9: Terra Cotta Loading | RJB

Terra Cotta Facade – Design Loads			
Total Load	**Mu**	**Vu**	**Deflection**
1.15 kip / ft.	219.52 kip-ft.	21.83 kip	0.57”

Typical loading values were used for live and dead loads on the beam, including the dead load from the weight of the terra cotta façade system. The results showed that the loading for the system was acceptable as designed. After determining the structural member performance with the original façade design, the new brick veneer façade was analyzed. As mentioned in the previous section, the brick veneer system has an increased weight than the terra cotta and with this an increase in loading, moments, shear, and deflection is expected. Screenshots of the results from WebStructural Beam Design program for the terra cotta façade are located in Appendix E.2-E.3.

Loading: Brick Veneer Façade

The same loading calculations were performed to determine how the structural member would react when loaded with the brick veneer façade system. The WebStructural Beam Design software calculated the loading for bending, shear, and deflection. The information obtained from the brick veneer results are shown below in Table 10.

Table 10: Brick Veneer Loading | RJB

Brick Veneer Facade – Design Loads			
Total Load	**Mu**	**Vu**	**Deflection**
1.84 kip / ft.	346.41 kip-ft.	34.45 kip	0.94”

The results showed that the loading for the new system were acceptable. As expected with the increase in weight of the system brought and increase in demand for the bending, shear, and deflection. The existing W21x83 beam at 34’-10” in length provides sufficient support to carry the increased load. With the change in façade type, both the moment and shear increased by 57.8%. The loading difference between the systems was increased by 0.69 kip/ft. which is a 60% increase from the original design. Table 11 shows the demand of the two different systems and the capacity of the beam.

Table 11: Facade Loading Comparison | RJB

Façade Loading Comparison				
Description	**Total Load**	**Mu**	**Vu**	**Deflection**
Terra Cotta System	1.15 kip / ft.	219.52 kip-ft.	21.83 kip	0.57”
Brick Veneer System	1.84 kip /ft.	346.41 kip-ft.	34.45 kip	0.94”
Percent Increase	**60%**	**57.8%**	**57.8%**	**64.9%**

The WebStructural calculation results for both façade systems are provided in Appendix E.2-E.3.

Structural Breadth: Conclusion

As previously mentioned, regardless of the increases the existing structural member will support the additional load of the new façade design. Due to the large increase in loading, moment, shear and deflection it is assumed that there will be some structural members that will require upsizing as result of the increased load.

Constructability Issues

With the overall dimensions difference of each wall system being 1.125" the transition from each façade type must be looked at to make up for the greater dimension of the brick veneer. The current design calls for an area which facilitates the transition between different exterior façade components; such as the terra cotta rain screen and the glazed aluminum curtain wall. Figure 12 below shows a detail of the transition from between the rain screen and curtain wall. Another area of issue that needs to be addressed is the vertical transition between components.

At the MPR the aluminum glazed curtain wall is topped off by the terra cotta base. In this situation the change from terra cotta to brick would cause the brick to stick out by the 1.125" compared to the curtain wall. However due to the location of the design being at the parapet the extra depth can be absorbed into the parapet itself.

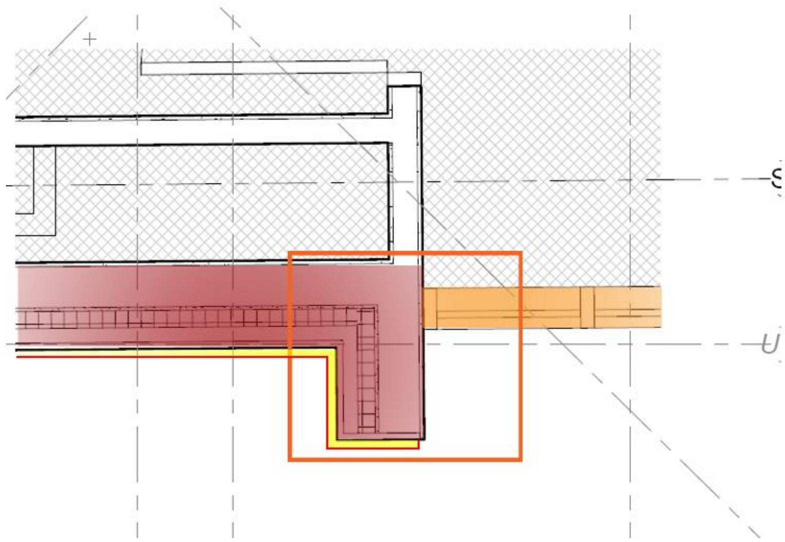

Figure 12: Transition Detail | RJB

Schedule Impact

In order to figure out the schedule impact of switching from the terra cotta rain screen system to the brick veneer focus shifts towards the exterior of the bookstore. The bookstore exterior is comprised of the following building façade types: Terra Cotta Rain Screen, Aluminum Curtain Wall, and Brick Veneer. Focusing on the south façade of the bookstore, the terra cotta rain screen system's original duration is 35 days which equates to approximately 6.3 square feet installed per hour. The brick veneer can be installed at a rate of 7.8 square feet per hour and replacing the same square footage on the south façade of the bookstore totaling approximately 29 days. The switch in façade equates to a 20 percent saving in overall duration and eliminates over a week worth of installation time. Table 12 shows the breakdown of the durations for the south façade of the bookstore.

Table 12: Bookstore Facade Schedule Comparison | RJB

Schedule Comparison – Bookstore South Façade			
Description	**Start Date**	**End Date**	**Total Duration**
Terra Cotta Rain Screen	*02 December 2013*	*17 January 2014*	*35 Days*
Brick Veneer	*02 December 2013*	*09 January 2014*	*29 Days*

Cost Impact

Still focusing on the south façade of the bookstore the overall cost of the material and labor is approximately $64,144.00 less for the switch to brick veneer. The total material cost was calculated using material cost per square foot and the amount of façade being changed from the terra cotta rain screen system to the brick veneer. The labor costs were calculated by using the durations calculated previously for the schedule comparison between the two systems. Table 13 shows the cost breakdown for the south façade of the bookstore. Due to the 20 percent decrease in overall duration it provides a labor cost of $5,520.00 less with the implementation of the brick veneer. Most of the savings comes from the cost of the materials itself, with terra cotta costing $33 per square foot more than brick. For the south façade of the bookstore alone it provides a savings of approximately $58,624.00 with the use of brick veneer.

Table 13: Bookstore Facade Cost Comparison | RJB

Cost Comparison – Bookstore South Façade						
Description	**Area**	**Duration**	**Material Cost**	**Material Total**	**Labor Total**	**Total**
Terra Cotta Rain Screen	1777 SF	35 Days	$38 / SF	$67,505.48	$32,200.00	$99,705.48
Brick Veneer		29 Days	$5 / SF	$8,882.30	$26,680.00	$35,562.30
			Difference:	**$58,623.18**	**$5,520.00**	**$64,143.18**

Looking at the entire building surface area and amount of square footage changing from the terra cotta rain screen system to the brick veneer is 51 percent of the building. The material cost for the brick veneer to cover the nearly 13,813 square feet of the building exterior currently designed for terra cotta will cost $69,061.00. The price for the brick material itself is only 13 percent the price of the terra cotta. Table 14 below breaks down the material cost differences between the terra cotta and brick.

Table 14: Material Facade Cost Comparison | RJB

Cost Comparison – Material Cost			
Description	**Area**	**Material Cost**	**Material Total**
Terra Cotta Rain Screen	13,813 SF	$38 / SF	$524,858.00
Brick Veneer		$5 / SF	$69,061.00
		Difference:	$455,797.00

Conclusion

Changing the facade type from the terra cotta rain screen to a brick veneer will save both time and money. The change to brick veneer will allow the project to save 6 Days of work during the installation of exterior facade of the bookstore. Overall the project would see a cost savings of $455,797.00 in material alone and the installation and material cost per the bookstore exterior facade schedule would save $64,142.18. The terra cotta and brick veneer perform similarly thermally and the structural results accepted both designs. It is recommended that the brick veneer be substituted for the current terra cotta rain screen design in order to save time for the overall project duration.

Analysis # 3: GPS Material Tracking System – Structural Steel

Problem

Due to the amount of student traffic and limited access around the HUB deliveries to the site can be highly problematic. A Just-in-Time delivery method will be implemented on the project for delivery of the structural steel. Maintaining the proper tracking of the pieces delivered to the site will help prevent any delays. Barcodes can be scanned when the pieces are shipped and in route to the site notifying the team of expected delivery times.

Research Goal

This analysis will require research into the most cost effect type of tagging system for steel pieces. The project team will require software to interface with the RFID barcodes to collect the data. Along with an analysis of the tagging system a look into current software available for displaying the data will need to take place. The goal of this analysis is to research the benefit of using RFID tags for the steel erection for material tracking and site logistics.

Methodology

- Obtain steel erection schedule and details
- Identify erection sequence
- Identify required RFID software programs
- Evaluate information to be included on RFID tags
- Determine best method for implementation
- Analyze cost impacts
- Analyze schedule impacts

Resources

- Related Literature
- Gilbane Project Team
- AE Department Faculty & Other Industry Professional(s)
- RFID Tag Specification & Software

PACE Research Aspect

During the 22nd Annual PACE Roundtable held in November great insight was provided into current industry issues and potential solutions for these issues. Information management for the workforce was a topic of the morning break-out sessions. During the session the use of RFID tags were brought up by one of the industry professionals in attendance. Using RFID tags can help eliminate common industry issues through inventory management, receiving shipping accuracy, reducing cycle time, improving product quality, better planning and forecast, and facilitating statistical process control. For a site with tight site logistic, a RFID tagging system can help enhance the ability to keep the project on schedule providing savings in labor costs. A RFID tagging system allows for more accurate and timely deliveries getting the right materials in the right place at the right time. Through proper research into RFID tagging systems a system can be implemented in the HUB project for the steel erection sequence allowing for a multiplicity of benefits to the schedule and cost of the project.

Expected Outcome

This analysis is expected to provide an efficient way of tracking the steel deliveries from the time it leaves the production factory until it is installed and nay required testing is done with the RFID tags. The tracking will provide the project team to better plan the deliveries of all steel throughout the project. In addition, the tracking system will help the steel erection on schedule providing both schedule and cost savings on the overall project.

Background Information

The structural system for the addition to the HUB is comprised of structural steel supports with pre-engineered bolted connections. The Steel is being fabricated by Supermetal in Rock Hill, South Carolina and will be shipped to the site in State College, PA. With classes out for a week in Spring Semester for Spring Break, Gilbane has chosen this time to have the brunt of the steel trucked in during that time period. With only a week for steel erection of main parts of the addition, having the correct steel pieces on site is crucial to completing the task in the allotted time. During Spring Break the amount of traffic will be cut down however the site is still constricting with narrow limitations for large truck loads to be brought on site. Implementing a GPS tracking system on the steel pieces would allow Gilbane to efficiently track and manage all steel deliveries and erections.

Erection and Sequence

During the week of spring break every piece of steel will be picked directly from the delivery truck and then lifted into place. This one week aggressive schedule will allow for Gilbane to complete a majority of the steel erection when most of the Penn State community is away. Supermetal separated the erection into sixteen different sequences which correlates to Gilbane's seven sequences which are outlined in Figure 13 below. The erection sequence starts with the lobby and shifts towards the atrium/courtyard area ending with the canopy system above.

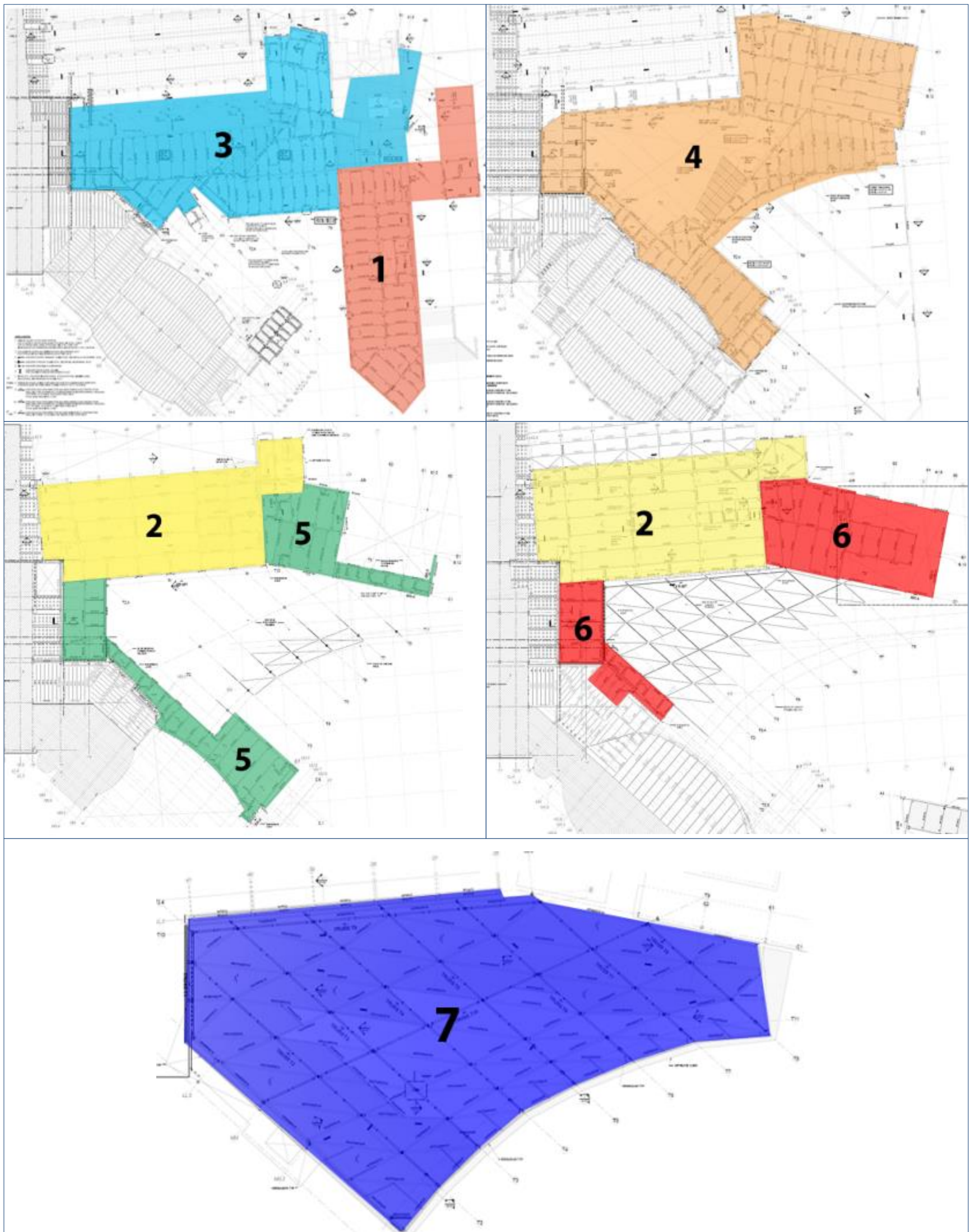

Figure 13: Steel Erection Sequence | RJB

Inspection and Testing

The inspection and testing of all structural steel fabrication and erection will be performed by an independent Testing Agency under a contract with Penn State University. The contractor must provide the Testing Agency with the following items: Complete sets of approved Shop Drawings, cutting lists, order lists, material bills, shipping lists, mill reports, information as to time and place of all rollings and shipments of materials to shops and field, representative sample pieces, and free and safe access when testing materials.

Field bolted connections need to be accordance with RCSC specifications and wrenches need to be calibrated periodically. A minimum of two bolts in each connection shall be tested and verification of washer position and method of tightening nut must be provided.

All Field welding is to be inspected and tested during fabrication of structural steel assemblies and in accordance with AWS Codes. 100% ultrasonic testing must be accordance with ASTM E-164, for all field full penetration welds. Visual inspection of welds must be performed as well as certify welders and conduct inspections and tests are required.

GPS Software Programs

There are numerous GPS tracking programs available on the market today similar to ones that are used by transportation companies to track the location of their fleet. Systems such as these have multiple benefits one of which is the fact that they have the ability to be an entirely web based GPS tracking system. Being a web based system the information can be viewed on any computer or mobile device such as a tablet or even a smart phone. With the technology integrated into a construction site now is the time to implement GPS tracking systems into the everyday construction world. Intelliwave Technologies is one of the global leaders in providing RFID and GPS material tracking solutions for construction projects.

Figure 15.1: Tablet Used in Field| intelliwavetechnologies.com

Figure 16.2: RFID Tag | intelliwavetechnologies.com

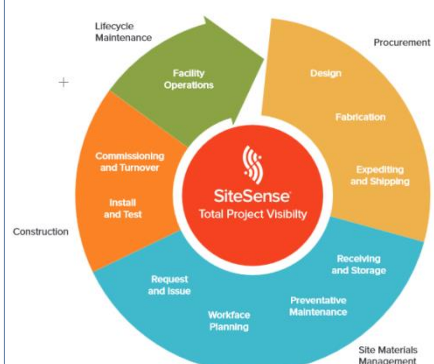

Figure 14.3: SiteSense Diagram | intelliwavetechnologies.com

Intelliwave provides construction projects with the ability to track the location of equipment, personnel and equipment resulting in improved scheduling helping to keep projects on track and on budget. SiteSense materials tracking system by Intelliwave gives total visibility to construction materials and will allow the HUB Project team the ability to track every steel piece from the production facility to the site on campus. The RFID tracking tags can withstand outdoor environments as well as impact from other materials in order to survive the abuse they may face during production, transportation and installation. The battery life of each RFID tag typically lasts 4 years, and each has the ability to be decommissioned from a tag assignment and used multiple times throughout the projects life cycle. This will allow the HUB project team to use a select number of RFID tags throughout the steel erection process on the project.

Implementing SiteSense materials tracking system into a construction project has multiple benefits which include: finding materials faster, it helps reduce material management costs, reduce re-fabrication costs and provides a more predictable construction schedule. Using active RFID tags to track the location of materials on a site will help reduce the amount of time it takes to locate each piece of steel on site. According to Intelliwave Technologies, third party studies have demonstrated that the time to find materials was reduced from 31 minutes to 4 minutes per piece. This will allow the project team to account for each piece of steel in a timely manner on the construction site. The greatest advantage of using the RFID tagging system is the ability to track in real time.

Due to the complexity of location of the project and the limited space available around the site, the just-in-time delivery method for the steel is perfect for RFID tagging. The current method calls for trucking in multiple steel deliveries to an offsite location and one by one radioing a truck onsite to make picks from each. The SiteSense materials tacking system will allow the project team to know the location of each piece of steel as it arrives on campus and passes through the gate on site and flagged “Received on Site”. This will allow for less times checking that each truck has the right pieces in order to complete the erection sequence. This will help with quality control and allow for the erection sequence to occur without the possibility of delay. The worry of material not showing up on site on time will provide extra cost savings due to reducing the need to re-fabricate items which were lost. RFID tags provide initial benefits as well as long term benefits.

Using SiteSense materials tracking system not only will help predict the schedule on a current project but will help the accuracy of scheduling on future projects. Due to the nature of the fast paced work environment on construction site it is impossible to track the movement of material on a job site from day to day. With the tracking system recording all information to a secure web-based database, information from each construction project will be readily available to help schedule work for future projects.

Choosing Intelliwave Technologies SiteSense Material Tracking System

While researching RFID tagging systems and software Intelliwave Technologies stood out among the rest on multiple accounts. The battery life of the RFID tags for the SiteSense material tracking system allows for the ability to re-use the tags without having to recharge them which other competitors could not provide. A lot of the RFID tagging systems required the installation of high price software onto computers in order to collect the information from each tag. Intelliwave Technologies provides a secure web-based software the helps keep support cost low by having information available from multiple devices through the internet. Figure 14.1 displays a worker accessing tracking data from a tablet. RFID tracking tags can be expensive and with the rugged RFID tags provided by Intelliwave, there is no worry about damage to the technology.

Information on RFID Tags

The SiteSense material tracking system will record the following information in order to provide the project team with necessary information to complete the steel erection on time: tagging, receiving, storing (if necessary), and locating. The project team will have the ability to check the correct steel pieces are en-route to the site. This will ensure that the correct pieces are on each truck and will be on site in time each day for the pick. Since the university has and independent testing agency inspect and test the fabrication and erection the data will not collect testing information in order to allow for reuse of tracking tags. All of the information collected by the RFID tags will be stored and be available throughout the current project and help improve efficiency on future projects.

Schedule Impact

Using the SiteSense material tracking system will be beneficial to the schedule of the steel erection. With the tracking system in place for the steel erection the project team will be able to meet the proposed deadlines for each phase of work. Keeping the steel erection sequence on schedule will allow the Tower Crane to stay on site for a shorter amount of time saving money as well as aesthetically pleasing the university's skyline.

The addition of the tracking system will give the project team the ability to eliminate delays in the erection sequence. This form of quality control will occur from the time the pieces are loaded until each piece is put into place and tested. If there is any steel missing from a shipment the project team will know before they are trucked to campus, saving time on having to wait for missing pieces leading to more efficient shipments.

When erecting a steel structure unforeseen circumstances are inevitable, delays from high winds stop the use of the crane. The quality control from the tracking system will allow for circumstances as such to occur without the worry of further delays from missing steel, testing issues, and other controlled issues. Although there is no exact number of days using the RFID tagging system will save, the ability to have added quality control will help the steel erection sequence run smooth.

Cost Impact

Implementing the GPS tracking system to the steel erection will cost money upfront but this extra cost will directly ensure the schedule is kept on track. With so many schedule issues affecting the project the extra quality control from the tracking system will help maintain the target date.

The cost of each GPS unit is approximately $350 and with the amount of steel being delivered and used in the construction it would be inefficient to use a different GPS unit for each piece. After examining the delivery schedule for the steel, the amount of pieces per load was looked at to determine the largest truck load that would be delivered which totals 215 pieces. This number is the lowest amount of GPS units that could be used in order to track every piece on every truck load.

The ability to recycle and reuse the GPS units is crucial to lowering the upfront cost that Gilbane will take on as well as limit the service fee during the project. The charge is approximately $15 per month per device with the devices required activation length for this project being 4 months. The total service charge for 215 devices over the 4 month period would be $12,900 this would increase with the more units in use and the length each is needed to be in service. The upfront cost of purchasing 215 GPS units would be approximately $75,250. The overall cost for the GPS tracking system will cost a total of $88,150 and the cost is outlined in Table 15 below.

Table 15: GPS Cost Breakdown | RJB

GPS Cost Breakdown	
Description	**Cost**
GPS Tracking Units (215 Units)	$75,250
GPS Tracking Service Fee	$12,900
Total:	**$88,150**

Conclusion

Although implementing a GPS tracking system would help the project team immensely with quality control it would be more beneficial for a project of larger scale than the HUB. The project team is confident in the current system in place and it will allow for the steel erection to be completed on time.

The upfront cost of $75,250 will help the project finish on time but with such a large cost for an addition to an existing building is hard to justify. However with the decrease of price in newer technology over time a GPS tracking system will benefit many construction projects in the future whether it is tracking people, equipment, material and much more.

Analysis # 4: Removal of Habitable Green Roof Design

Problem

Currently the HUB project is on course for a LEED Silver Rating, with the main feature being the habitable green roof above the existing bookstore. With all new construction on campus centered on sustainability and achievement of a LEED rating is a green roof the most efficient step in obtaining a "green building". Typically a habitable green roof requires a substantial structural design to handle the extra load of the roof system. Do the long run benefits of the green roof system outweigh the carbon footprint from its construction? Should other areas of the project be targeted for the LEED points?

Research Goal

The technical analysis for this option will incorporate an in depth look into the additional material required to support the Green Roof system compared to an alternative system. The carbon footprint of the constructing such a system can be compared directly to the schedule in order to find room for acceleration. I intend to compare the long term benefits of a Green Roof to its environmental construction impacts. After analyzing the Green Roof an alternative roofing system will be chosen to compare with the original Green Roof design.

Methodology

- Gain knowledge of green roof systems
  - Including construction methods & long term benefits
- Quantify pros and cons of green roof system
- Look into structural design of bookstore roof
- Compare and contrast the opposing roof systems (cost, schedule, environmental impacts)
- Make recommendation to which overall roof system is the more beneficial

Resources

- Gilbane Project Team - (Project Manager: Randy Holman, Project Engineer(s): Derek & Devin)
- AE Faculty - (Advisor: Robert Leicht)
- Other Industry Professional(s) – (OPP Staff Members)
- Green Roof & Conventional Roofing System Specifications

Expected Outcome

The expected outcome for this analysis is reduced costs and schedule acceleration if the green roof proves to be economically unnecessary. This will allow for further schedule acceleration that is necessary for installation of the green roof. If the redesigned roof system does not disprove the green roof option, it will be recommended that the design remains the same.

Background Information

A 9,681 square foot habitable green roof manufactured by Hydro-Tech Inc. will sit on top of the existing student bookstore. Currently The Pennsylvania State University has multiple building on campus with green roofs however the design for the HUB will be the first habitable green roof on campus. Even though the design is habitable only 17 percent of the total roof area provides the ability for occupation, the remaining area is similar to other green roof designs. Green roofs provide multiple benefits which include the following environmentally friendly characteristics: Reduction of the "heat island" effect, storm water management, beneficial thermal properties, CO_2 sequestering and the use of organic material. Figure 15 below highlight in red the area of the building which will incorporate the green roof.

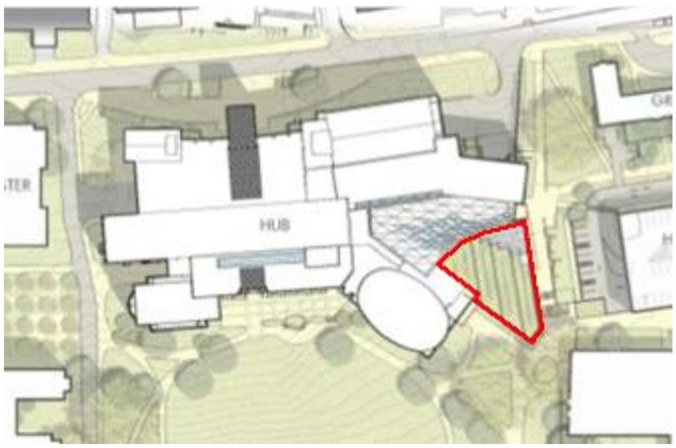

Figure 17: Green Roof Location | RJB

Current Green Roof Design

As stated previously only a small percentage of the entire green roof design is going to have the ability to be occupied. Table 16 below breaks down the area of the current design of the green roof. The roof assembly for the vegetated roof assembly is the Extensive Green Roof design manufactured by American Hydro-Tech Inc. Extensive Green Roofs are designed to help reduce the "urban heat island" effect and minimize storm water runoff. One key feature of the Extensive Green Roof is shallow growing media required which adds less weight to the roof structure compared to other green roofs. The Extensive Assembly can even be used over metal decking however since it is being implemented over the existing bookstore roof it is going to over concrete. Figure16 shows the design of the green roof and highlights the breakdown of Extensive Assembly and Habitable Walkway Paver.

Table 16: Green Roof SF | RJB

Green Roof – Design Breakdown		
Description	**Area**	**Percentage**
Extensive Assembly - Vegetation	7972.5 SF	83%
Ultimate Assembly - Pavers	1708.5 SF	17%
Total:	9681 SF	100%

Figure 18: Green Roof Design | RJB

Green Roof Physical Components

The two different types of roofing assembly called out in the design are Extensive Garden Roof Assembly and Ultimate Assembly with roof pavers. The Extensive Assembly consists of multiple layers topped off with a layer of vegetation. Underneath the vegetation there is a layer of growing media on top of a garden drain. The remaining layers that make up the assembly are: Styrofoam, root stop, Hydroflex 30, MM6125 EV-FR and the existing substrate (concrete). Figure 17.1 shows the detail of the assembly provided by Hydro-Tech Inc. The Ultimate Assembly with roof pavers is constructed of similar components with a few alterations.

The Ultimate Assembly from the existing roof surface up to the Styrofoam is the same as the Extensive Assembly except for the extra layer of root stop in the Extensive Assembly. On top of the Styrofoam a layer of paver supports is spaced out evenly in order to help support the pavers themselves. The assembly is topped off by architectural pavers to allow occupants to move around freely. Figure 17.2 shows the detail of the assembly provided by Hydro-Tech Inc. Even though the two assemblies have similarities in physical components the overall loading of the Extensive Assembly is greater. The Extensive Assembly concentrates a load of 35 PSF compared to the Ultimate Assembly which loading is 22 PSF. The difference in loading is due to the weight of the growing media and vegetation required for the green roof itself.

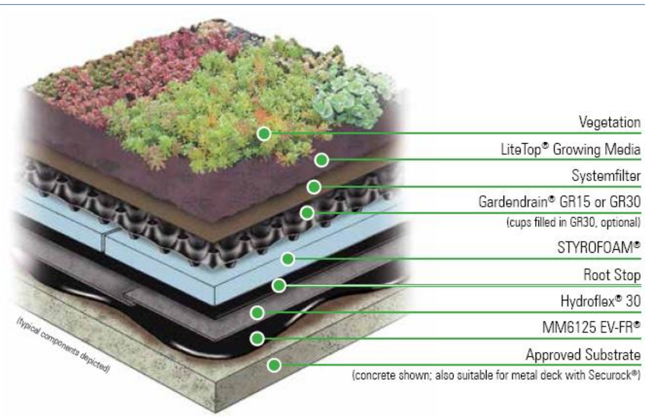

Figure 17.1: Extensive Assembly | hydrotechusa.com

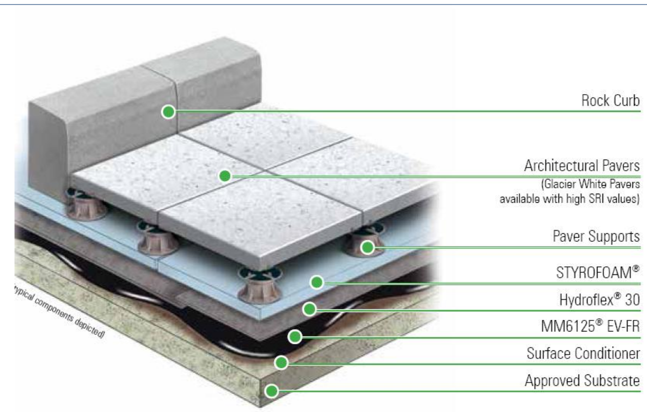

Figure 17.2: Ultimate Assembly | hydrotechusa.com

Alternative Design

Keeping the habitable side of the current green roof design was looked into; however due to the schedule and cost savings of using an entirely different roof type an alternate design was created for the entire bookstore roof. In other locations on the building, thermoplastic membrane roofing is being used manufactured by Duro-Last Roofing Inc. This Duro-Last Cool Zone membrane will be a good substitute for the green roof not only because of the saving in cost and schedule but also because of the benefits of the cool roof design.

Cool roofs provide positive benefits in multiple climates such as: significant difference in temperature during hot summer days (compared to traditional roofing materials), help save money and energy during peak cooling demand periods, help reduce urban heat-island effect, and keep moisture out while reflecting ultraviolet (UV) and infrared radiation (IR). These multiple energy savings will allow ease the removal of the green roof, replacing it with an alternative sustainable system.

The Duro-Last Cool Zone system can obtain 1 credit from the U.S. Green Building Council's LEED program and may lead to more credits if combined with other design criteria. The Duro-Last warranty for the product covers materials for 10-20 years. This alternate design provides multiple benefits such as a much lower assembly load for the building to carry.

Alternative Design: Roof Loading

The Duro-Last Cool Zone roofing assembly consists of a 50 Mil polyvinyl membrane which needs to be adhered to the existing roof of the bookstore. Insulation will still be laid down along with the polyvinyl membrane but overall the entire loading is considerably lower. The 50 Mil polyvinyl weighs 0.29 PSF, which compares to the Extensive Green Roof Assembly at 35 PSF.

Schedule Impact

The current green roof design calls for installation of a roof membrane, the green roof / accessories, and the actual planting membrane. The total duration for the green roof design is 55 Days with the installation of the green roof accessories and components accounting for 45 Days. For a project with scheduling issues 55 Days for installation of a new roof design on an existing roof is an area of concern. Table 17 breaks down the durations of the current green roof design.

Table 17: Green Roof Schedule | RJB

Schedule Breakdown – Current Green Roof Design

Description	Start Date	End Date	Total Duration
Roof Membrane	02 December 2013	13 December 2013	10 Days
Green Roof / Accessories	16 December 2013	24 January 2014	30 Days
Install Green Roof - Planting	27 January 2014	14 February 2014	15 Days
		Total Green Roof Duration:	**55 Days**

Implementing the Duro-Last Cool Zone design will provide roofing for the same surface area as the green roof in 40 Days shorter. The membrane layer is the only duration required with the Duro-Last design and provides sufficient enclosure for the building. The overall time saving of 8 weeks provides the ability to shift focus towards other physics of the buildings. Table 18 shows the scheduling implications of the Duro-Last and Green Roof and the time savings that come along with it.

Table 18: New Design Schedule Breakdown | RJB

Schedule Breakdown – Duro-Last Design			
Description	**Start Date**	**End Date**	**Total Duration**
Green Roof Assembly	02 December 2013	14 February 2014	55 Days
Duro-Last Assembly	02 December 2013	20 December 2013	15 Days
		Total Difference:	**40 Days**

Carbon Footprint Investigation

A research study published in Energy and Buildings Journal shows the overall CO_2 offset of using white roofs and green roofs. Both white roof and green roofs provide sufficient benefits to the environment however green roofs are less reflective and have lower global cooling potential. Compared to typical black roof s, white roofs will offset 10 tons of CO_2 for every 1076 SF of roof area, while green roofs offset 3-4 tons of CO_2 over the lifetime of the roof (Sproul, 2014). This means for the existing roof of the bookstore a white roof would offset nearly 90 tons of CO_2 compared to a green roof which would offset 35 tons of CO_2 over the roofs lifetime. One benefit of the green roof is the ability to help with storm water management. Extensive Green Roofs intercept and retain the first 0.5-0.8 in of rain preventing it from running off. However does the upfront cost of implementing a green roof over a white roof benefit the owner and environment?

Cost Impact

The existing roof of the bookstore does not have to change for the current design green roof design or the alternate Cool Roof design. Changing the green roof design to the Duro-Last Cool Zone Assembly will save the project a total of $154,896.00 for the 9,681 SF of roof. The Cool Roof design will allow for a 72% reduction in price compared to the green roof design. The cost breakdown below in Table 19 shows the installation and material cost of the Hydro-Tech Roof and the Duro-Last Roof. The total does not include the structure itself since the existing concrete is an approved substrate for both designs.

Table 19: Cost Comparison - Roof Design | RJB

Cost Comparison – Existing Bookstore Roof			
Description	**Area**	**Cost / SF**	**Total Cost**
Hydro-Tech Green Roof Assembly	9681 SF	$22.00	$212,982.00
Duro-Last Cool Zone Assembly		$6.00	$58,086.00
		Difference:	**$154,896.00**

Conclusion

The removal of the green roof will save both time and money. Implementing a Duro-Last Cool Roof will allow the project to save 40 Days of installation while saving $154,896.00. It is recommended to substitute the current green roof system with the Duro-Last Cool Zone System.

Report Conclusion

Final Recommendations

Over the fall 2013 and spring 2014 academic year, the HUB Renovations and Addition Project of The Pennsylvania State University was analyzed in order to identify areas that had potential to enhance the project overall. Through countless hours of research, feedback from academic members, the project team, multiple site visits, and construction professionals, four main areas were focused on for further analysis. Sequencing recommendations as well as Last Planner a lean building tactic was analyzed for the bookstore interior schedule. Two of the remaining analysis dealt with schedule saving redesigns, with the other one focused on research into quality control tactics. The purpose of this thesis project is strictly educational and is not intended to critique the work performed by the project team in any way.

Analysis #1: Schedule Resequence

The first analysis addressed the feasibility of resequencing the interior bookstore phase of the original schedule. Analyzing the schedule by decreasing unnecessary float, sequencing improvements, and schedule overlap the schedule was looked to be improved. Areas of the project were looked at in order to accelerate the schedule which later analyses touch on. In addition, the lean principle of Last Planner was investigated for implementation on a project such as the HUB. The project team is encouraged to use the suggested acceleration techniques as well as the idea of Last Planner to make up for schedule delay.

Analysis #2: Terra Cotta Rain Screen Redesign

Nearly half of the renovations and addition on the HUB façade is comprised of a complex terra cotta rain screen. This analysis addresses the need for schedule acceleration by providing an alternative brick veneer design. By switching the rain screen to brick veneer the project was able to save over a week of work days on the exterior façade of the bookstore alone, while saving $64,143.18. With similar thermal properties analysis and acceptable structural loading, the project team is encouraged to use the alternative design to provide schedule and cost savings.

Analysis #3: GPS Material tracking System – Structural Steel

Topics discussed during The 22nd Annual PACE Roundtable by construction professionals led to the research portion provided in the third analysis. With a Just-In-Time delivery system for the structural steel a GPS tag tracking system will help ensure quality control by preventing schedule delays. The cost of the tracking system is roughly $88,150 and the schedule would not see any savings. Although the technology to track the steel pieces will promote quality control, implementation would not benefit the project team due to the cost impact on a project of this size.

Analysis #4: Removal of Habitable Green Roof Design

The final analysis looks at the current design of the habitable green roof to be constructed on the existing bookstore roof. Providing an alternative cool roof design will further address the need for schedule acceleration due to unforeseen issues. The alternative design provides a cost savings of $154,896.00 and a schedule savings of 40 work days. The project team is encouraged to use the alternative design due to the cost and schedule savings of switching the design of an already existing roof structure.

Conclusion

In conclusion, it is recommended that three of the four proposed alternatives are applied to the Hub Renovations and Addition Project on The Pennsylvania State University's campus. Cost savings for the two main redesigns of the exterior façade and green roof would result in a schedule savings of 46 Days for the exterior of the bookstore alone. Further time savings will come from changing the remaining façade of the exterior of the building. These two analyses will also provide considerable cost savings totally nearly $220,000.00 for the bookstore exterior alone. Using lean construction principle and total resequencing of the project will help keep the project on track as the project team deals with potential scheduling issues. As a result, the three of the four analyses are recommended as they will benefit the HUB Renovations and Addition Project.

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Appendix

A.1: Original Bid Schedule

Technical Assignment 2

Activity Name	Original Duration	Start	Finish
HUB Renovation & Addition	503	27-Feb-13	06-Feb-15
Construction	503	27-Feb-13	06-Feb-15
Phase 1: Temporary Book Store	71	04-Apr-13	15-Jul-13
Prepare Site for Trailers	26	04-Apr-13	09-May-13
Set Up Book Store Trailers	13	24-May-13	12-Jun-13
Interior Contrstuction: Book Store	20	03-Jun-13	28-Jun-13
Exterior Façade @ Book Store	5	13-Jun-13	19-Jun-13
Obtain CO Temporary Book Store	3	01-Jul-13	03-Jul-13
Relocate Temporary Book Store / Reopen for Busin	10	01-Jul-13	15-Jul-13
L & I Inspection Book Store Trailer	2	01-Jul-13	02-Jul-13
Tower Crane	256	30-May-13	28-May-14
Teporary Partition/ Demo for Tower Foundation	10	30-May-13	12-Jun-13
F/R/P Tower Crane Foundation	9	27-Jun-13	10-Jul-13
Cure Time Tower Crane Foundation	10	11-Jul-13	24-Jul-13
Tower Crane Installation	6	04-Nov-13*	11-Nov-13
Remove Tower Crane	26	09-Apr-14*	14-May-14
Close Crane Opening	21	16-Apr-14*	14-May-14
Interior Finishes @ Crane Opening	11	14-May-14*	28-May-14
Phase 2: Bookstore Interior/Exterior	292	31-May-13	18-Jul-14
Interior	292	31-May-13	18-Jul-14
Fit Out Computer Store / 110 / 235	10	31-May-13	13-Jun-13
Computer Store Vacated	0	31-May-13	
Relocate AT&T to HUB Retail	19	14-Jun-13	11-Jul-13
Relocate FS Manager to 235	5	14-Jun-13	20-Jun-13
Relocate Copy Center/ Student Employment	5	17-Jun-13	21-Jun-13
Demolition Bookstore Interior	34	05-Jul-13	21-Aug-13
Relocate FS Director to Trailer	4	05-Jul-13	10-Jul-13
Reinforce Columns & Slabs	15	11-Sep-13	01-Oct-13
Erect Strucutral Steel Mezzanine	20	14-Oct-13	08-Nov-13
Detail Structural Steel & Deck Mezzanine	10	11-Nov-13*	22-Nov-13
Prepare & Place Concrete on Deck Mezzanine	4	25-Nov-13*	29-Nov-13
Overhead Rough Ins Bookstore Interiors	19	02-Dec-13*	27-Dec-13
Frame Walls/ Drywall Bookstore Interiors	19	23-Dec-13*	17-Jan-14
Perimeter Walls Bookstore Interiors	25	20-Jan-14*	21-Feb-14
Wall Finishes Bookstore Interiors	25	20-Jan-14*	21-Feb-14
Ceiling Finishes Bookstore Interiors	35	24-Feb-14*	11-Apr-14
Floor Finishes Bookstore Interiors	25	14-Apr-14*	16-May-14
Tenant Improvement Bookstore	5	05-May-14*	09-May-14
Move - In Bookstore	10	07-Jul-14*	18-Jul-14
Exterior	54	02-Dec-13	14-Feb-14
Exterior Façade TC Book Store	34	02-Dec-13*	17-Jan-14
Exterior Façade Curatin Wall Bookstore	15	02-Dec-13*	20-Dec-13
Roof membrane Bookstore	10	02-Dec-13*	13-Dec-13
Green Roof/ Accessories/ Rails	29	16-Dec-13*	24-Jan-14
Install Green Roof - Planting	15	27-Jan-14*	14-Feb-14
Phase 3: Lobby	337	16-May-13	05-Sep-14
Demolition Areaway/Cage/Stairs B4	5	16-May-13	22-May-13

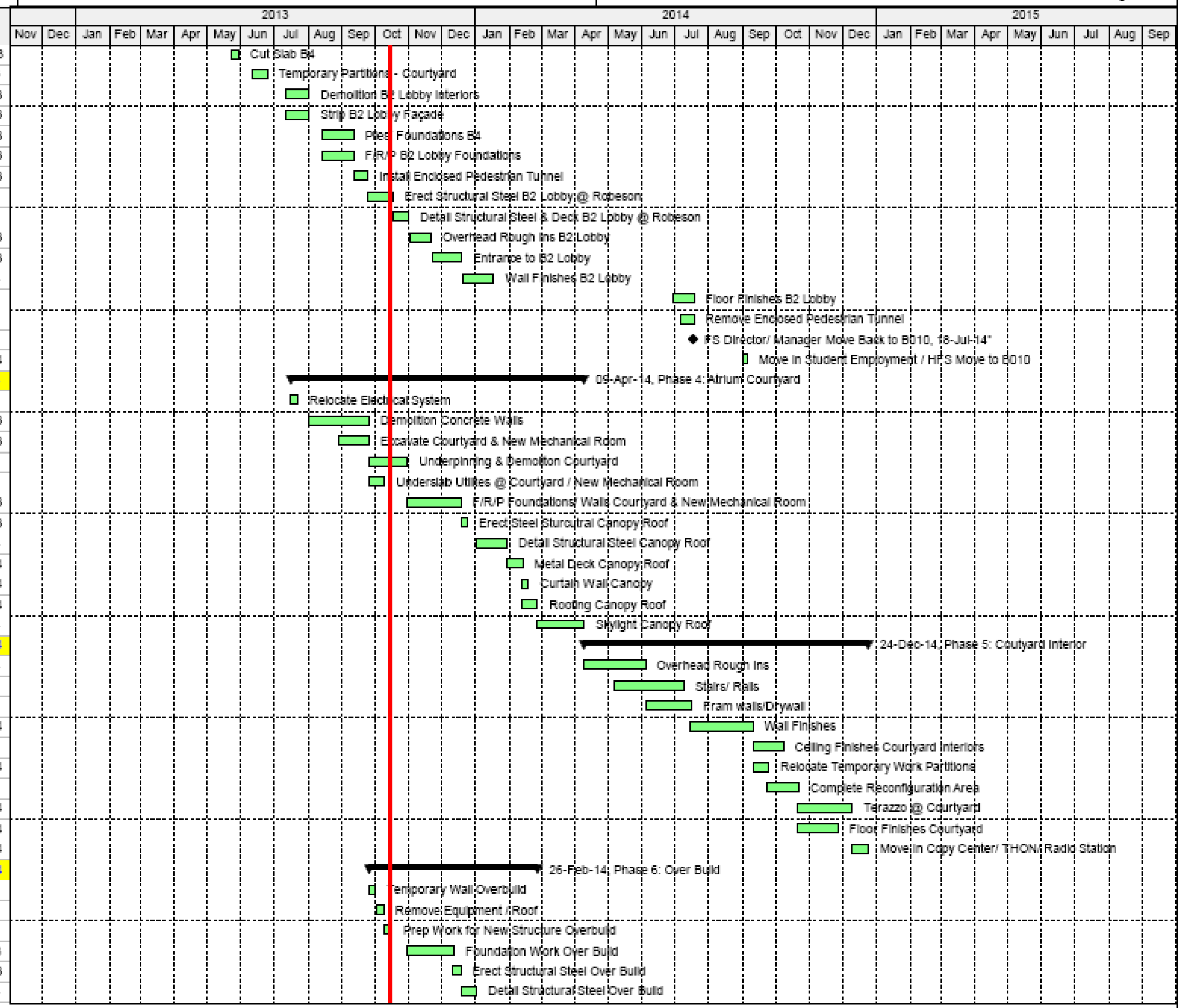
HUB Renovation & Addition

Robert Justin Barlow

Gilbane

Technical Assignment 2

Activity Name	Original Duration	Start	Finish
Cut Slab B4	4	23-May-13	29-May-13
Temporary Partitions - Courtyard	10	11-Jun-13	24-Jun-13
Demolition B2 Lobby Interiors	15	12-Jul-13	01-Aug-13
Strip B2 Lobby Façade	15	12-Jul-13	01-Aug-13
Piles/ Foundations B4	19	14-Aug-13	10-Sep-13
F/R/P B2 Lobby Foundations	19	14-Aug-13	10-Sep-13
Install Enclosed Pedestrian Tunnel	10	11-Sep-13	24-Sep-13
Erect Structural Steel B2 Lobby @ Robeson	18	24-Sep-13	17-Oct-13
Detail Structural Steel & Deck B2 Lobby @ Robeson	10	18-Oct-13*	31-Oct-13
Overhead Rough Ins B2 Lobby	15	01-Nov-13*	21-Nov-13
Entrance to B2 Lobby	19	22-Nov-13*	19-Dec-13
Wall Finishes B2 Lobby	19	20-Dec-13*	16-Jan-14
Floor Finishes B2 Lobby	15	30-Jun-14*	18-Jul-14
Remove Enclosed Pedestrian Tunnel	10	07-Jul-14*	18-Jul-14
FS Director/ Manager Move Back to B010	5	18-Jul-14*	
Move in Student Employment / HFS Move to B010	5	01-Sep-14*	05-Sep-14
Phase 4: Atrium Courtyard	189	16-Jul-13	09-Apr-14
Relocate Electrical System	5	16-Jul-13	22-Jul-13
Demolition Concrete Walls	40	31-Jul-13	25-Sep-13
Excavate Courtyard & New Mechanical Room	20	28-Aug-13	25-Sep-13
Underpinning & Demoliton Courtyard	26	25-Sep-13	30-Oct-13
Underslab Utilites @ Courtyard / New Mechanical R	11	25-Sep-13	09-Oct-13
F/R/P Foundations/ Walls Courtyard & New Mechan	35	30-Oct-13*	18-Dec-13
Erect Steel Sturcutral Canopy Roof	5	18-Dec-13*	24-Dec-13
Detail Structural Steel Canopy Roof	21	01-Jan-14*	29-Jan-14
Metal Deck Canopy Roof	11	29-Jan-14*	12-Feb-14
Curtain Wall Canopy	5	12-Feb-14*	18-Feb-14
Roofing Canopy Roof	11	12-Feb-14*	26-Feb-14
Skylight Canopy Roof	31	26-Feb-14*	09-Apr-14
Phase 5: Coutyard Interior	186	09-Apr-14	24-Dec-14
Overhead Rough Ins	41	09-Apr-14*	04-Jun-14
Stairs/ Rails	46	07-May-14*	09-Jul-14
Fram walls/Drywall	31	04-Jun-14*	16-Jul-14
Wall Finishes	41	16-Jul-14*	10-Sep-14
Ceiling Finishes Courtyard Interiors	21	10-Sep-14*	08-Oct-14
Relocate Temporary Work Partitions	11	10-Sep-14*	24-Sep-14
Complete Reconfiguration Area	21	24-Sep-14*	22-Oct-14
Terazzo @ Courtyard	36	22-Oct-14*	10-Dec-14
Floor Finishes Courtyard	26	22-Oct-14*	26-Nov-14
Move in Copy Center/ THON/ Radio Station	11	10-Dec-14*	24-Dec-14
Phase 6: Over Build	109	25-Sep-13	26-Feb-14
Temporary Wall Overbuild	5	25-Sep-13	01-Oct-13
Remove Equipment / Roof	5	02-Oct-13	08-Oct-13
Prep Work for New Structure Overbuild	5	09-Oct-13	15-Oct-13
Foundation Work Over Build	30	30-Oct-13*	11-Dec-13
Erect Structural Steel Over Build	6	11-Dec-13*	18-Dec-13
Detail Structural Steel Over Build	10	18-Dec-13*	01-Jan-14



HUB Renovation & Addition

Robert Justin Barlow

Technical Assignment 2

Activity Name	Original Duration	Start	Finish
Roof Over Build	11	01-Jan-14*	15-Jan-14
Interior Finishes - Over Build	31	15-Jan-14*	26-Feb-14
Phase 7: MPR Volume	153	25-Oct-13	29-May-14
Erect Strucutral Steel - MPR Volume	10	25-Oct-13*	07-Nov-13
Detail Structural Steel & Deck MPR Volume	14	08-Nov-13*	27-Nov-13
Prepare & Place Concrete on Deck MPR	10	29-Nov-13*	12-Dec-13
Roof MPR	9	13-Dec-13*	26-Dec-13
Exterior Façade	40	27-Dec-13*	20-Feb-14
Overhead Rough Ins	30	21-Feb-14*	03-Apr-14
Frame Walls/ Drywall MPR	17	21-Mar-14*	14-Apr-14
Wall Finishes	30	04-Apr-14*	15-May-14
Ceiling Finishes	30	18-Apr-14*	29-May-14
Floor Finishes	20	02-May-14*	29-May-14
Phase 8: Food Service Renovation	378	27-Feb-13	15-Aug-14
Concept Design	14	27-Feb-13	18-Mar-13
Prepare Initial Budget	9	19-Mar-13	29-Mar-13
Issue Initial Budget	0	29-Mar-13	
Finalize Eastimate	4	01-Apr-13	04-Apr-13
Final Design	76	18-Apr-13	05-Aug-13
Review Final Design	10	06-Aug-13	19-Aug-13
Finalize Drawings / Issue Permit	29	20-Aug-13	30-Sep-13
Issue Permit	0	01-Oct-13	
Permit Review	20	02-Oct-13	29-Oct-13
Bid & Award	43	30-Oct-13*	31-Dec-13
Submit Shop Drawings	19	27-Nov-13*	24-Dec-13
R&A Shops	19	26-Dec-13*	21-Jan-14
Fab & Deliver Equipment	78	22-Jan-14*	09-May-14
Food Service Renovation	60	12-May-14*	01-Aug-14
L & I Inspection / Certification	2	04-Aug-14*	05-Aug-14
Corrective Work	7	06-Aug-14*	14-Aug-14
Final Inspection	1	15-Aug-14*	15-Aug-14
Phase 9: Credit Union/CCSR/Convience Store	160	12-May-14	19-Dec-14
Convenience Store	25	12-May-14	13-Jun-14
Tenant Improvement	20	12-May-14*	06-Jun-14
Open Convience Store	5	09-Jun-14*	13-Jun-14
Credit Union	40	21-Jul-14	12-Sep-14
Tenant Improvement - Credit Union & PNC ID	30	21-Jul-14*	29-Aug-14
Relocate Credit Union / PNC ID	10	01-Sep-14*	12-Sep-14
CCSR	70	15-Sep-14	19-Dec-14
Demoltion CCSR	10	15-Sep-14*	26-Sep-14
Overhead Rough In	15	29-Sep-14*	17-Oct-14
Frame Walls	15	13-Oct-14*	31-Oct-14
Wall Finishes	15	03-Nov-14*	21-Nov-14
Ceiling Finishes	15	17-Nov-14*	05-Dec-14
Floor Finishes	15	01-Dec-14*	19-Dec-14
All Trade Contractor Work Complete - Entire Proj	1	19-Dec-14*	19-Dec-14
Demobolize Site & Restore	11	10-Dec-14	24-Dec-14

HUB Renovation & Addition

Robert Justin Barlow

Gilbane

Technical Assignment 2

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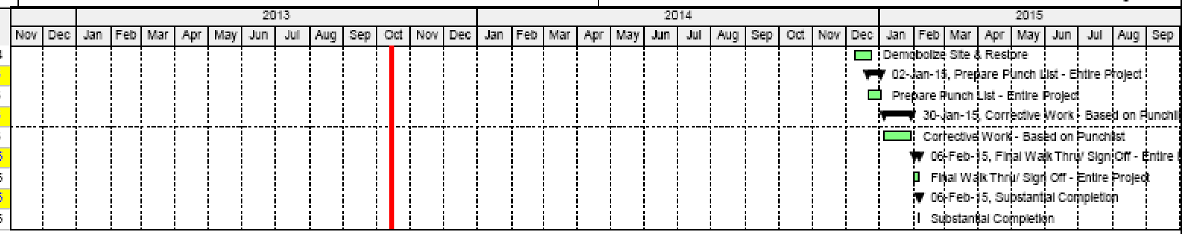
Activity Name	Original Duration	Start	Finish
Demobolize Site & Restore	11	10-Dec-14*	24-Dec-14
Prepare Punch List - Entire Project	10	22-Dec-14	02-Jan-15
Prepare Punch List - Entire Project	10	22-Dec-14*	02-Jan-15
Corrective Work - Based on Punchlist	20	05-Jan-15	30-Jan-15
Corrective Work - Based on Punchlist	20	05-Jan-15*	30-Jan-15
Final Walk Thru/ Sign Off - Entire Project	5	02-Feb-15	06-Feb-15
Final Walk Thru/ Sign Off - Entire Project	5	02-Feb-15*	06-Feb-15
Substantial Completion	1	06-Feb-15	06-Feb-15
Substantial Completion	1	06-Feb-15*	06-Feb-15



HUB Renovation & Addition

Robert Justin Barlow

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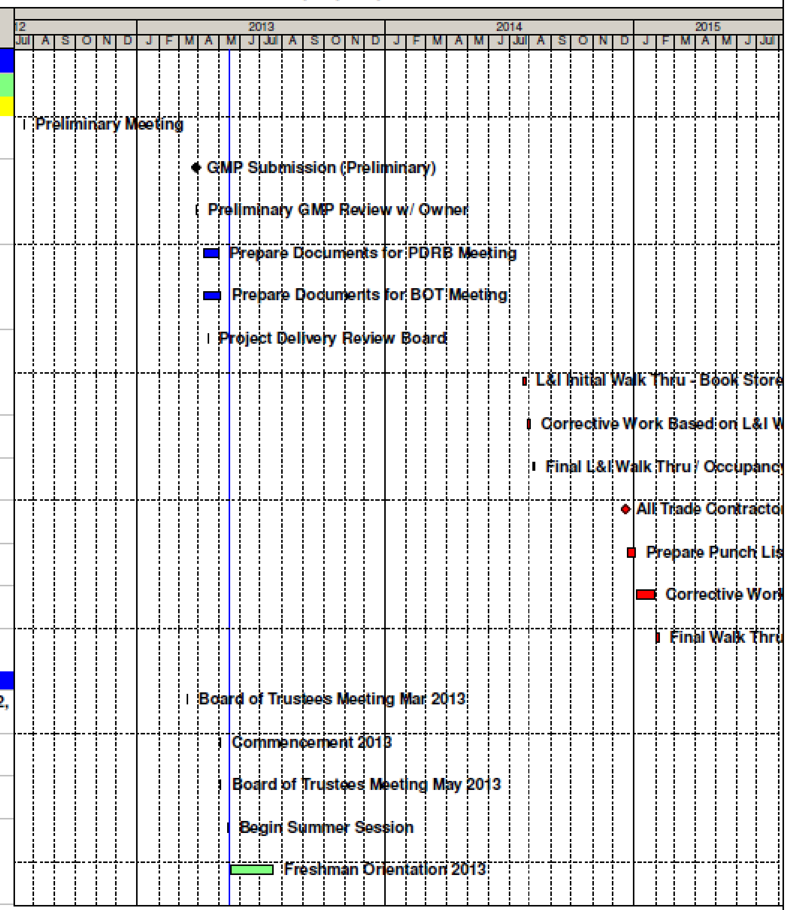
Appendix

A.2: Gilbane's Preconstruction Bid Schedule

PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2						
PSU - HUB Expansion Project						
Project Milestone						
1000	Preliminary Meeting	0	07-18-12 A	07-18-12 A		
80	GMP Submission (Preliminary)	0		03-27-13 A	9400	82
82	Preliminary GMP Review w/ Owner	0	03-28-13 A	03-29-13 A	80	90, 88
88	Prepare Documents for PDRB Meeting	0	04-08-13 A	04-29-13 A	82, 2224	90
98	Prepare Documents for BOT Meeting	0	04-08-13 A	05-02-13 A	90	9600
90	Project Delivery Review Board	0	04-15-13 A	04-15-13 A	82, 88	98
9340	L&I Initial Walk Thru - Book Store / B2 Lobby	5	07-21-14	07-25-14	9120, 9492, 4460	9350
9350	Corrective Work Based on L&I Walk Thru - Book Store / B2	5	07-28-14	08-01-14	9340	9360
9360	Final L&I Walk Thru / Occupancy Certificate Book	5	08-04-14	08-08-14*	9350	9330
9300	All Trade Contractor Work Complete - Entire Project	0		12-19-14	7500, 9140, 7820	9310
9310	Prepare Punch List - Entire Project	10	12-22-14	01-02-15	9300	9320
9320	Corrective Work Based on Punch List - Entire Project	20	01-05-15	01-30-15	9310	9330
9330	Final Walk Thru / Sign Off - Entire Project	5	02-02-15	02-06-15	9320, 9360, 9100	
Owner Activities						
100	Board of Trustees Meeting Mar 2013	0	03-15-13 A	03-15-13 A		3000, 2500, 6500, 2442, 2442
9800	Commencement 2013	0	05-03-13 A	05-03-13 A		4200
9600	Board of Trustees Meeting May 2013	0	05-03-13 A	05-03-13 A	98	4200, 3200
9610	Begin Summer Session	0	05-14-13 A	05-14-13 A		3220
9630	Freshman Orientation 2013	62	05-19-13*	07-19-13		



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WBS Full Schedule - Basic All Activities

Gilbane

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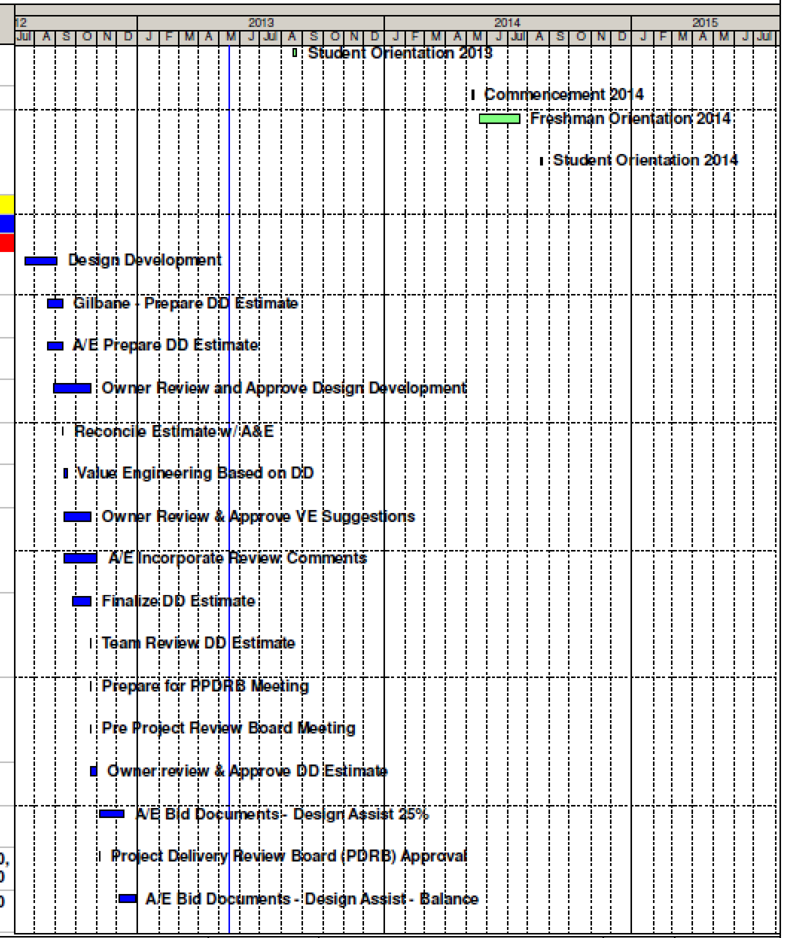
05-21-13	Revised Per EMail 05/20/13	Teddy	
05-23-13	Additional Report Per Request	Teddy	

PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
9640	Student Orientation 2013	5	08-19-13*	08-23-13		
9810	Commencement 2014	3	05-09-14*	05-11-14		9760, 7800
9850	Freshman Orientation 2014	61	05-19-14*	07-18-14		
9860	Student Orientation 2014	4	08-19-14*	08-22-14		
Pre Construction						
Design						
Design Development						
1100	Design Development	0	07-18-12 A	09-03-12 A		1120, 1140
1120	Gilbane - Prepare DD Estimate	0	08-21-12 A	09-11-12 A	1100	1160
1140	A/E Prepare DD Estimate	0	08-21-12 A	09-11-12 A	1100	1160
1142	Owner Review and Approve Design Development	0	08-29-12 A	10-23-12 A		1160, DI1000
1160	Reconcile Estimate w/ A&E	0	09-12-12 A	09-13-12 A	1120, 1140, 1142	1180
1180	Value Engineering Based on DD	0	09-14-12 A	09-17-12 A	1160	1200
1200	Owner Review & Approve VE Suggestions	0	09-14-12 A	10-23-12 A	1180	1220
DI1000	A/E Incorporate Review Comments	0	09-14-12 A	11-02-12 A	1142	DI1002
1220	Finalize DD Estimate	0	09-27-12 A	10-23-12 A	1200	1240
1240	Team Review DD Estimate	0	10-23-12 A	10-23-12 A	1220	1260, 1280
1280	Prepare for PPDRB Meeting	0	10-23-12 A	10-23-12 A	1240	1300, 1260
1300	Pre Project Review Board Meeting	0	10-23-12 A	10-23-12 A	1280	1320, 1260
1260	Owner review & Approve DD Estimate	0	10-24-12 A	11-01-12 A	1240, 1280, 1300	1320
DI1002	A/E Bid Documents - Design Assist 25%	0	11-05-12 A	12-12-12 A	DI1000	DI1004, DI1020
1320	Project Delivery Review Board (PDRB) Approval	0	11-06-12 A	11-06-12 A	1260, 1300	1400, 1500, 1600, 1700, 1800, 1900, 2100, 2400
DI1020	A/E Bid Documents - Design Assist - Balance	0	12-03-12 A	12-28-12 A	DI1002	9400, 1700, 1800, 1900



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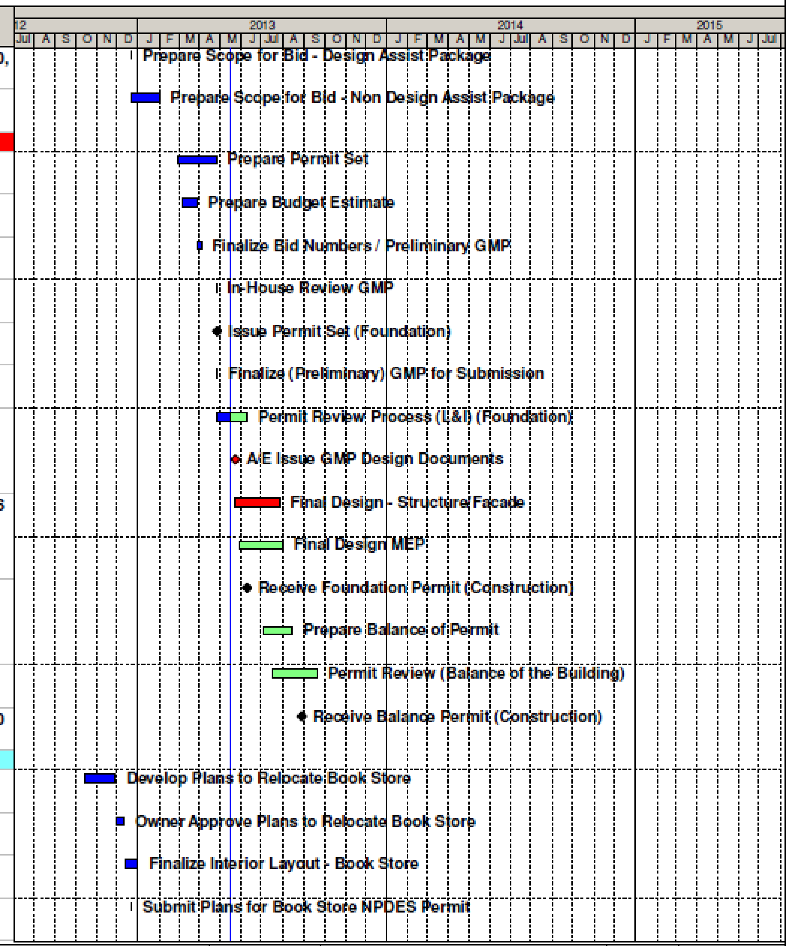
05-23-13	Additional Report Per Request	Teddy	

PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
DI1004	Prepare Scope for Bid - Design Assist Package	0	12-23-12 A	12-23-12 A	DI1002	1400, 1500, 1600, 1700, 1800, 1900, 9620
9700	Prepare Scope for Bid - Non Design Assist Package	0	12-23-12 A	02-01-13 A		4000, 5500, 4100
Construction Documents						
2240	Prepare Permit Set	0	02-27-13 A	04-25-13 A		2242
9400	Prepare Budget Estimate	0	03-06-13 A	03-27-13 A	DI1020, 1400, 1500, 1600, 1700, 1800, 1900, 4100,	2220, 80
2220	Finalize Bid Numbers / Preliminary GMP	0	03-28-13 A	04-03-13 A	9400	2222
2222	In-House Review GMP	0	04-25-13 A	04-25-13 A	2220, 9650	2224
2242	Issue Permit Set (Foundation)	0	04-26-13 A		2240	2244
2224	Finalize (Preliminary) GMP for Submission	0	04-26-13 A	04-26-13 A	2222	88
2244	Permit Review Process (L&I) (Foundation)	17	04-26-13 A	06-10-13	2242	2246
2200	A/E Issue GMP Design Documents	0	05-23-13		1404, 1504, 1604	2100, 9780
2100	Final Design - Structure/Facade	45	05-23-13	07-26-13	1320, 2200, 1404	9410, 5600, 4030, 4036
9780	Final Design MEP	45	05-29-13	07-31-13	2200, 1604, 1704, 1804, 1904	4400, 6740, 9410
2246	Receive Foundation Permit (Construction)	0		06-10-13	2244	3200, 4200
9410	Prepare Balance of Permit	30	07-03-13	08-14-13	2100, 9780	9420
9420	Permit Review (Balance of the Building)	45	07-18-13	09-19-13	9410	9422
9422	Receive Balance Permit (Construction)	0		08-28-13	9420	4320, 5200, 5780, 6680
Book Store						
2400	Develop Plans to Relocate Book Store	0	10-16-12 A	11-29-12 A	1320	2420
2420	Owner Approve Plans to Relocate Book Store	0	11-30-12 A	12-12-12 A	2400	2422, 2440, 9440
9440	Finalize Interior Layout - Book Store	0	12-13-12 A	01-01-13 A	2420	2422, 9450
9450	Submit Plans for Book Store NPDES Permit	0	12-22-12 A	12-22-12 A	9440	9462



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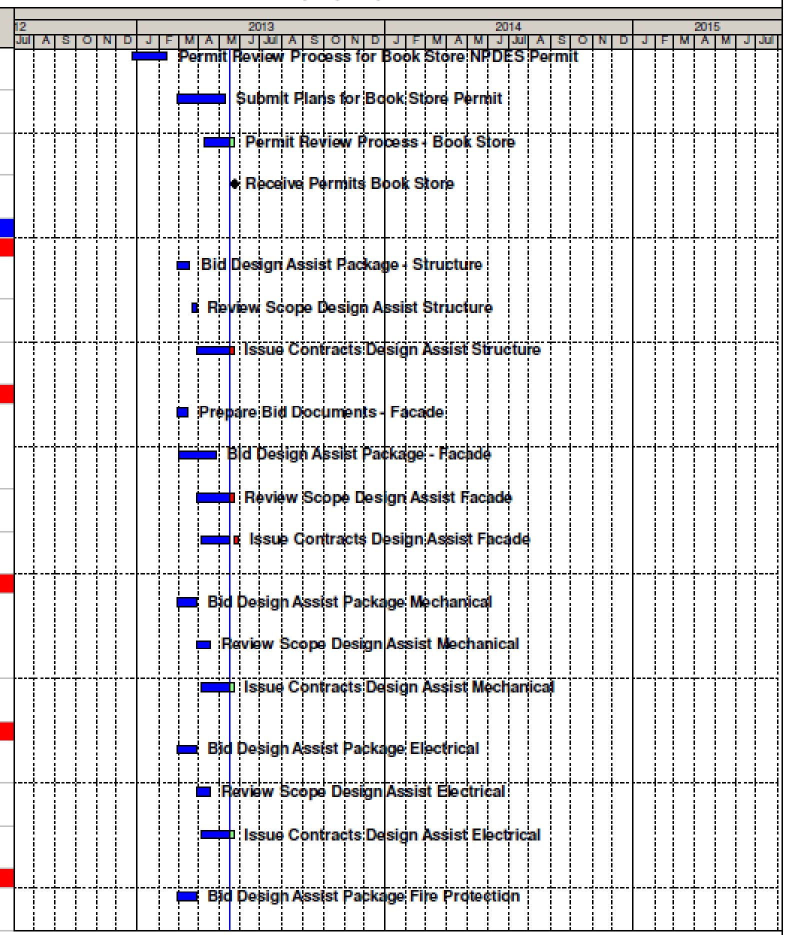
PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
9462	Permit Review Process for Book Store NPDES Permit	0	12-24-12 A	02-14-13 A	9450	2500, 2424
2422	Submit Plans for Book Store Permit	0	02-27-13 A	05-09-13 A	2420, 9440	2424
2424	Permit Review Process - Book Store	6	04-10-13 A	05-23-13	2422, 9462	2480, 2500
2480	Receive Permits Book Store	0		05-23-13	2424	2520
Design Assist						
Structure						
1400	Bid Design Assist Package - Structure	0	02-27-13 A	03-19-13 A	1320, DI1004	1402, 9400
1402	Review Scope Design Assist Structure	0	03-21-13 A	03-27-13 A	1400	1404
1404	Issue Contracts Design Assist Structure	5	03-28-13 A	05-22-13	1402	2100, 2200
Facade						
9620	Prepare Bid Documents - Facade	0	02-27-13 A	03-15-13 A	DI1004	1500
1500	Bid Design Assist Package - Facade	0	03-01-13 A	04-25-13 A	1320, DI1004, 9620	1502, 9400
1502	Review Scope Design Assist Facade	5	03-28-13 A	05-22-13	1500	1504
1504	Issue Contracts Design Assist Facade	5	04-04-13 A	05-30-13	1502	2200
Mechanical						
1600	Bid Design Assist Package Mechanical	0	02-27-13 A	03-27-13 A	1320, DI1004	1602, 9400
1602	Review Scope Design Assist Mechanical	0	03-28-13 A	04-18-13 A	1600	1604
1604	Issue Contracts Design Assist Mechanical	5	04-04-13 A	05-22-13	1602	9780, 2200
Electrical						
1700	Bid Design Assist Package Electrical	0	02-27-13 A	03-27-13 A	1320, DI1004, DI1020	1702, 9400
1702	Review Scope Design Assist Electrical	0	03-28-13 A	04-18-13 A	1700	1704
1704	Issue Contracts Design Assist Electrical	5	04-04-13 A	05-22-13	1702	9780
Fire Protection						
1800	Bid Design Assist Package Fire Protection	0	02-27-13 A	03-27-13 A	1320, DI1004, DI1020	1802, 9400



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WBS Full Schedule - Basic All Activities

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PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
1802	Review Scope Design Assist Fire Protection	0	03-28-13 A	04-15-13 A	1800	1804
1804	Issue Contracts Design Assist Fire Protection	5	04-04-13 A	05-22-13	1802	9780
Controls						
1900	Bid Design Assist Package Controls	3	02-27-13 A	05-20-13	1320, DI1004, DI1020	1902, 9400
1902	Review Scope Design Assist Controls	2	05-21-13	05-22-13	1900	1904
1904	Issue Contracts Design Assist Controls	3	05-23-13	05-28-13	1902	9780
Trade Contract Procurement						
4100	Bid Structural Steel	0	02-27-13 A	03-19-13 A	9700	9710, 9400
5500	Bid Concrete	0	02-27-13 A	04-25-13 A	9700	9710, 9400
4000	Bid General Trades	0	02-27-13 A	04-30-13 A	9700	9710, 9400
9710	Scope Review Non-Design Assist PAckages	0	03-15-13 A	05-07-13 A	4100, 4000, 5500	9720
3000	Bid & Award Tower Cranes	2	03-18-13 A	05-17-13	100	3020
9720	Award Non-Design Assist Package	4	05-16-13	05-21-13	9710	5600, 4020, 9990, 9890
Buy Out						
2440	Bid - Book Store Trailers	0	12-13-12 A	01-03-13 A	2420	2442
2442	Award Book Store Trailers	0	03-21-13 A	03-27-13 A	2440, 100, 100	2460
Engineering and Off-site Fabrication						
2460	Shops for Book Store Trailers	0	03-28-13 A	04-19-13 A	2442	2462
2462	Approve Book Store Trailer Shops	0	04-22-13 A	04-26-13 A	2460	2464, 2500
2464	Procure Book Store Trailers	5	04-29-13 A	05-22-13	2462	2520
DI1040	Soil Boring Information - Tower Crane Location	10	05-16-13	05-29-13		3020
4020	Shops Demoliton Plans	5	05-22-13	05-28-13	9720	4022
9890	Shops Rebar - Level B4	20	05-22-13	06-18-13	9720	9892

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PSU - HUB Expansion Project 01-24-13R (w/o BOT) - 05-16-13 Rev #2 - Project ID: HUB Expansion-1

Current Data Date: 05-16-13

Activity ID	Activity Name	Rem Dur	Start	Finish	Predecessors	Successors
9990	Shops Rebar - Level B2	20	05-22-13	06-18-13	9720	9992
4022	Approve Demolition Plans	5	05-29-13	06-04-13	4020	4024
3020	Shops Tower Crane Foundations	10	05-30-13	06-12-13	3000, DI1040	3022
4024	Procure Materials Demolition	5	06-05-13	06-11-13	4022, 10000	4240
3022	Approve Shops Tower Crane Foundations	5	06-13-13	06-19-13	3020	3024
9892	R&A Shops Rebar - Level B4	20	06-19-13	07-16-13	9890	9894
9992	R&A Shops Rebar - Level B2	20	06-19-13	07-16-13	9990	9994
3024	Procure Rebar - Tower Crane Foundations	5	06-20-13	06-26-13	3022	3200
4030	Shops Structural Steel B2 Lobby	20	06-21-13	07-18-13	2100	4032
4036	Mill Order Structural Steel	60	06-21-13	09-12-13	2100	4034, 9790
5600	Shops Rebar - Courtyard / Atrium	20	07-08-13	08-02-13	9720, 2100	5602
9894	Fab & Deliver Shops Rebar - Level B4	20	07-17-13	08-13-13	9892	10020
9994	Fab & Deliver Shops Rebar - Level B2	20	07-17-13	08-13-13	9992	4300
4032	Approve Structural Steel B2 Lobby	20	07-19-13	08-15-13	4030	4034, 9790, 4044
5602	Approve Rebar Shops Courtyard / Atrium	20	08-05-13	08-30-13	5600	5604
5604	Procure Rebar Courtyard / Atrium	15	09-02-13	09-20-13	5602	5760
4034	Procure Structural Steel B2 Lobby	10	09-13-13	09-26-13	4032, 4036	4320, 4044
9790	Procure Structural Steel Mezz	21	09-13-13	10-11-13	4036, 4032	6680
4044	Procure Structural Steel MPR Volume	20	09-27-13	10-24-13	4034, 4032	5200
Construction						
Temporary Book Store						
2500	Prepare Site for Book Store Trailers	0	04-04-13 A	05-09-13 A	100, 9462, 2424, 2462	2520

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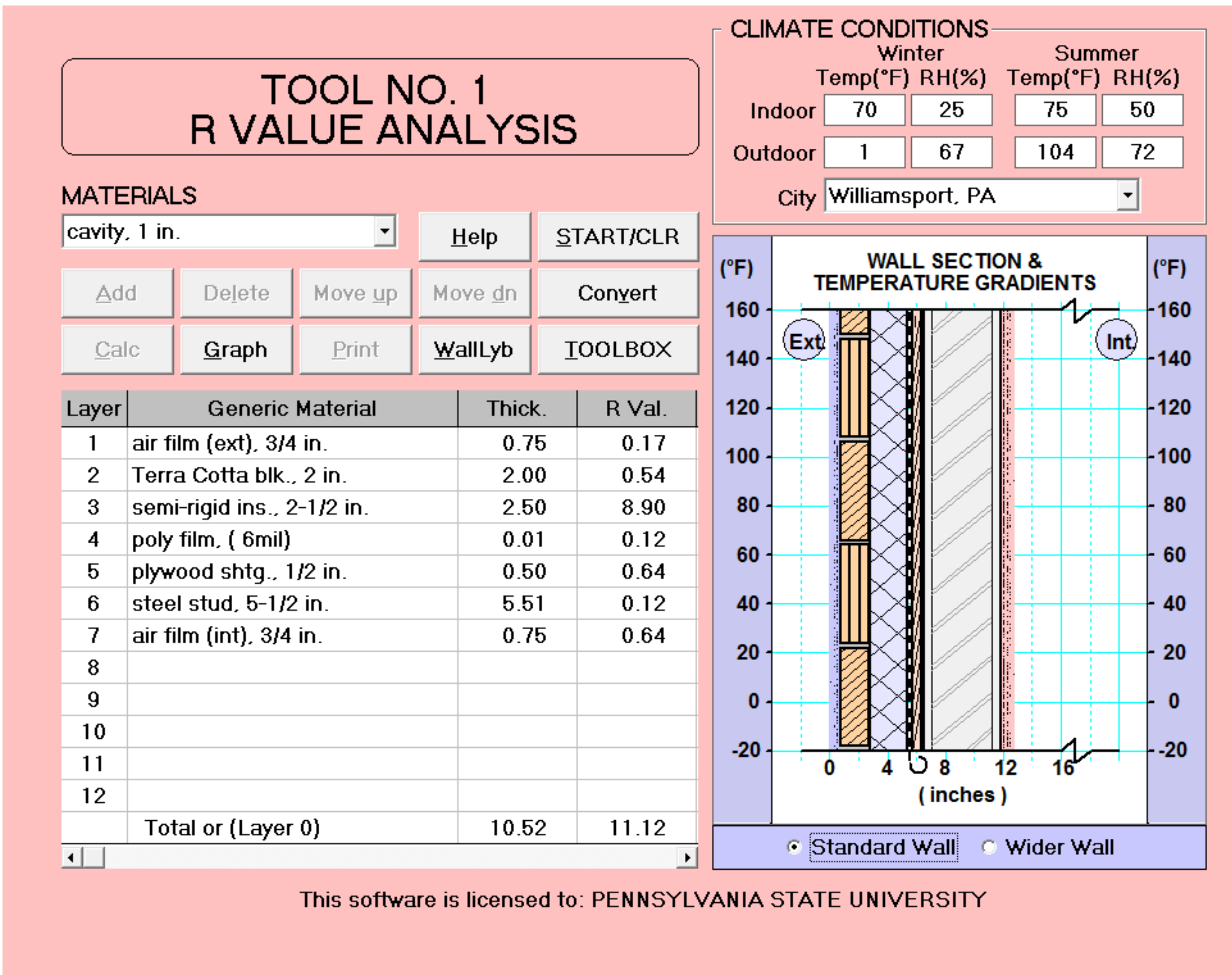
Appendix

B: Thermal Properties

Descsription		Density lb/ft(3)	Conductivity (k) Btu-in./h ft(2) F	Conducance (C) btu h/ft(2) F	Per Inch Thickness (1/k) F ft(2) h BTU-in	For Thickness Listed (1/C) F ft(2) h Btu	Specific Heat Btu/lb F
Terra Cotta							
Terra Cotta Panel		114	2.5				0.21
2.5" Mineral Wool		4	0.25		4		0.232
AVB Membrane		0	16.7		0.12		0
1/2" Ext Sheathing		34	0.8	3.2	1.25	0.31	0.29
6" Metal Stud		12	0.166				0.168
Brick Veneer (OLD)							
3 5/8" Brick		120	0.42				0.2
Airspace		0	0				0
2.5" Mineral Wool		4	0.25		4		0.232
AVB Membrane		0	16.7		0.12		0
Exist. Concrete		140	1				0.22
Metal Panels							
2.5" Mineral Wool		4	0.25		4		0.232
AVB Membrane			16.7		0.12		
1/2" Ext Sheathing		34	0.8	3.2	1.25	0.31	0.29
6" Metal Stud							
Brick Veneer (NEW)							
3 5/8" Brick		120	0.42				0.2
Airspace		0	0				0
2.5" Mineral Wool		4	0.25		4		0.232
AVB Membrane		0	16.7		0.12		0
1/2" Ext Sheathing		34	0.8	3.2	1.25	0.31	0.29
6" Metal Stud		12	0.166				0.168
Green Roof							
Earth	4	100	0.45				0.2
Polyiso Foam	2.5	1	0.0133				0.29
Concrete	4	140	1				0.2
Ceiling Air Space	24	0	0				0

Appendix

C.1: HAM Toolbox Terra Cotta


TOOL NO. 1
R VALUE ANALYSIS
MATERIALS
cavity, 1 in.
Help
START/CLR
Add
Delete
Move up
Move dn
Convert
Calc
Graph
Print
WallLyb
TOOLBOX
Layer | Generic Material | Thick. | R Val.
1 | air film (ext), 3/4 in. | 0.75 | 0.17
2 | Terra Cotta blk., 2 in. | 2.00 | 0.54
3 | semi-rigid ins., 2-1/2 in. | 2.50 | 8.90
4 | poly film, (6mil) | 0.01 | 0.12
5 | plywood shtg., 1/2 in. | 0.50 | 0.64
6 | steel stud, 5-1/2 in. | 5.51 | 0.12
7 | air film (int), 3/4 in. | 0.75 | 0.64
8
9
10
11
12
Total or (Layer 0) | 10.52 | 11.12
CLIMATE CONDITIONS
Winter
Summer
Temp(°F) RH(%) Temp(°F) RH(%)
Indoor 70 25 75 50
Outdoor 1 67 104 72
City Williamsport, PA
WALL SECTION &
TEMPERATURE GRADIENTS
(°F)
160
140
120
100
80
60
40
20
0
-20
Ext
Int
0 4 8 12 16
(inches)
Standard Wall
Wider Wall
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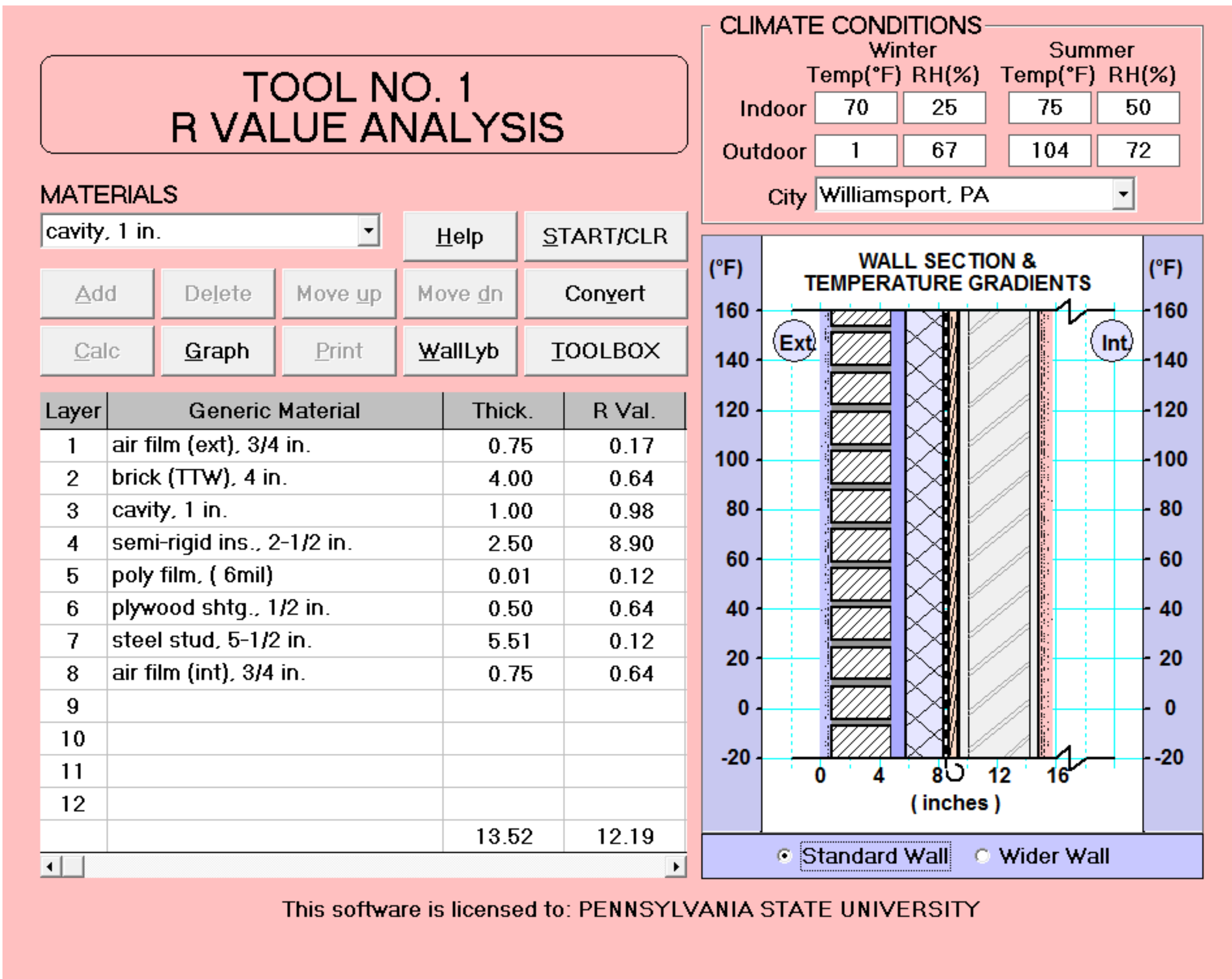
Appendix

C.2: HAM Toolbox Brick Veneer



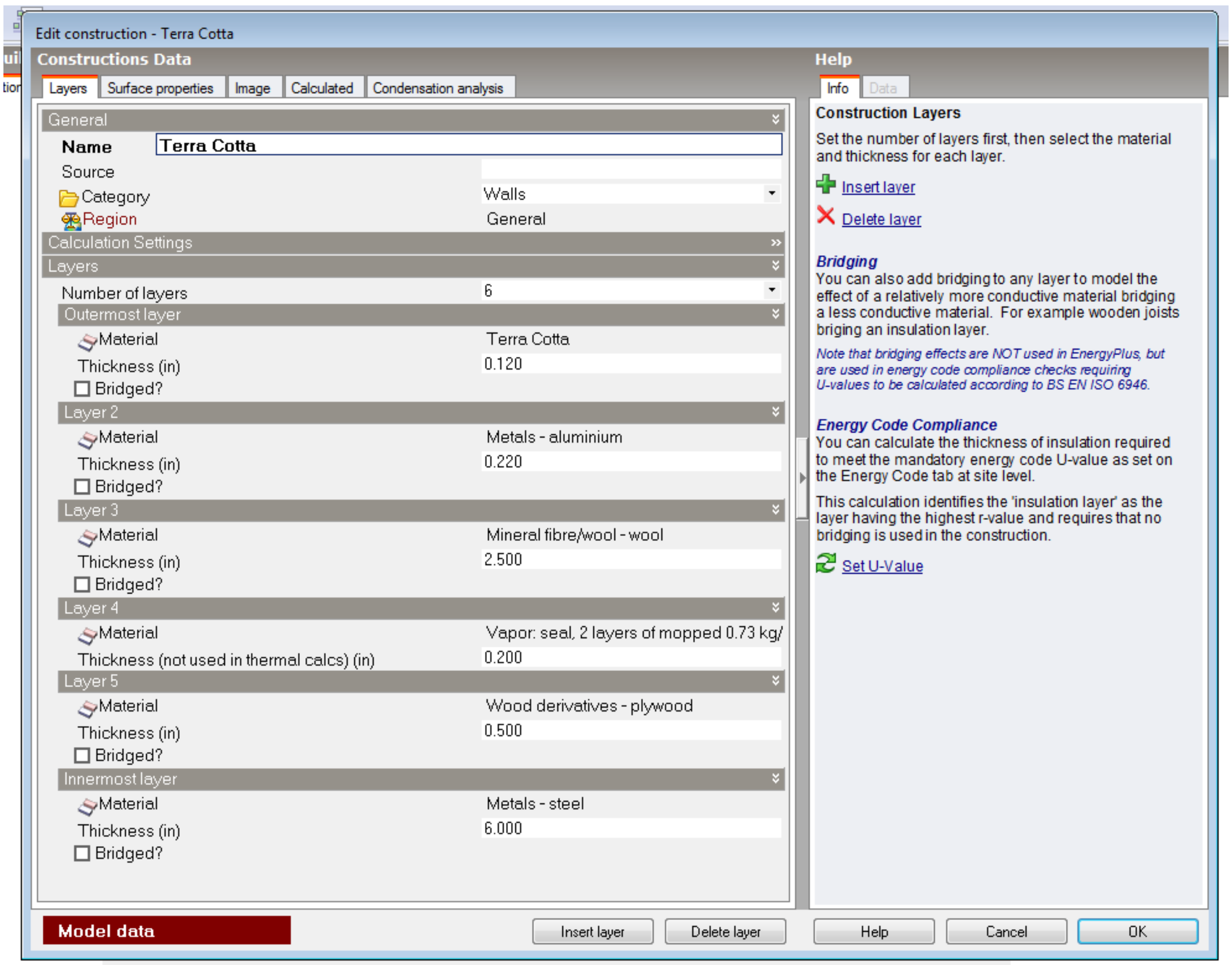
Layer	Generic Material	Thick.	R Val.
1	air film (ext), 3/4 in.	0.75	0.17
2	brick (TTW), 4 in.	4.00	0.64
3	cavity, 1 in.	1.00	0.98
4	semi-rigid ins., 2-1/2 in.	2.50	8.90
5	poly film, (6mil)	0.01	0.12
6	plywood shtg., 1/2 in.	0.50	0.64
7	steel stud, 5-1/2 in.	5.51	0.12
8	air film (int), 3/4 in.	0.75	0.64
9			
10			
11			
12			
		13.52	12.19

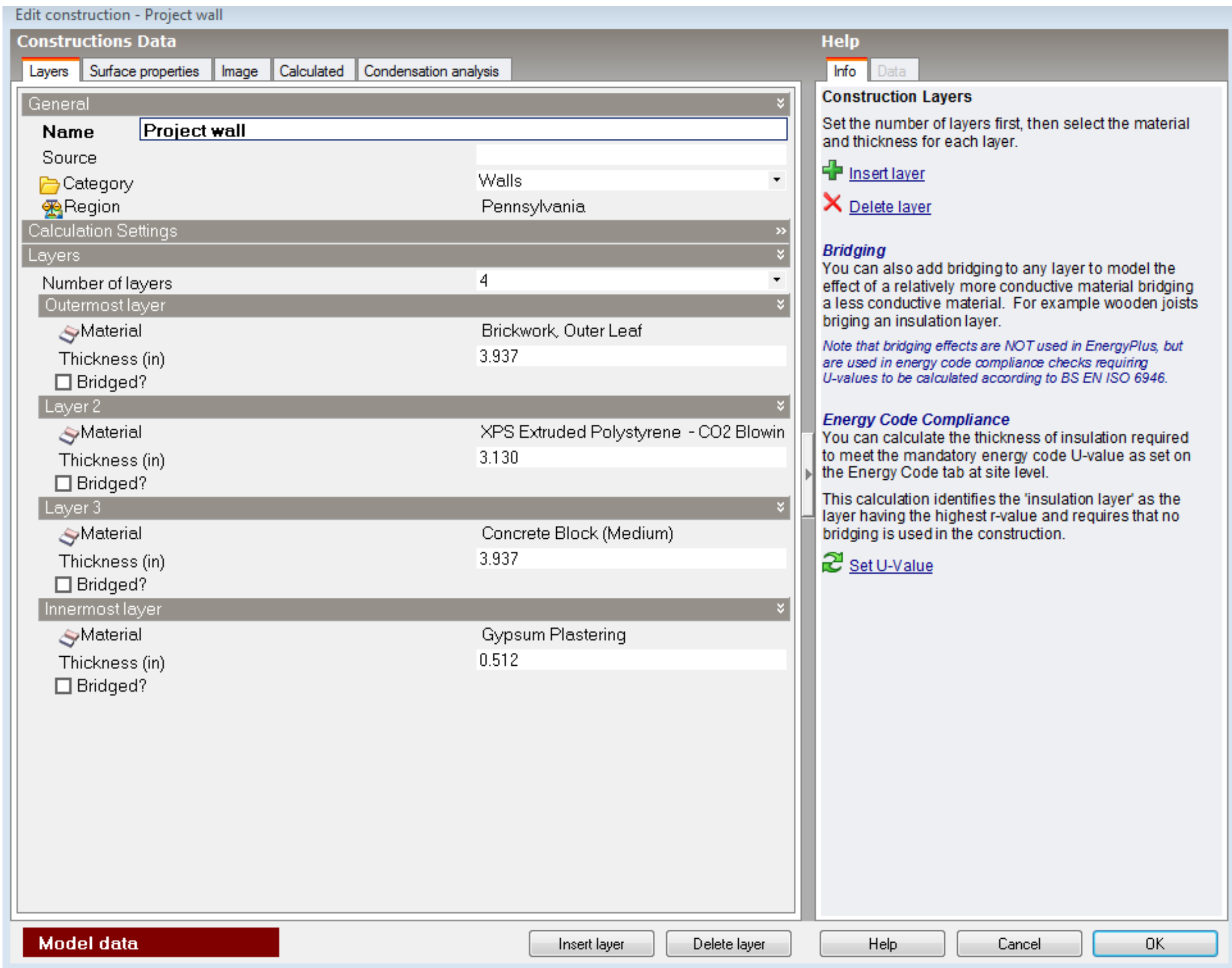
Appendix

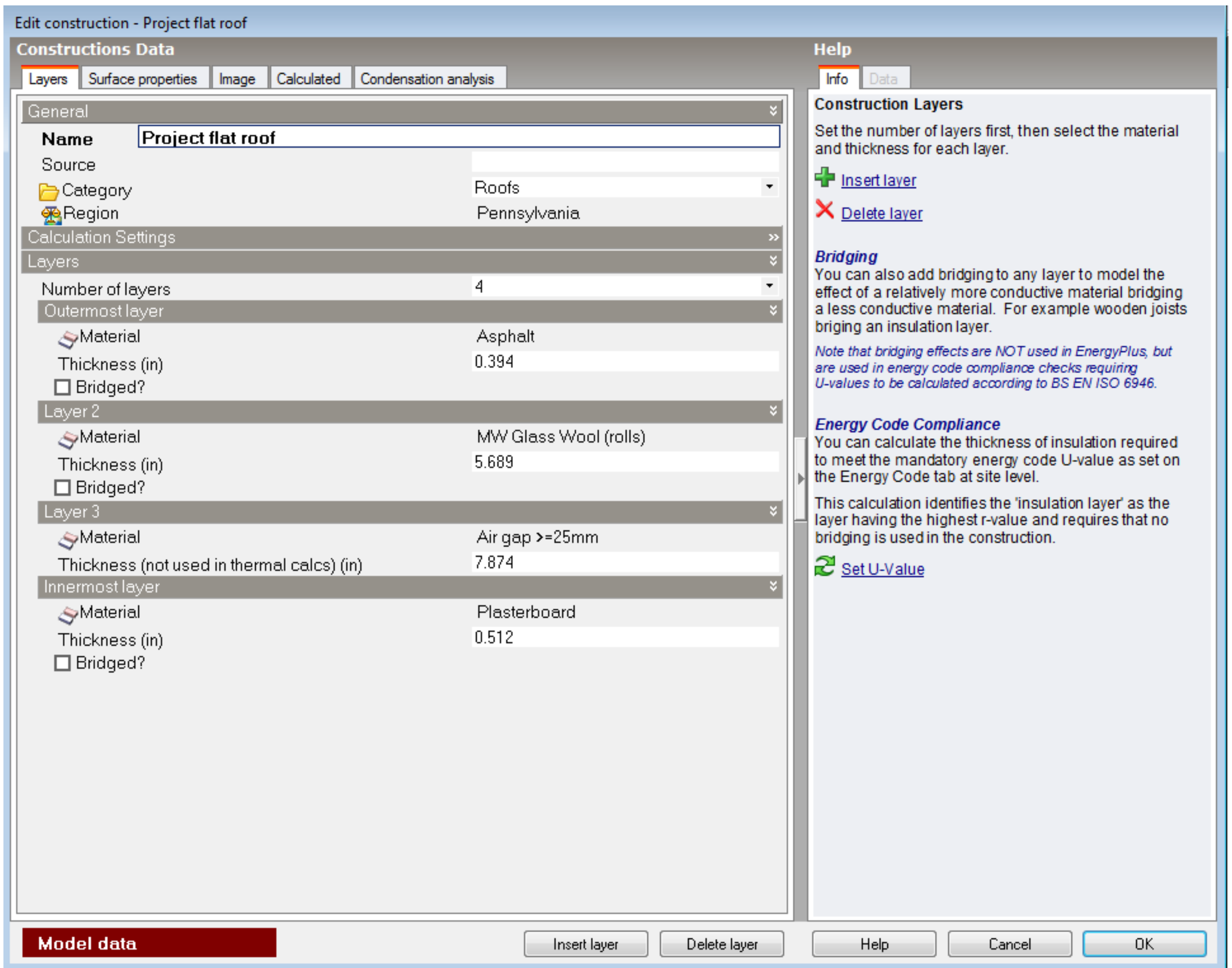
D.1: DesignBuilder Screenshots

Location Template	
Template	**PA - WILKES-BARRE/S**
Site Location	
Latitude (°)	41.32
Longitude (°)	-75.72
Site Details	
Elevation above sea level (ft)	948.2
Exposure to wind	2-Normal
Site orientation (°)	0
Ground	
Water Mains Temperature	
Precipitation	
Site Green Roof Irrigation	
Time and Daylight Saving	
Time zone	(GMT-05:00) Eastern Time (US & Canada)
☑ Use daylight saving	
Start of Winter	Oct
End of Winter	Mar
Start of Summer	Apr
End of Summer	Sep
Simulation Weather Data	
Hourly weather data	USA_PA_WILKES-BARRE-SCRANTON INTL AP_TMY3
Winter Design Weather Data	
◉ Heating 99.6% coverage	
Outside design temperature (°F)	2.8
Wind speed (ft/min)	2185.1
Wind direction (°)	0.0
○ Heating 99% coverage	
Summer Design Weather Data	

Legislative Region	
Region	Pennsylvania
Energy Codes / Insulation Standards	
Uninsulated	Uninsulated
Typical	IECC-1998
Mandatory energy code	IECC-2000
Best practice	Cold winter 'best practice'


Edit construction - Terra Cotta
Constructions Data
Help
Layers
Surface properties
Image
Calculated
Condensation analysis
Info
Data
General
Name
Terra Cotta
Source
Category
Walls
Region
General
Calculation Settings
Layers
Number of layers
6
Outermost layer
Material
Terra Cotta
Thickness (in)
0.120
Bridged?
Layer 2
Material
Metals - aluminium
Thickness (in)
0.220
Bridged?
Layer 3
Material
Mineral fibre/wool - wool
Thickness (in)
2.500
Bridged?
Layer 4
Material
Vapor: seal, 2 layers of mopped 0.73 kg/
Thickness (not used in thermal calcs) (in)
0.200
Layer 5
Material
Wood derivatives - plywood
Thickness (in)
0.500
Bridged?
Innermost layer
Material
Metals - steel
Thickness (in)
6.000
Bridged?
Construction Layers
Set the number of layers first, then select the material and thickness for each layer.
Insert layer
Delete layer
Bridging
You can also add bridging to any layer to model the effect of a relatively more conductive material bridging a less conductive material. For example wooden joists briging an insulation layer.
Note that bridging effects are NOT used in EnergyPlus, but are used in energy code compliance checks requiring U-values to be calculated according to BS EN ISO 6946.
Energy Code Compliance
You can calculate the thickness of insulation required to meet the mandatory energy code U-value as set on the Energy Code tab at site level.
This calculation identifies the 'insulation layer' as the layer having the highest r-value and requires that no bridging is used in the construction.
Set U-Value
Model data
Insert layer
Delete layer
Help
Cancel
OK

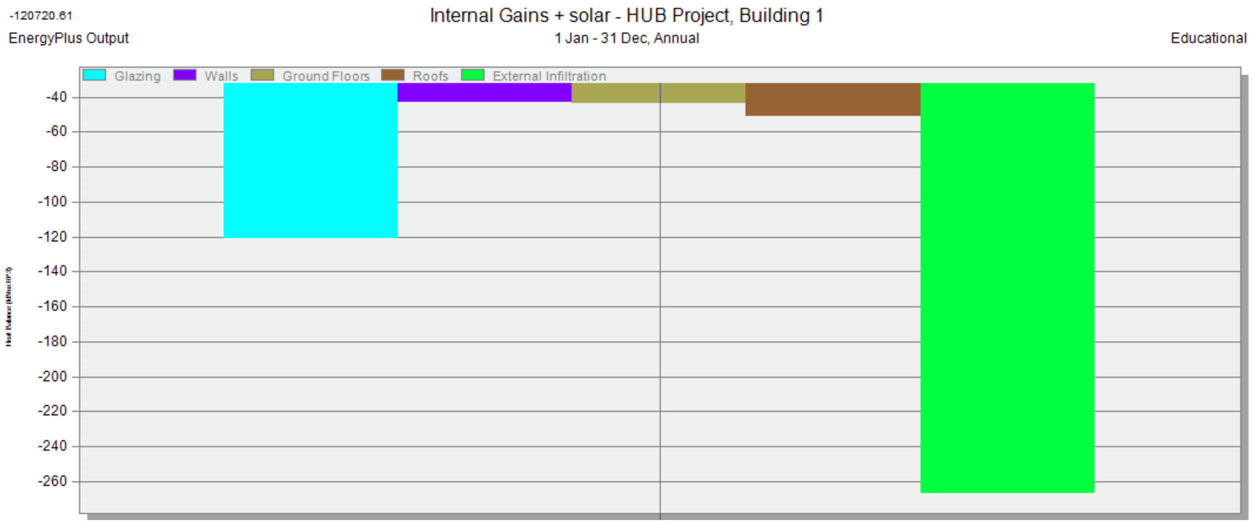

Edit construction - Project wall
Constructions Data
Layers
Surface properties
Image
Calculated
Condensation analysis
General
Name
Project wall
Source
Category
Walls
Region
Pennsylvania
Calculation Settings
Layers
Number of layers
4
Outermost layer
Material
Brickwork, Outer Leaf
Thickness (in)
3.937
Bridged?
Layer 2
Material
XPS Extruded Polystyrene - CO2 Blowin
Thickness (in)
3.130
Bridged?
Layer 3
Material
Concrete Block (Medium)
Thickness (in)
3.937
Bridged?
Innermost layer
Material
Gypsum Plastering
Thickness (in)
0.512
Bridged?
Help
Info
Data
Construction Layers
Set the number of layers first, then select the material and thickness for each layer.
Insert layer
Delete layer
Bridging
You can also add bridging to any layer to model the effect of a relatively more conductive material bridging a less conductive material. For example wooden joists briging an insulation layer.
Note that bridging effects are NOT used in EnergyPlus, but are used in energy code compliance checks requiring U-values to be calculated according to BS EN ISO 6946.
Energy Code Compliance
You can calculate the thickness of insulation required to meet the mandatory energy code U-value as set on the Energy Code tab at site level.
This calculation identifies the 'insulation layer' as the layer having the highest r-value and requires that no bridging is used in the construction.
Set U-Value
Model data
Insert layer
Delete layer
Help
Cancel
OK


Edit construction - Project flat roof
Constructions Data
Layers
Surface properties
Image
Calculated
Condensation analysis
General
Name
Project flat roof
Source
Category
Roofs
Region
Pennsylvania
Calculation Settings
Layers
Number of layers
4
Outermost layer
Material
Asphalt
Thickness (in)
0.394
Bridged?
Layer 2
Material
MW Glass Wool (rolls)
Thickness (in)
5.689
Bridged?
Layer 3
Material
Air gap >=25mm
Thickness (not used in thermal calcs) (in)
7.874
Innermost layer
Material
Plasterboard
Thickness (in)
0.512
Bridged?
Help
Info
Data
Construction Layers
Set the number of layers first, then select the material and thickness for each layer.
Insert layer
Delete layer
Bridging
You can also add bridging to any layer to model the effect of a relatively more conductive material bridging a less conductive material. For example wooden joists briging an insulation layer.
Note that bridging effects are NOT used in EnergyPlus, but are used in energy code compliance checks requiring U-values to be calculated according to BS EN ISO 6946.
Energy Code Compliance
You can calculate the thickness of insulation required to meet the mandatory energy code U-value as set on the Energy Code tab at site level.
This calculation identifies the 'insulation layer' as the layer having the highest r-value and requires that no bridging is used in the construction.
Set U-Value
Model data
Insert layer
Delete layer
Help
Cancel
OK

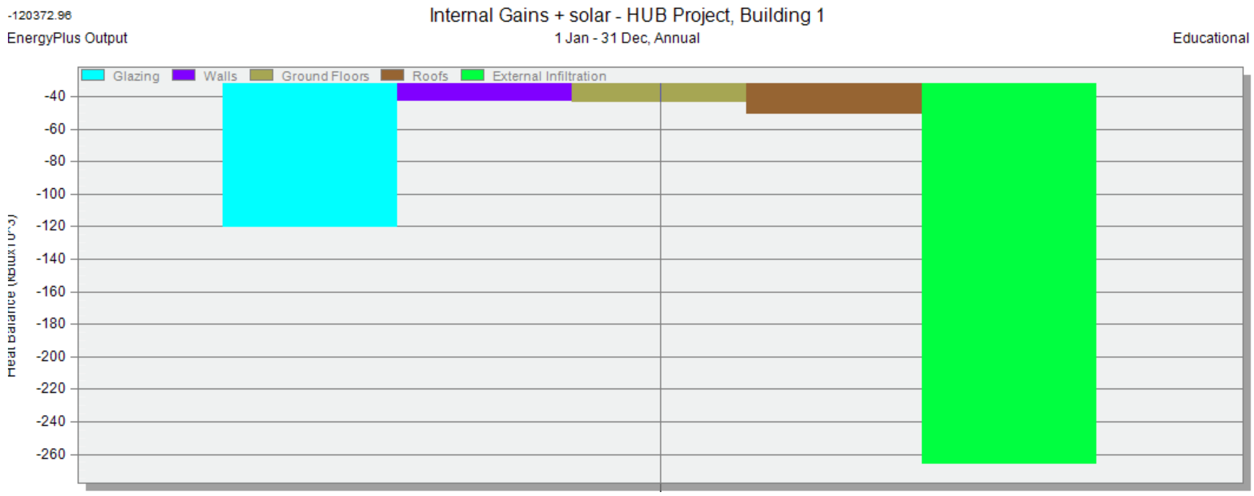
Appendix

D.2: DesignBuilder Graphs

Graph – Terra Cotta



Graph – Brick Veneer



Appendix

D.3: DesignBuilder Outputs

Output – Terra Cotta

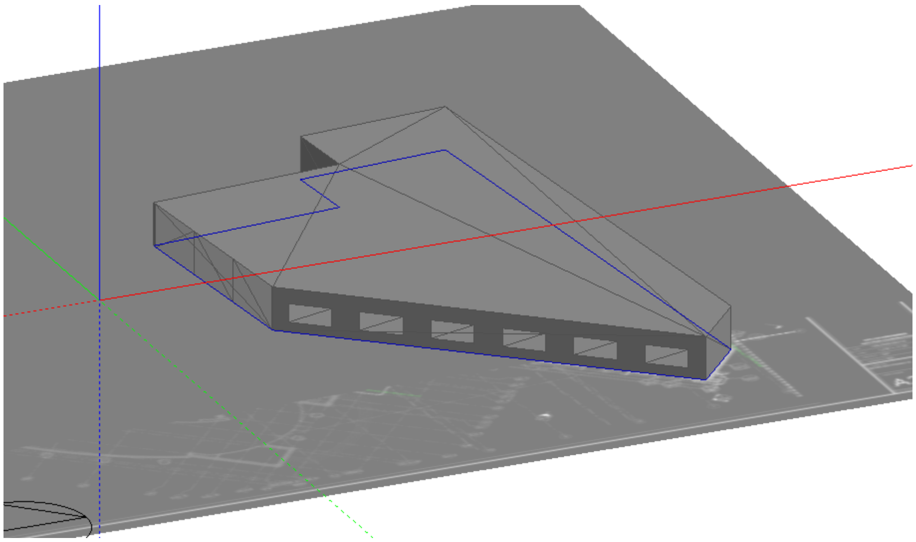
	ZONE PEOPLE TOTAL HEAT GAIN [kBtu]	ZONE LIGHTS TOTAL HEAT GAIN [kBtu]	ZONE ELECTRIC EQUIPMENT TOTAL HEAT GAIN [kWh]	ZONE INFILTRATION SENSIBLE HEAT LOSS [kBtu]
anuary	8394.35	18217.35	3654.68	40812.24
bruary	7299.44	15841.18	3192.23	37224.06
March	7664.41	16633.24	3373.68	32648.13
April	8029.38	17425.29	3500.53	20913.30
May	8394.35	18217.35	3654.68	15063.05
June	7299.44	15841.18	3219.53	9355.47
July	8394.35	18217.35	3654.68	6902.95
August	8029.38	17425.29	3514.18	9500.46
ember	7664.41	16633.24	3360.03	13583.00
ctober	8394.35	18217.35	3654.68	19298.65
ember	7664.41	16633.24	3360.03	26098.04
ember	8029.38	17425.29	3514.18	38967.50
Annual Sum or verage	95257.64	206727.36	41653.10	270366.86
nimum Months	7299.44	15841.18	3192.23	6902.95
ximum Months	8394.35	18217.35	3654.68	40812.24

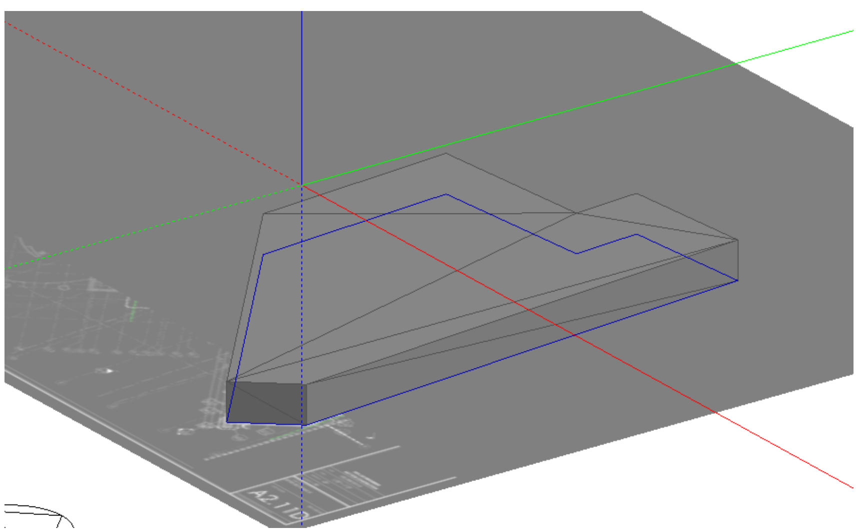
Output – Brick Veneer

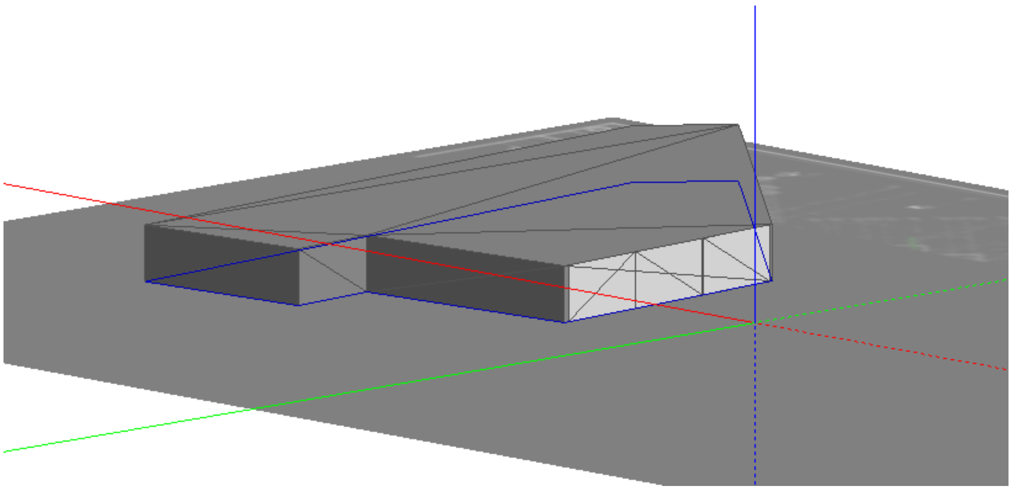
	ZONE PEOPLE TOTAL HEAT GAIN [kBtu]	ZONE LIGHTS TOTAL HEAT GAIN [kBtu]	ZONE ELECTRIC EQUIPMENT TOTAL HEAT GAIN [kWh]	ZONE INFILTRATION SENSIBLE HEAT LOSS [kBtu]
January	8394.35	18217.35	3654.68	40806.65
'ebruary	7299.44	15841.18	3192.23	37206.79
March	7664.41	16633.24	3373.68	32597.73
April	8029.38	17425.29	3500.53	20884.43
May	8394.35	18217.35	3654.68	15011.84
June	7299.44	15841.18	3219.53	9259.81
July	8394.35	18217.35	3654.68	6808.29
August	8029.38	17425.29	3514.18	9415.90
ptember	7664.41	16633.24	3360.03	13549.01
October	8394.35	18217.35	3654.68	19304.45
ovember	7664.41	16633.24	3360.03	26096.85
ecember	8029.38	17425.29	3514.18	38953.66
Annual Sum or Average	95257.64	206727.36	41653.10	269895.41
Iinimum Months	7299.44	15841.18	3192.23	6808.29
Iaximum Months	8394.35	18217.35	3654.68	40806.65

Appendix

D.4: Model Images

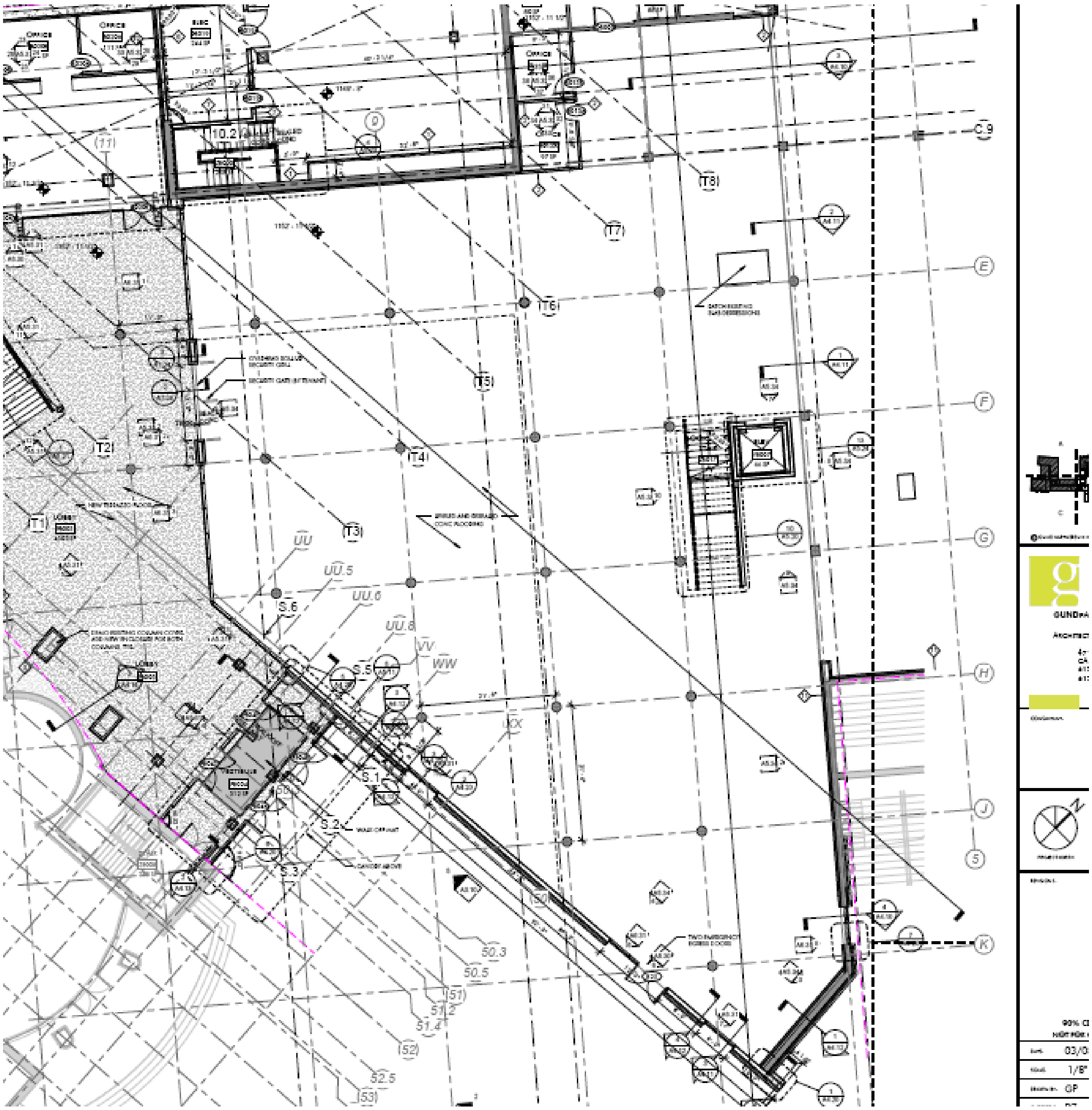






Appendix

D.5: Student Bookstore Drawing Document



Appendix

E.1: Structural Loads

Terra Cotta – Dead Load

Self-weight: (WebStructural accounts for this already)

Slab Weight: 45 PSF

Superimposed: 15 PSF

TC System Weight: 25 PSF

Brick Veneer – Dead Load

Self-weight: (WebStructural accounts for this already)

Slab Weight: 45 PSF

Superimposed: 15 PSF

BV System Weight: 65 PSF

Live Load – Both Systems

Classroom: 40 PSF

Partitions: 20PSF

Conversions

Slab Self-weight: $\frac{45\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 6.25\ ft\ = 0.28125\ {}^{kip}/_{ft}$

Superimposed: $\frac{15\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 6.25\ ft\ = 0.09375\ {}^{kip}/_{ft}$

Terra Cotta: $\frac{25\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 15.5\ ft\ = 0.3875\ {}^{kip}/_{ft}$

Brick Veneer: $\frac{65\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 15.5\ ft\ = 1.0075\ {}^{kip}/_{ft}$

Live Load (C): $\frac{40\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 6.25\ ft\ = 0.3875\ {}^{kip}/_{ft}$

Live Load (P): $\frac{20\ lb}{ft^2} \times \frac{1\ kip}{1000\ lb} \times 6.25\ ft\ = 0.3875\ {}^{kip}/_{ft}$

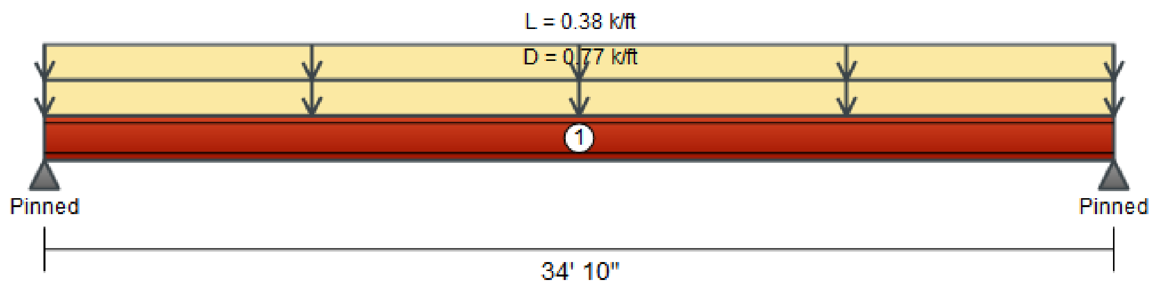
Total Loading (TC): 0.77 k/ft

Total Loading (BV): 1.46 k/ft

Total Loading (LL): 0.38 k/ft

Appendix

E.2: WebStructural – Terra Cotta Loading



Design This Beam

Design OK | **LRFD** | **W21X83** | **A992**

Bending	0.41
Mu (Demand)	219.52 kip-ft
Φ Mn (Capacity)	529.20 kip-ft
Controlling Equation	F2.1: Yielding
Location	17' 5"
Load Combo	1.2D + 1.6L + 0.5Lr

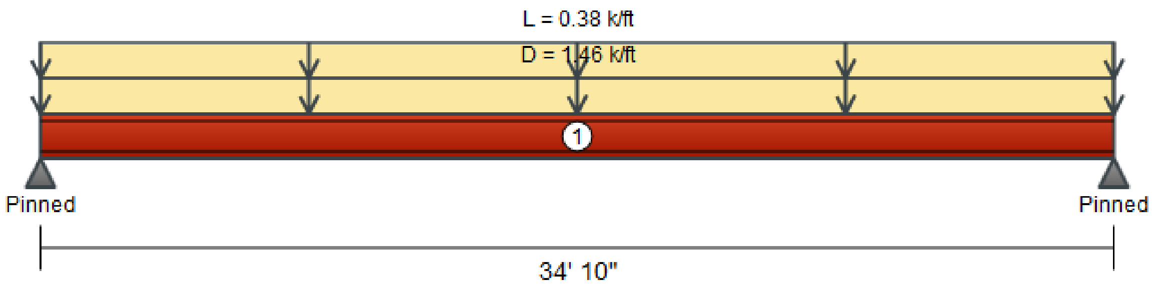
Shear	0.09
Vu (Demand)	21.83 kip
ΦVn (Capacity)	238.05 kip
Controlling Equation	G2.1: Nominal Shear Strength
Location	0' 0"
Load Combo	1.2D + 1.6L + 0.5Lr

Deflection	0.57
Based On	Service Cases
Max Service Case	Wind Limit
Max Dy	-0.666 in = L/630
Live Load Limit	L/360
Dead + Live Limit	L/360
Snow or Wind Limit	L/360
Total Load Limit	L/240

Design Info	
Shape Type	W21X83
Weight	83.00 lbs/ft
Self Weight	Included
Ix	1830.00 in ^{4}
Bracing	Continuous Bracing

Appendix

E.3: WebStructural – Brick Veneer Loading



Design This Beam

Design OK | LRFD | W21X83 | A992

Bending	0.65
Mu (Demand)	346.41 kip-ft
Φ Mn (Capacity)	529.20 kip-ft
Controlling Equation	F2.1: Yielding
Location	17' 5"
Load Combo	1.2D + 1.6L + 0.5Lr

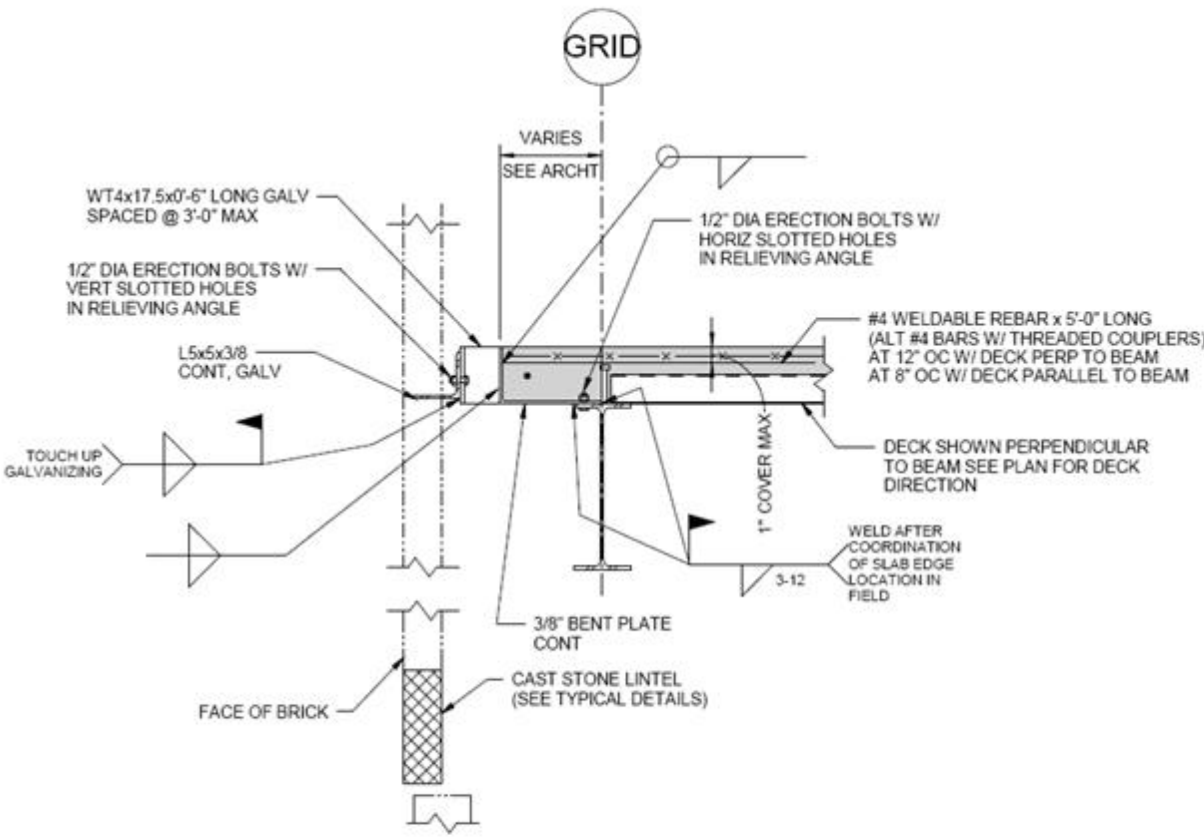
Shear	0.14
Vu (Demand)	34.45 kip
ΦVn (Capacity)	238.05 kip
Controlling Equation	G2.1: Nominal Shear Strength
Location	0' 0"
Load Combo	1.2D + 1.6L + 0.5Lr

Deflection	0.94
Based On	Service Cases
Max Service Case	Wind Limit
Max Dy	-1.097 in = L/390
Live Load Limit	L/360
Dead + Live Limit	L/360
Snow or Wind Limit	L/360
Total Load Limit	L/240

Design Info	
Shape Type	W21X83
Weight	83.00 lbs/ft
Self Weight	Included
Ix	1830.00 in^4
Bracing	Continuous Bracing

Appendix

F: Typical Brick Relief Detail at Slab

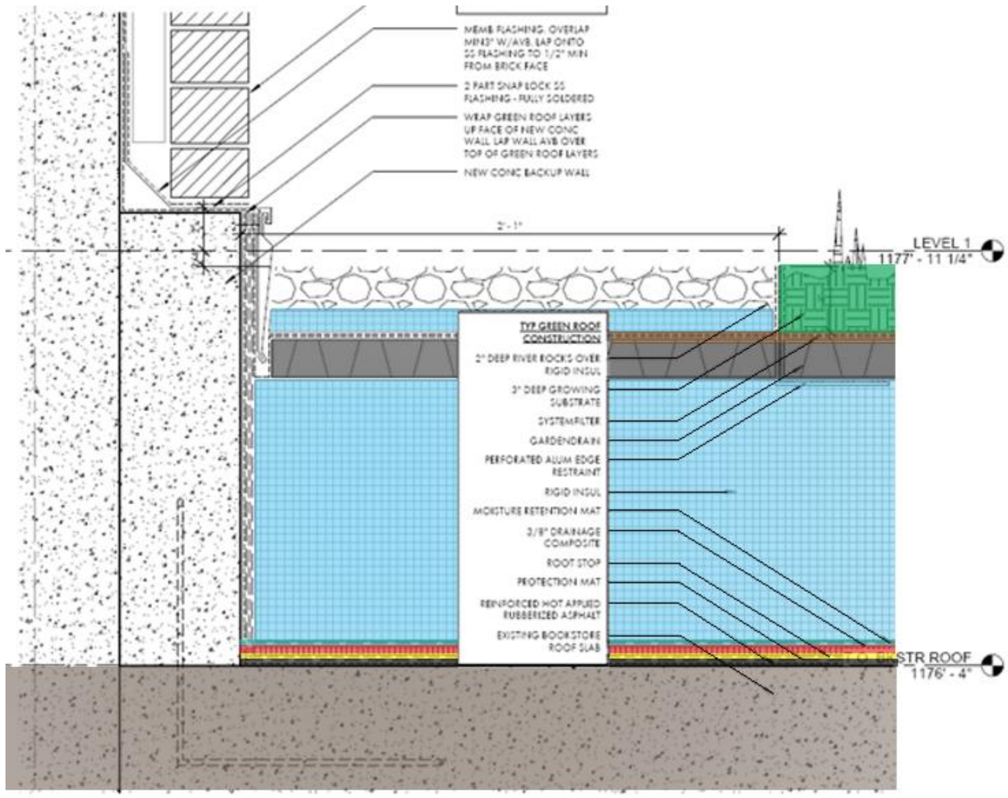


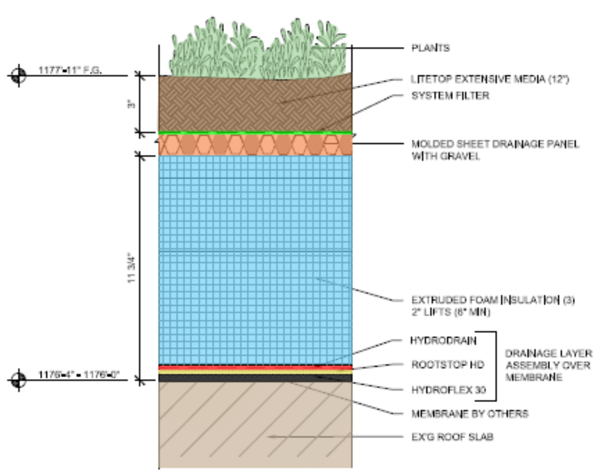
4 TYPICAL BRICK RELIEF DETAIL AT SLAB

SCALE: 1" = 1'-0"

Appendix

G: Green Roof Details



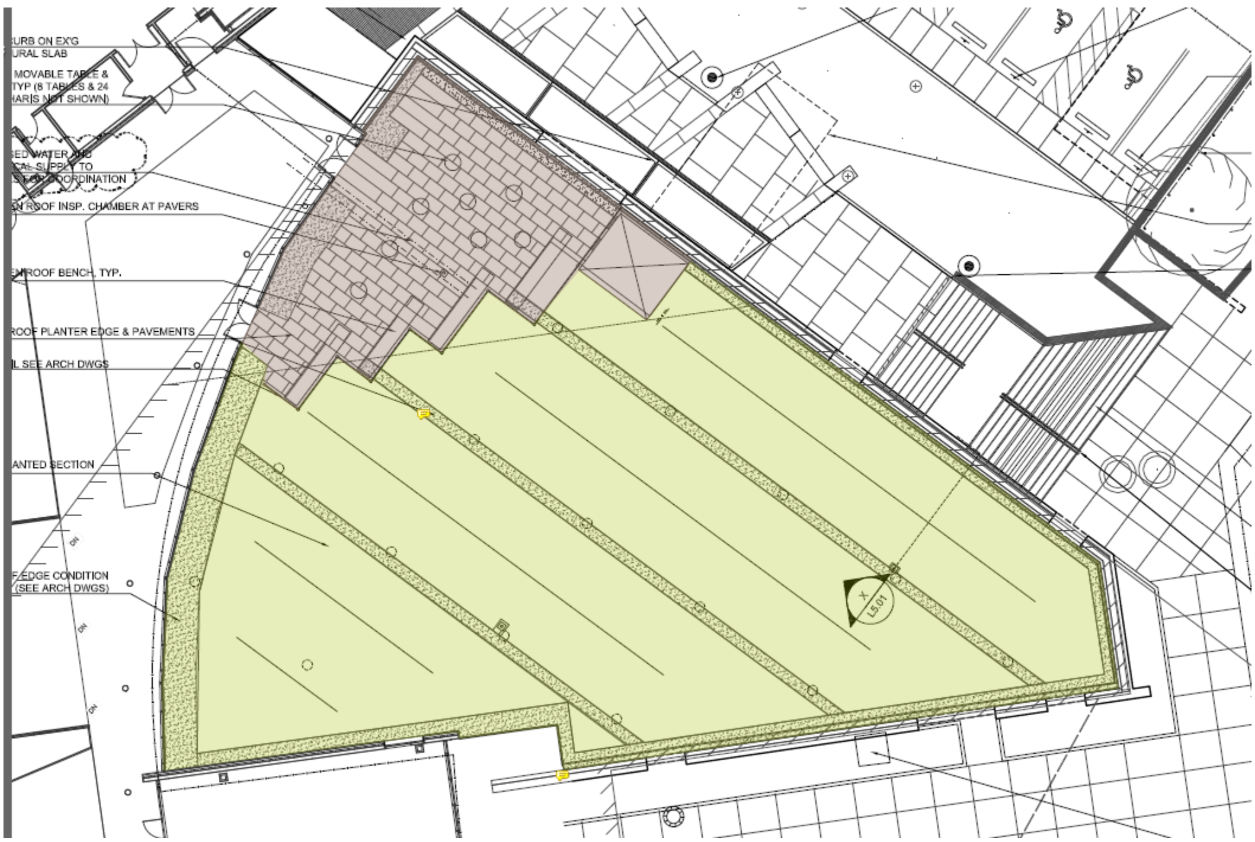


SECTION

1 / L5,01 TYPICAL PLANTED SECTION
SCALE 3"=1'-0"

Appendix

H: SF Green Roof Design


URB ON EX'G
URAL SLAB
MOVABLE TABLE &
TYP (8 TABLES & 24
HAIRS NOT SHOWN)
ROOF INSP. CHAMBER AT PAVERS
ROOF BENCH, TYP.
ROOF PLANTER EDGE & PAVEMENTS
L SEE ARCH DWGS
ANTED SECTION
EDGE CONDITION
(SEE ARCH DWGS)
L5.01

Appendix

I: Presentation Slides

SLIDES WILL BE ADDED ON PRESENTATION DAY