Steidle Building Renewal Project

Rendering courtesy of Mascaro Construction Company

Architectural Engineering Senior Thesis
Final Report

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STEIDLE BUILDING RENEWAL PROJECT

University Park, Pennsylvania

Project Overview

Size:
100,000 Square Feet

Height:
5 Stories

Occupancy Type:
Mixed Use Facility

Delivery Method:
Const. Manager At Risk

Project Budget:
$52 million

Project Timeline:
June 2014 – June 2016

Project Team

Owner:
Penn State University

Occupant:
Material Sciences and Engineering Department

Architect:
EYP Architects & Engineers

Construction Manager:
Mascaro Construction Co.

Rendering courtesy of Mascaro Construction Co.

Architecture:

Existing Building

- Beaux-Arts style exterior
- Renovated lab and office spaces

Central Wing

- Houses an 80-seat lecture hall, computer lab and three research labs
- Glass-and-Limestone Curtain Wall on the South Side

Electrical:

- 4000 Amp Main-Tie-Main Switch-gear
- Three separate electrical systems:
  - Emergency Stand-By Power
  - Low Voltage Power (120/208V)
  - High Voltage Power (277/480V)
- Localized panelboards for power distribution

Structural:

Existing Building

- Steel column and concrete slab interior frame
- Steel trusses and girders which supports new TPO roofing system

Central Wing

- Concrete Structure utilizing:
  - Post-Tensioned Beams
  - Flat Plate Slabs
  - One-way Beam System

Mechanical:

- 100% Outside Air System
  - Two 70,000 CFM AHU's
  - Two 65,000 CFM EAHU's
  - Serviced by a variety of Re-heat Coils, Fan Coil Units, and Terminal Boxes.
- Specialized Portable Exhaust (PEX) Extractors
  - Used for dedicated equipment and bench-work exhaust

Jeffrey Duclos | Construction Option | Advisor: Dr. John Messner
http://www.engr.psu.edu/ae/thesis/portfolios/2016/jid5237/index.htm

Acknowledgements

I would like to thank the following groups and people for their assistance in the creation of this report:

The Pennsylvania State University

The *Department of Architectural Engineering*

Dr. Kevin Parfitt, Head of Thesis

Dr. John Messner, Thesis Advisor

The Office of Physical Plant

Mr. John Bechtel, Assistant Director of the Desogn and Construction Division

Mr. Dwayne Rush, Project Manager – Steidle Building Renewal Project

Ms. Rachel Prinkey, Project Manager – Nursing Building Renovation Project

Mascaro Construction Company

Steidle Building Project Team

Mr. Ed Elinski, Project Executive

Mr. Matt Morris, Project Manager

Mr. Mike Scoeneman, Superintendent

Ms. Penny Luck, Project Administrator

Ms. Erin Dunbar, Project Engineer

Mr. Chaz Ott, MEP Coordinator

EYP Architects and Engineers

Steidle Building Project Team

Mr. Hacig Tacvorian, Lead Architect

Mr. Ervin Kulenica, BIM Manager

I would also like to thank Mr. Sean Flynn from National Resources group for sharing his knowledge about precast facades with me, Mr. Jeremy Duckett and Mr. Matthew Baker for sharing their BIM experiences with me, Dr. Ryan Solnosky for pointing me in the right direction for my structural breadth, and Dr. Moses Ling for helping me decide on my mechanical breadth.

And finally, I would like to thank all my friends and family for being there to support me over the past 23 years. I love you all and couldn't have gotten here without you.

Executive Summary

The purpose of this report is to present and discuss four different analyses based on various aspects of pre-construction planning. These aspects include Schedule Development, Identification of Prefabrication Opportunities, Building Information Modeling (BIM) Execution and Planning, and Subcontractor Procurement.

The first analysis involves developing two resequenced schedules – one focusing on erecting the new stairwells before demolishing the existing stairs and the other focusing on accelerating the construction of the elevator – and comparing them with the original schedule. The two schedules were built based off of major project milestones like move-out or dry-in. Once these schedules were built, they were analyzed based on their cost differences with the original schedule. The resequenced stairwells schedule cost approximately an extra $12,300 to remobilize some of the crews, whereas the original schedule cost $17,400 to rent to scaffolding stair towers. The accelerated elevator schedule required the use of a freight-sized elevator that would cost about $297,000, whereas the designed elevator in the original schedule only cost $264,000.

The second analysis investigates the possibility of prefabricating the façade on the south side of the central wing instead of using limestone courses. Among the various designs and materials investigated, a bisected precast concrete column design was selected. The design was then checked for structural integrity and thermal and moisture performance before the unit costs between the proposed design and the existing design were compared. The precast concrete columns passed the structural, thermal and moisture checks. However, it costs $37.85 per square foot to build while the original limestone façade only costs $33.32 per square foot to build.

The third analysis evaluates the project team's current usage of BIM, specifically their usage of 3D Coordination. The goal was to identify the issues that resulted in an excessive number of model clashes at bid and to propose a change to the BIM Process Design that would assist in preventing or mitigating the issues. To do this, members of the project team were interviewed to gauge where the issues came about. Then, two project managers who worked on BIM-integrated projects at Penn State were interviewed to see what could have been done better. Based on these interviews, the underlying issue was concluded to be a breakdown in communication. Thus a Level 2 process design was created to improve communication and generate more support for the team.

The fourth Analysis is an Industry Research Topic that looks at forming a Best-Value procurement criteria list for Penn State's Office of Physical Plant to use when selecting subcontractors. This list was created based off of the feedback from OPP's project managers and coordinators via a questionnaire about Best-Value selection. While almost everything was considered "valuable," the top performers were Personnel, Team Chemistry, Safety Record, Past Experience, QA/QC Program, Schedule, Reputation, Cost, and BIM Experience.

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Project Overview

About The Building

The original Steidle Building was built in 1929 under the direction of the former dean of the College of Mineral Industries, Edward Steidle. The building needed to accommodate the growing college with new lab and facility spaces. Charles Klauder, architect for previous Penn State projects like Henderson, Sackett and Old Main, was selected to design the new building. His plan boasted a classical, Beaux-Arts design style with a distinctive rotunda and portico, as seen below in Figure 1.

Figure A-1: The Steidle Building as photographed back in 1929. The main feature of the building is its rotunda and portico centered between the two wings of the building.

Although the building has undergone many updates, a major renovation hasn't occurred since 1940 when a central wing was added to house additional lab space. The main focus this project's design is to rebuild the central wing primarily as classroom space on the first and open lab spaces on the second through fourth floors. Renovations are also being made to the original building to include specialized labs on the first floor and office space on the second through fourth floors. Additionally, a open floor-to-ceiling atrium is being built in between the north side of the new central wing and the south side of the existing building. Finally, a fifth-floor penthouse has been added to house the new HVAC and plumbing systems.

Project Details

For this project, Penn State hired EYP Architects and Engineers to design the Steidle Building. EYP then consulted with Keast & Hood Co. for the structural design and with Pennoni Associates Inc. for civil engineering work. Once the designs were finalized, the project was bid out in April of 2014. In the end, Mascaro Construction won the bid and became the Construction Manager At Risk for the Steidle Building Project. Mascaro then selected its subcontractors from among a list of Penn State's prequalified subcontract bidders and awarded contracts to over a dozen companies.

Although the primary owner is The Pennsylvania State University, the end users will be the Department of Materials Science and Engineering (MatSE), a part of the College of Earth and Mineral Sciences. MatSE provides education and research opportunities on material properties, applications and limitations. Over the years, MatSE's breadth of subjects has steadily expanded along with its technical capabilities. As a result, it has become an internationally recognized leader in materials education and research. MatSE's end goals for this project are to upgrade the facilities to meet the demands of the growing department, reorganize laboratory and office spaces to better serve research and education, create engaging and collaborative spaces, and to create a professional, modern atmosphere reflective of the department.

The project itself is split into three phases. The first phase is focused on the demolition of the existing central wing that was originally constructed in 1940. Also occurring during this phase is the gutting of the interior of the existing building that is to remain. This includes demolishing the existing stair towers as well as sections of the existing southwest and southeast wings to make room for the new stair towers. The second phase is focused on the erection of the concrete structure for the central wing. It starts with installing the micropile foundation and slab-on-grade that support the rest of the columns and slabs. Also during this phase, interior work starts in the existing building. This includes the ductwork, piping, plumbing and metal stud walls. The third phase is focused on continuing the interior work while commencing the exterior work, including installing the limestone facade on the south side of the central wing and touching up the brick on the existing building.

Building Systems

Structural

The structural system for the existing building utilizes steel beams supporting concrete decks for the interior frame and load-bearing masonry walls for the exterior system. The roof is supported by a network of steel trusses for the east and west wings and long-span steel girders for the north side of the building. For the renovation, the exterior walls are being cleaned and touched up in order to preserve the historic look of the building.

On the other hand, the new central wing expansion primarily utilizes a concrete structural system with various subsystems used throughout. The second floor deck utilizes post-tensioned beams that run along the column lines through the 80 seat classroom and the computer learning lab. Since both of these rooms require a wide open space to promote the educational environment, having columns in the space is not allowed. However, there are columns on the floors above that are located right in the middle of the rooms. Since these columns and their respective loads cannot be supported by columns underneath, post-tensioned beams are utilized instead to support these columns. The third and fourth floor decks comprise of a flat plate concrete slab system to support the lab spaces above. The only item of note for these slabs is that there is additional reinforcing around the two mechanical shaft openings in each slab. This helps to prevent localized deformations in the slab for these semi-cantilevered areas. The fifth floor slab utilizes a one-way concrete slab system that is significantly deeper than the other slabs. That is because the fifth floor is where the mechanical penthouse is located, which houses the AHU's, Exhaust Air Handling Units (EAHU's), and other pieces of heavy equipment.

The penthouse itself does not use a concrete system, but rather employs a steel framing system to support its enclosure. Of particular note are the roof wells where the exhaust fans for the EAHU's reside, as well as the exhausts for the fume hoods in the laboratories. Due to the fact that space would be limited in this area once the AHU's and EAHU's were installed, special coordination considerations had to be made for the steel in this area.

MEP Systems

The mechanical system for this project is primarily serviced by two 70,000 CFM AHU's and two 65,000 CFM EAHU's located in the fifth floor penthouse. The AHU's facilitate heating and cooling throughout the building through a variety of reheat coils, fan coil units, and VAV boxes. The system uses 100% outside air intake, but recycles air through the fan coil units in the office spaces in order to lighten the heating and cooling loads. Meanwhile, the EAHU's primarily service the lab spaces, where research often produces contaminants as experimental byproducts that need to be exhausted from the space. A unique feature of the exhaust system in the lab spaces is the use of portable exhaust extractors, or PEX devices. These PEX devices are either used for local bench work extraction or are hard-connected to equipment pieces that need dedicated exhaust lines. Another feature of this system is that it utilizes a Heat Recovery Unit in order to provide additional heating to the outside air before it reaches the AHU's. This helps to cut the demand on the AHU's, leading to smaller and less expensive units than originally needed.

While the air systems are located in the penthouse, the heat exchangers, system pumps, domestic water heaters, and glycol heating systems are located in the mechanical wing just to the west of the main building. This area is being completely gutted as part of the renovation so that brand new equipment that can handle the increased building demands may be installed. It is in this area that the steam line from Penn State's steam plant connects to the building to provide low-pressure steam for heating.

The building also houses a 4000 Amp Main-Tie-Main Switchgear that receives electricity from the aforementioned steam plant and distributes it to the entire building. The system itself is broken down into three distinct subsystems. The first is the emergency standby system that powers the emergency lighting and equipment in the event of a power failure. The second is the low-voltage system (120/208V) that powers the receptacles and low-demand equipment of the building. The third is the high power system (277/480V) that powers all of the lighting and high-demand equipment. Panelboards are localized to service specific areas of the building and are serviced from each floors east and west electrical rooms where the conduit risers are located.

Sustainability Implementation

One of the goals of the Steidle Building Renewal Project is to create a sustainable structure with a certification level of LEED Silver or higher based on the LEED 2009 for New Construction and Major Renovation rating system. It aims to achieve that level through a diversified approach across all aspects of sustainable development: sustainable sites, water efficiency, energy & atmosphere, materials and resources, indoor environmental quality, and innovation in design.

Analysis #1 – Alternate Vertical Transportation Systems during Construction

Introduction

The scheduling for the Steidle Building Renewal Project is broken down into three distinct phases – Demolition, Structural Work, and Interior Installations. The Demolition phase started on July 14th, 2014 and finished on February 12th, 2015. The Structural Work phase overlaps Demolition a little bit, having started on October 20th, 2014 with the excavation for the central wing and concluded on July 24th, 2015. The Interior Installations phase, which also includes some exterior work, started on October 7th, 2014 and is expected to finish on June 16th, 2016. The means by which workers, materials and equipment access the building during each phase changes to meet the conditions of the building at that time. Scheduling around these changes is critical to ensuring that project activities and operations run smoothly and don't cause delays.

One of the scheduling issues that arose on this project was the erection of the stairwells. The way that the schedule was originally sequenced meant that the stairs would not be fully built and open for use until about midway through the Interiors phase of the project. While this wasn't necessarily a problem for the overall construction process, it did result in additional costs from having to rent two scaffolding stairs for the extended period. Another area for potential savings is in the installation of the elevator. Before the building even opens up to the general occupants, an elevator can be used to transport workers and materials between floors. This would save money on not having to rent the smaller lifts to move materials, although larger cranes would be needed for items that couldn't fit into the elevator.

The purpose of this analysis is to develop two resequenced schedules and compare them with the original schedule. The first resequenced schedule will focus on erecting the new stairwells before demolishing the existing stairs. The second resequenced schedule will focus on accelerating the construction of the elevator. Both of these new schedules will be primarily analyzed based on costs. However, if there are any other applicable benefits that could improve either schedules viability, then those factors will be considered. Additionally, any challenges that these schedules may encounter will be addressed to see if those challenges prevent the implementation of these schedules.

For this analysis, it will be assumed that fabrication and delivery costs will remain unchanged for the resequenced schedules unless what is being installed needs to change. For the most part, fabrication and delivery comes down to a matter of when the call is made to place the order, while the costs and durations usually remain constant. Also, while benefits and challenges will be mentioned, it will be beyond the scope of this report to quantify their impacts due to their complexity. Instead, these will be tallied to see which outweighs the other.

Analysis Process

1. Review the original schedule, focusing on the relationships between activities that either precede or follow erecting the stairwell
2. Interview the project manager and superintendent to obtain relevant information on the stairwell erection and elevator installation processes

3. Develop the two initial resequenced schedules based on the two proposed solutions
4. Obtain feedback from the project team
5. Develop the final resequenced schedules and perform the cost analyses
6. Compile findings into final report

Solution Overview

The first alternative addressed in this analysis will be to reschedule the erection of the stairwells. Specifically, the schedule shall be resequenced so that the new stairwells (highlighted below in blue in Figure 1-1) are erected during the Demolition phase instead of during the Interiors phase, before the existing stairs are removed (former location highlighted in red in Figure 1-1). Originally, the stairs were fabricated and delivered to the site along with the steel for the penthouse structure, but for this new sequence they are being split into two separate sequences. This would result in increased costs as a second mobilization of the steel crew and an extra crane would be needed. However, it also means that temporary scaffolding stairs would no longer be needed on the project. The resequenced schedule will be evaluated to see if there are cost savings from remobilizing the steel crew compared to renting out the scaffolding stairs.

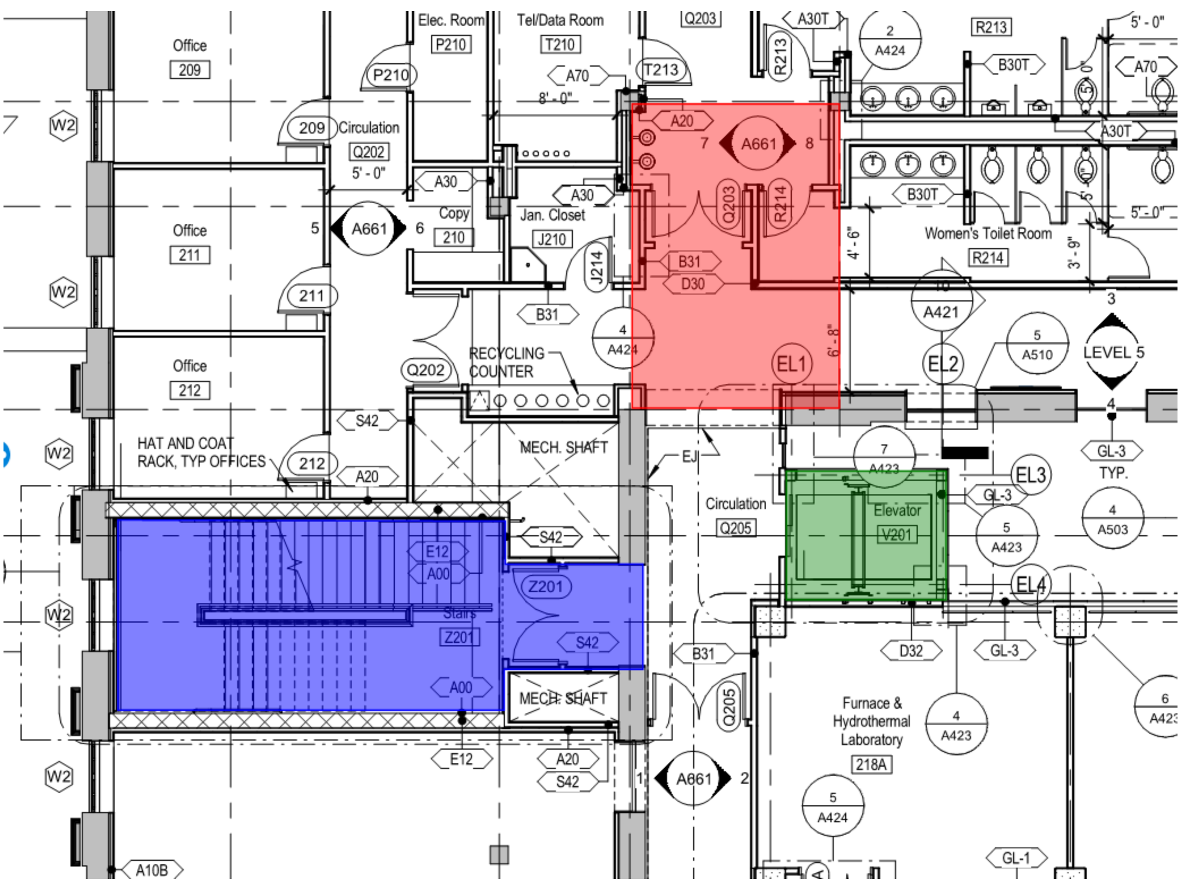


Figure 1-1: Locations of the newly constructed West Stairwell (blue), the demolished existing west stairwell (former area in red) and the glass elevator (green). The existing stairwell and newly constructed stairwell on the east side are a mirror image of the west.

The second alternative addressed will be to accelerate the installation of the building's elevator (highlighted in green in Figure 1-1) and evaluating whether or not the acceleration costs are outweighed by the reduced costs stemming from having the elevator available at a sooner time. This results in eliminating the need for a boom lift to deliver materials to the different floors. The elevator prescribed for the building is able to handle loads up to 4000 pounds in order to allow the Department of Materials Science and Engineering to move equipment between floors. However, this also means that if the elevator were to be operational and certified earlier during construction, then it could be used to deliver materials and equipment to each of the floors. This would replace the need for lifts or a crane on site for the majority of the Interiors phase of the project, aside from larger building elements like the Air Handling Units.

Creating the Schedules

The first schedule to be built was the resequenced stairwells schedule. While the original schedule started with the demolition of the existing stairs on September 22nd, 2014, the new schedule starts on August 22nd which is when Penn State completes its move-out procedures. Even though the timing changed, the sequence of activities within each task was kept the same. Also during the project, there were breaks between activities which I assumed to be because the crews would be working elsewhere on the project before moving on to the next stair-related activity. Since during the resequenced schedules the trades wouldn't need to be working elsewhere, I decided to eliminate the breaks between activities to allow for a better flow of work except for the demolition of the existing beams and the erection of the steel. That said, I did keep the actual durations in place instead of using the original estimated durations. This was done because it would be more reflective of the actual construction process and to account for any issues that were activity-dependent. Plus, this would ensure that the crew costs between the two schedules would remain equivalent and thus wouldn't need to be considered when performing the cost analyses.

The second schedule to be built was the accelerated elevator schedule. In the original schedule, work on the elevator started on July 3rd, 2015 with the support steel wasn't fully installed until April 4th, 2016. In the accelerated elevator schedule, the support steel starts going in on Jun 18th, right after the penthouse slab finishes curing. Once the steel is installed, the elevator glazing is postponed slightly until the atrium skylight starts to be installed. The elevator glazing would be installed alongside of the skylight due to the similarity of work. Once the skylight has been finished and the surrounding area is dry, then the elevator itself can be installed without worry of being exposed to the elements. In this schedule, the elevator finishes on November 2nd, 2015, a full five months ahead of when it was originally completed. Once the elevator is functional, then an operator can be hired to run the elevator, shipping materials and transporting workers to wherever they need to go. This would go on until June 16th, 2016, which is when the building is planned to be substantially complete, occupancy permits are acquired and the personnel from the Materials Sciences and Engineering Department are able to use the elevator themselves.

All three schedules – the original schedule, the resequenced stairwell erection schedule, and the accelerated elevator installation schedule – can be found in Appendix 1-1.

Cost Analyses

When calculating the cost differences between the resequenced stairwell schedule and the original stairwell schedule, I only accounted for the costs for items that changed between them. For costs that I did need to account for, I reference RS Means Building Construction Costs 2015 (which is when the bulk of the work for these activities took place). The only exceptions are the costs for the two stair towers and the window glass trim. The actual rental cots for those were provided by Mascaro, while the price for the window glass trim was obtained online from The Builder Depot since a similar product couldn't be located in RS Means 2015.

The only costs associated with the original schedule that aren't shared with the resequenced stairwells schedule are the mobilization and rental costs for the two scaffolding stairwells. It is assumed that the trades will be able to balance their crews such that no cost differences will occur when comparing the crews except for extra mobilization costs.

The resequenced stairwells posed a few more differences than the original schedule due to the mobilization of crews that weren't working on the site at the time the resequenced stairwells schedule needs them. At this time, demolition has already started in the central wing, so I decided that the already-present demolition crews would be capable of balancing their crews to complete the demolition of the slabs where the new stairs are to be installed with no additional costs. Also, the way the schedule played out meant that the concrete stair pans would be placed while the concrete crews were building the new structure for the central wing. I figured that the concrete crews would be able place the pans during that time without incurring extra costs.

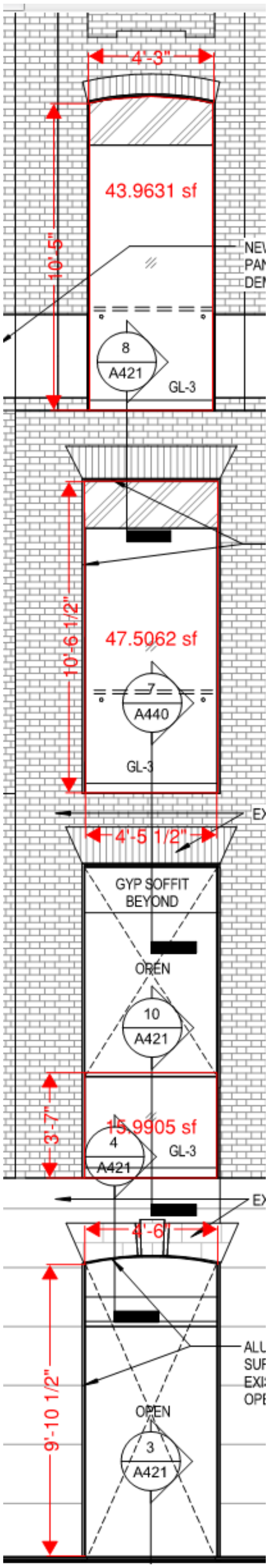
However, the bricklayers for the CMU walls that form the new stair shafts and the steel erectors for the actual stair steel would need a secondary mobilization to be accounted for. In the original schedule, the bricklayers and steel erectors worked on the stairwells while working on the rest of their scope, so only one mobilization was needed. For the resequenced stairwells schedule, I had to account for this secondary mobilization and demobilization. The CMU erectors didn't have any additional equipment, so all that had to be accounted for there were the bricklayers and their helpers. The steel erectors, on the other hand, needed to have a gas-engine welder and a mobile crane on site. To account for this, I budgeted two extra days for the crews – one for set-up and one for tear-down. I assumed that the extra mobilization would not impact the set schedule durations. I also assumed that the gas-engine welder and the mobile crane (or aerial lift track) would be on site for all 44 days of the erection of the stair steel, but that those costs would be included as part of the original contract. However, I did decide to add two days to their rental period as part of the added mobilization and demobilization of the crews. I should note that the crew I assigned to the work on the CMU Walls comprises of 3 bricklayers and 2 helpers, while the crew I assigned to the steel erection comprises of one steel foreman, three steel erectors, a gas-engine welder and an aerial lift truck with a 60' Boom. The unique costs breakdowns for the original schedule and the resequenced stairwells schedule can be found below in Table 1-1 and Table 1-2 respectively.

Table 1-1: Cost Breakdown for the Original Stairwell Schedule

Item Description	*Quantity*	*Unit*	*Cost / Unit*	*Total Cost*
East Scaffolding Stairwell – Mobilization	1	EA	$3,000	$3,000.00
West Scaffolding Stairwell - Mobilization	1	EA	$1,900	$1,900.00
East Scaffolding Stairwell – Rental Rate	5	Mo.	$1,800	$9,000.00
West Scaffolding Stairwell – Rental Rate	7	Mo.	$500	$3,500.00
Total Budget				**$17,400.00**

Table 1-2: Cost Breakdown for the Resequenced Stairwell Schedule

Item Description	*Quantity*	*Unit*	*Cost / Unit*	*Total Cost*
Bricklayers (3)	2	Day	$1,690.80	$3,381.60
Bricklayer Helpers (2)	2	Day	$929.60	$1,859.20
Steel Foreman (1)	2	Day	$759.60	$1,519.20
Steel Workers (3)	2	Day	$2,194.80	$4,389.60
Welder, Gas Engine, 300A	2	Day	$160.44	$320.88
Aerial Lift Truck, 60' Boom	2	Day	$435.60	$871.20
Total Budget				**$12,341.68**



The costs for the elevator are a little more difficult because the elevator itself needs to change in order to useful to the project members. According to Mr. Morris, the project manager, the elevator would need to be sized like a freight elevator in order for pallets and carts to fit. After doing some research, I found some freight elevator sizes from ThyssenKrupp Elevator Corporation (refer to Appendix 1-2 for details). Of the elevator sizes listed, I chose to use the 8000 lb. capacity sizes because of how snuggly it would fit into the atrium. The atrium is approximately 11'-4" wide at its narrowest point whereas the "freight elevator" requires a width of 11', just fitting into the atrium.

However, the depth of that elevator is 12'-8", which means that the elevator will cross in front of the west-most windows from the existing building (shown at left in Figure 1-2 with annotated dimensions). This means that the windows would need to be filled in and covered. Originally they contained glass with an aluminum trim around the top and sides of all the openings. The first floor window remained open and the second floor window only partially contained glass, with a glass line trim on top. I decided fill in the windows with a 6" wide CMU back-up wall that would be covered up by a metal stud and gypsum board system equivalent to the wall type adjacent to the windows. This would not only result in a cost difference between the different elevators but also between what went into the windows.

To preserve the architectural intent for the atrium, I also included full panel window for the back of the freight elevator. The cab's width is listed as 8'-4" and the cab's height is assumed to remain at 8', just like to original elevator. I added this window as a separate cost to the freight elevator's cost breakdown. Also, freight elevators in RS Means 2015 do not have the finishes that are needed for this freight elevator. To account for this, I used the RS Means cost for a 5000 lb. capacity freight elevator and increased its material costs by 60% in order to match the 8000 lb. capacity elevator being used for this analysis. Lastly, in changing the elevator there are some other changes to the south window wall in the atrium, but the costs to implement those changes were assumed to be equivalent to the original design.

Lastly, from November 2nd, 2015 to June 16th, 2016, both schedules have different costs associated with transportation. The original schedule needs two boom lifts to get materials into the building based on prior observations. The accelerated elevator schedule will need and elevator operator. It should be noted that by the time the elevator is operational, the scaffolding stairs will have already been removed, so costs for those are a non-issue.

Figure 1-2: Elevation view of the western-most windows on the north side of the atrium with dimension and area measurements.

Table 1-3: Budget for the Original Elevator Schedule

Item Description	*Quantity*	*Unit*	*Cost / Unit*	*Total Cost*
Passenger Elevator, 4000 lb. capacity	1	EA	$130,000.00	$130,000.00
Window Glass	107.5	SF	$16.25	$1746.88
Window Glass Trim	4.5	LF	$6.50	$29.25
Aluminum Trim for Openings (12" Wall)	86.5	LF	$22.50	$1946.25
60' Electric Boom Lift (2)	163	Day	$800.00	$130,400.00
Total Budget				**$264,122.38**

Table 1-4: Budget for the Accelerated Elevator Schedule

Item Description	*Quantity*	*Unit*	*Cost / Unit*	*Total Cost*
Freight Elevator, 5000 lb. capacity	1	EA	$180,800	$180,000.00
Elevator Glass	66.7	SF	$16.25	$1,083.88
CMU Block, 8"x16", 6" Thick	183.5	SF	$8.50	$1,559.75
Gypsum Wall Board, 5/8" Thick, Taped & Finished	183.5	SF	$1.61	$295.44
Metal Stud Framing, 2 ½" wide, 16" OC	183.5	SF	$1.30	$238.55
Elevator Operator	163	Day	$700.00	$114,100.00
Total Budget				**$297,277.62**

Benefits and Challenges

While discussing the schedule for the project, the superintendent for the project – Mike Schoeneman – mentioned that had the new stairs been installed before the MEP work in the adjacent shafts started, then the MEP trades could've had the shaft prefabricated offsite. The prefabricated shafts, according to Mr. Schoeneman, would've been able to use the stairs as structural supports. This would've saved some money on the MEP shaft work while maintaining or improving the quality of the work. This would've also sped up installation time since the project team could just lift the shafts and drop them into place. It also helps that these stairs are much safer to use than the scaffolding stairs. They are protected (for the most part) from rain which can make surfaces slippery. They have a lower rise-to-run ration than the scaffolding stairs which makes workers take their time going up and down and less likely to trip. Plus, the stairs' wider passageway allows for more traffic on the stairs than the narrow scaffolds. All of this helps to keep the workers safe, preventing time and money from being spent on avoidable accidents.

A benefit for using the accelerated elevator schedule would be that the larger elevator prescribed would help the Materials Science and Engineering Department with moving into the new building. MatSE utilizes a large variety of testing equipment in their laboratories, ranging in size from small table-top devices to gigantic testing apparatuses. Having the larger elevator would certainly ease the process of moving the larger equipment pieces into the building.

However, each of these proposed schedules are not without their issues. The challenge for resequencing the stairwell erection process is that the trades hired to work on the project may not be able to do the work at that time. The steel manufactures could be working on another project the time I have designated from them to be working on the Steidle Building, and thus the resequenced schedule would already be experiencing delays. This isn't as large of a problem for the accelerated elevator schedule as that takes place around the same general time frame and so the possibility of overlapping work with another project is greatly diminished. Furthermore, the schedule for strictly installing the stairs is about a month and a half longer than the original schedule. The original stairwell erection sequence turned out to not be on the critical path. However, these changes could very well put the stairwell erection sequence on the critical path for this project and potentially extend the overall duration of the project.

On the other hand, there is still the possibility that the larger elevator wouldn't get approved by either the architects or Penn State's representatives. They might say that the extra-large elevator isn't conducive to the design intent they had hoped to achieve. It's also likely that they wouldn't be too pleased with having to infill a column of windows and cover up part of a historic building. Plus, a larger elevator would consume more energy to operate. Short-term gains would not be able to make up for the elevator's continued excessive energy usage.

Conclusions

The purpose of this analysis was to create a resequenced stairwell erection schedule and an accelerated elevator installation schedule and to evaluate their merits in comparison to the original schedule. This was done by performing a detailed cost analysis for both proposed schedules and recognizing the benefits and challenges to implementing them. The resequenced stairwells schedule would cost about $17,400 extra to implement whereas the original schedule would cost about $12,300 extra to implement. The accelerated elevator schedule would require a larger elevator to be feasible and would cost around $297,000 to build. The originally designed elevator and its schedule would cost approximately $264,000 to construct. Resequencing the erection of the stairs would also allow for more MEP prefabrication abilities, but it also runs the risk of conflicting with other projects that the hired trades are working on. Accelerating the installation of a larger elevator would certainly be a boon to the occupants when moving their equipment back into the Steidle Building, but it also runs the risk of being rejected from a design standpoint and for interfering with the already existing building.

Based on the results from the above analysis, I would recommend that only the resequenced stairwell erection schedule have been used. Not only does it save money itself, but it also offers other areas for potential savings. While it does risk conflict with other trades' workload and increasing the project duration, these can be easily mitigated by the project team with proper planning and coordination. As for the accelerated elevator schedule, it failed to yield any cost savings and it doesn't offer a significant number of benefits to outweigh the challenges to its implementation. On future projects, the members of this project team should look at focusing on building new stairs first on projects that require new stairwells to be built.

Analysis #2 – Prefabrication Potential for the South Façade

Introduction

As the construction industry continues to evolve, new methods have been sought to increase productivity and efficiency on the job site. One of the most common methods that has gained recognition is prefabrication. The ability to make an assembly off-site and then deliver and install it rapidly has made prefabrication widely recognized as a means to increase both efficiency and quality.

The South façade of the Steidle Building (shown at right in Figure 2-1) provides a unique opportunity for prefabrication. As designed, the South Façade is made of limestone courses supported by concrete columns. Since limestone is very heavy and expensive, it is usually installed by hand in relatively small courses compared to the overall size of the façade. This results in a lengthy installation time for a very inefficient process. Yet, all of the columns are the same and the two side walls are mirror images of each other. This kind of uniformity makes the South Façade ideal for the installation of a prefabricated façade.

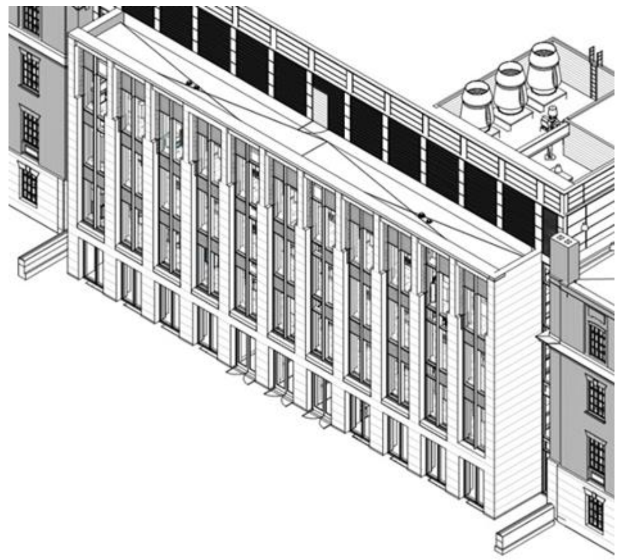


Figure 2-1: The South Façade of the Steidle Building, as viewed from the southeast corner of the site

The purpose of this analysis will be to research different kinds of prefabricated façades and to propose a prefabricated column design with the intention that it maintains the architectural integrity of the original design while saving on-site time, reducing costs and increasing the quality of the assembly. Two different design aspects will be analyzed in forming the design. The first aspect will be using either an entirely prefabricated column or splitting the column into either two or four sections. The second aspect will be utilizing different materials for the façade, including colored precast concrete or sandstone. All of the different column design aspects will be evaluated in forming a final column design. Once the design is finalized, the column design will be evaluated based on structural connections, thermal conductivity and moisture penetration requirements, and unit costs to determine if it's a more viable option than the original limestone façade.

Since the actual architectural design of the façade will remain unchanged, a full cost breakdown was deemed unnecessary. Instead, the unit costs for the limestone façade and the chosen prefabricated system will be directly compared. Additionally, due to the complexities at the parapet of the façade, the caps up at the top will not be included as part of the analysis of both the original design and the proposed prefabricated design. Lastly, the prefabricated façade will have interior straps or an equivalent method of holding it in place on the wall, but it is assumed that they can be neglected from the structural, mechanical or budgeting analyses.

This analysis contains both my structural and mechanical breadths to meet my thesis requirements. The structural breadth for this proposal will be to analyze the structural connections of both the limestone and precast concrete prefabricated columns. As changes are made to the materials of the faces, their structural connection requirements will also change. The existing connections will be evaluated to see if they can handle the change in loading. If not, then a different connection will need to be included with the proposed prefabricated wall design. The mechanical breadth for this proposal will be to analyze the differences in thermal and moisture performance between the limestone and precast concrete system. Temperature differences and water penetration are of the biggest reasons for the failure of the building envelope. Therefore, when a change to the envelope is made, it is prudent to see of the original thermal and moisture requirements are met or exceeded. This analysis will be performed by researching the specs for each of the materials. Then, the two assemblies will be evaluated by determining how each assembly affects the building load as a relative change in percentage, with the end difference heavily factoring into which façade system is selected. They will also be evaluated on where the vapor barrier would need to be installed in the assembly and how that would be accomplished.

Analysis Process

1. Research industry capabilities for prefabricated façade systems
2. Analyze the original façade design to determine how the columns perform structurally and how the façade itself is supported
3. Develop the prefabricated designs, including the structural connections
4. Perform a schedule, cost, thermal conductivity and moisture penetration analysis of all of the designs using the previously researched information
5. Determine if the prefabricated column design would be a suitable alternative to the current façade design.

Solution Development

Many factors were considered as I developed the design for the prefabricated façade system. The first one that was considered was transportation of the prefabricated façade elements to the site. If each column was fabricated as one single piece, then each column would be approximately 55’-7” in length. After sorting through various online catalogs and publications, the longest vehicle that could carry something like this was a 53’ flatbed trailer. Since I nor probably the project team would want to pay extra to ship an oversized load, I decided to go forego using a single-piece column design and focus on using either two-piece (two-story) or four-piece (one-story) column design. This is also true for the two side walls at the east and west end of the façade. However, since the wall wraps around the front column, the wall had to be split into two parts: as shown in Figure 2-2 on the next page, one part is attached to only the cast-in-place concrete support column (marked in red), and the other larger part is attached to only the CMU back-up wall (marked in blue).

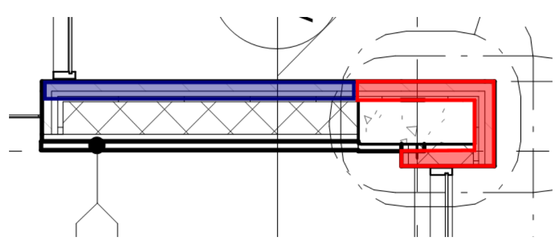


Figure 2-2: Limestone façade at the eastern wall; red marks attachment to the concrete column while blue marks attachment to the CMU wall.

Next, I looked into materials that had a life-span that could meet or exceed According to the Life-Cycle Assessment of Cladding Products, performed by the University of Tennessee's Center for Clean Products, three different cladding products are comparable to limestone: brick masonry, granite and precast concrete. Although there are other materials out there that may have equivalent life-cycles, I settled upon those three as I figured that they provided a wide enough base of comparison so that I wouldn't need to compare a dozen or more materials.

Another factor I looked into concerning the size of the column elements was hoisting. Depending on the material, the weights of the columns would impact what hoisting method could be used. For the original Limestone courses, they were small enough that a simple boom lift could lift them up and lower them into place. However, these lifts are only capable of handling up to 1000 lb., so I needed to check if the equipment had to change to hoist the columns into place. In order to find the total column weight I had to find the volume of the two different column designs. Using the column lengths and cross sections found in Figures 2-3 through 2-6 (found below), I determined that the volume of the one-story column element is 37.5 cu. ft. and the two-story element is 57.7 cu. ft.

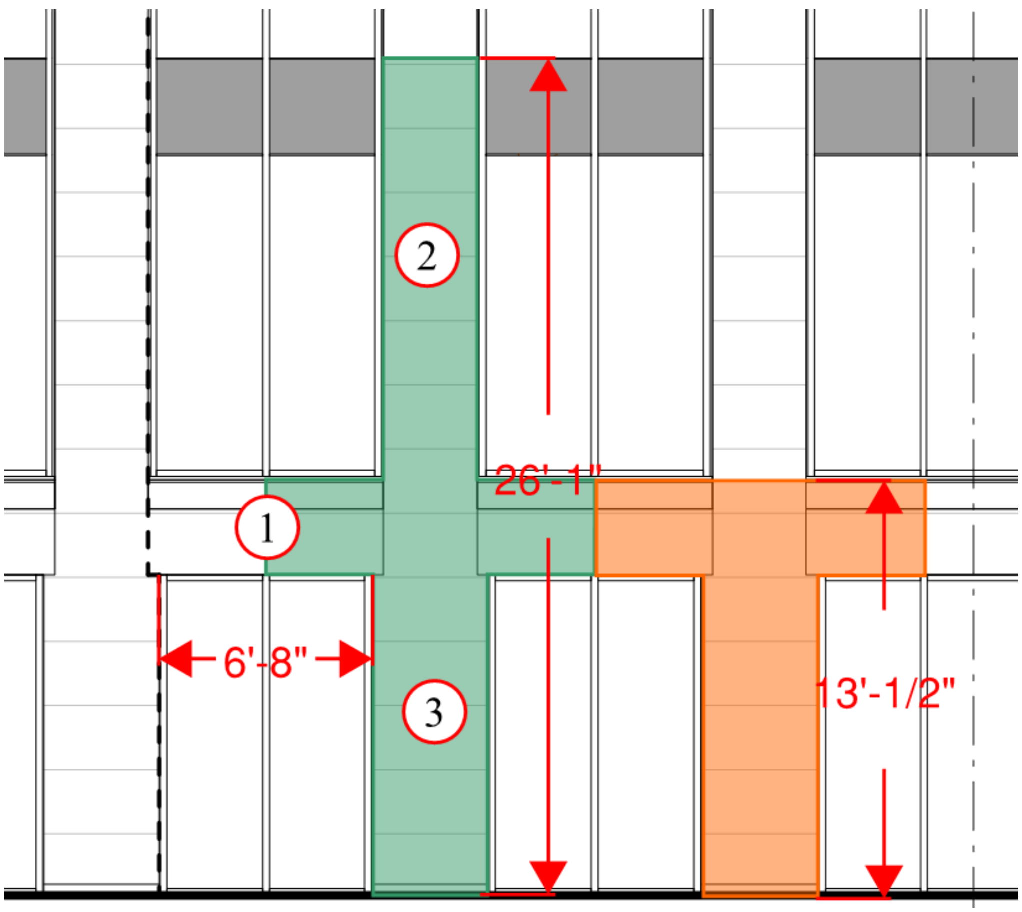


Figure 2-3: Graphical representation of the two-story column element (green) and the one-story column element (orange). Marker #1 refers to the cross-section in Figure 2-4, Marker #2 refers to Figure 2-5, and Marker #3 refers to Figure 2-6.

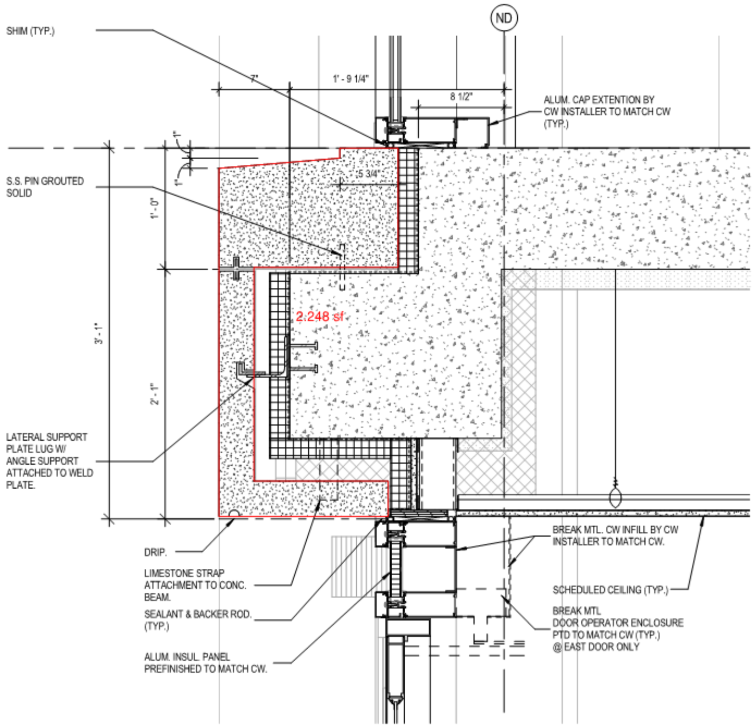
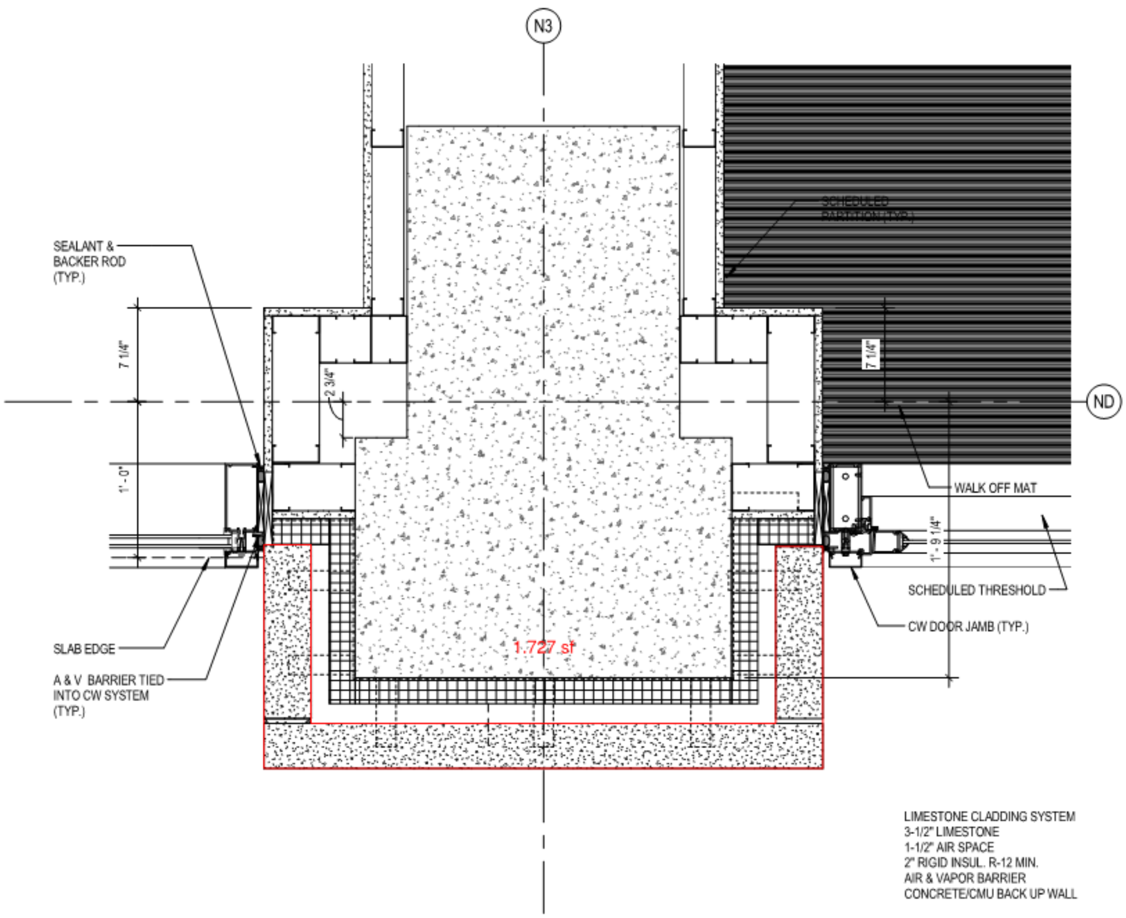


Figure 2-4: Cross-section #1 of the horizontal elements of the prefabricated façade. The area of the limestone is 2.248 sq. ft.

Figure 2-5: Cross-section #2 of the façade and supporting column on the first floor. The area of the limestone is 1.727 sq. ft.



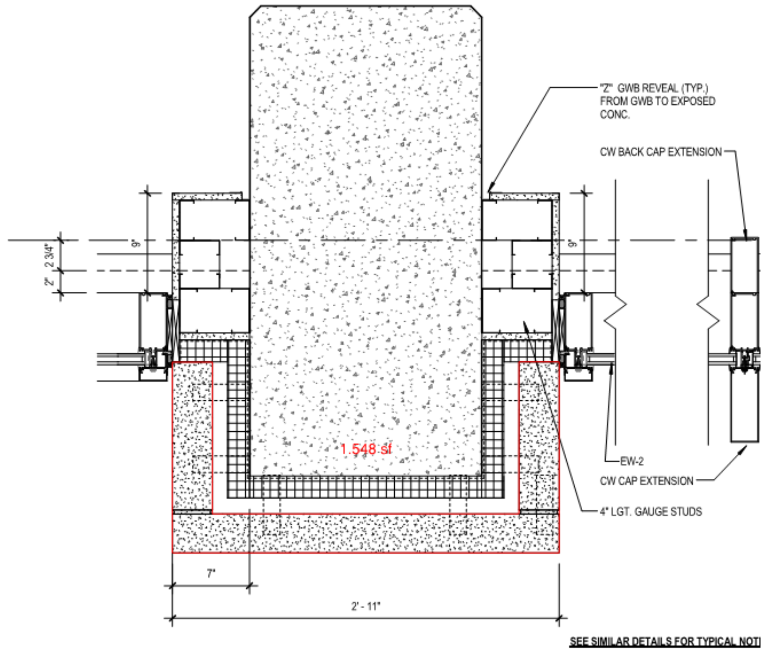


Figure 2-6: Cross-section #3 of the façade and supporting column on the second floor. The area is 1.548 sq.ft.

Combining those numbers with the unit weights of the materials yielded the weights of each type of column element for each type of material, the results of which can be found below in Table 2-1. Based on these results, I decided to narrow my choices down to the two-story column element using either brick masonry or precast concrete. The two-story element would offer greater erection efficiency and the brick masonry and precast concrete would let the project team use a 4 ton capacity mobile crane instead of using the more expensive 8 ton capacity mobile crane. Still though, it's not as cheap as the boom lift used for the original façade.

Table 2-1: Weights of the Prefabricated Façade Based on Size and Material

Material	*Unit Weight (pcf)*	*One-story Column Weight (lbs)*	*Two-story Column Weight (lbs)*
Limestone	156	5850	9001
Brick Masonry	120	4500	6924
Granite	168	6300	9694
Precast Concrete	125	4687.5	7213

However, the determining factor for material selection was aesthetics. One of the goals for the façade was to match it to the exiting limestone on the building. I talked to Mr. Sean Flynn, who works for the National Resources Group and is very experienced with precast facades, and he stated that concrete's versatility makes it amenable to any situation. With the right admixtures and finishing, concrete can be made to look just like limestone. Brick Masonry isn't as capable of doing that. Furthermore, brick masonry doesn't come in the sizes prescribed by the design, whereas the precast concrete, according to Mr. Flynn, can be made to look like a stone course of any shape and size.

Therefore, the prefabricated façade system I propose to use will be a precast concrete system split into two sections per column. In order to make sure that this is a viable option, I analyzed the structural connections, thermal performance, moisture protection requirements and unit costs to make a judgement as to whether or not the precast concrete design would have been feasible.

Structural Breadth: Connections Check

In the original design, a relieving angle is used to support the limestone courses, with pins and stainless steel wind straps anchoring the courses laterally to the columns to prevent horizontal movement. I assumed that these relieving angles are located at the floor slabs on the second, third and fourth floors. I would like to use a similar structural connection system for the precast concrete façade. In this case, there would only be one relieving angle at the third floor slab.

The first step to checking if the proposed design is feasible is to determine the relieving angle's shear and moment capacity. The size of the relieving angle is deemed to be L6"x6"x3/8" based on measurements taken from the drawings. It was also assumed that the angle is made from A36 steel; therefore, its modulus of elasticity (E) is 29e6 psi and its yield strength (f_y) is 36,000 psi. The angle itself is mounted to either the concrete support column or to the CMU back-up wall, as seen below in Figure 2-7. Given how the angle is mounted and that the stone is supported from the edge, I decided to analyze this system with just the flange acting as a cantilever. This cantilever has a 3/8" height (h) and a 1" unit width (b). That gives this cantilever a moment of inertia (I) of 0.0044 in4 and a section modulus (S) of 0.023 in3. With this information, the angle's shear capacity can be solved for by using Equation 1:

$$V_{cap} = \tau_y bh = \left(\frac{f_y}{\sqrt{3}}\right) bh \qquad (1)$$

The moment capacity of the angle can also be calculated by using Equation 2:

$$M_{cap} = f_y * S \qquad (2)$$

Based on these equations, the shear capacity of the flange of the angle is 7794 lbs. and the moment capacity is 69 ft.-lbs.

Once I attained the shear and moment capacities of the angle, I tested the original limestone façade design to see if it did indeed fall below the shear and moment capacities. The height of the limestone between two relieving angles was calculated to be about 13 ft. and referencing the drawings yielded that the limestone's thickness is 3.5." Furthermore, it was assumed that the angle was only supporting the limestone and that the weights of the flashing and mortar net were negligible. Using the unit weight of limestone mentioned above, the load on the flange was calculated to be 49.3 lbs. at 5 ¼" away from the fixed end of the flange. Using the equations found in the Steel Construction Manual for a cantilever with a single point load, I determined that the maximum shear load on the flange was 49.3 lbs. and the maximum moment at the fixed end of the cantilever was 21.6 ft.-lbs., both of which are within the shear and moment capacities for the flange. Furthermore, the deflection of the flange came out to be 0.0043 in.

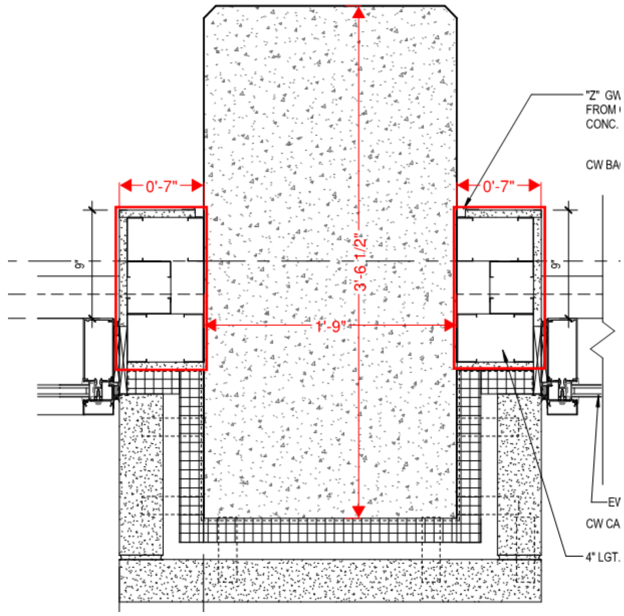
Upon verifying that the relieving angle did work for the limestone, I then tested out the same angle for use in the precast concrete façade system. In this case, however, the concrete is 4 in. thick (based on information provided by RS Means regarding precast concrete) and rises up 29.5' to the roof parapet. It also only weighs 125 pcf as I assumed that the precast façade elements would comprise of lightweight concrete that put less burden on the façade installers. Based on these numbers, I calculated the point load on the angle flange to be 102.4 lbs. at 5 in. from the fixed end. I then determined the maximum shear in the flange to be 102.4 lbs. and the maximum moment to be 42.7 ft.-lbs. Since both of these also fall within the tolerances of the prescribed angle size, I can conclude that the precast concrete façade is compatible with the existing structural connections. An interesting note, though, is that the deflection for the flange under the precast concrete is 0.043 in., about ten times what the deflection in the limestone façade was. While I do not think this is significant enough to render the design unsafe, I was surprised at how much more the angle flange bent under the precast concrete. For further details, all of my handwritten notes and calculations for this structural check can be found in the back of this report in Appendix 2-1

Mechanical Breadth: Thermal and Moisture Protection Check

When changing the limestone to concrete, there cannot be a significant change in the thermal performance; otherwise the occupants will be very unhappy if they're spending more on heating and cooling than they should. There also cannot be any changes to the vapor barrier on the wall. Water penetration is one of the most common causes of building failures today, so it becomes essential that the vapor remain unhindered by the material changes. To make sure of this, I will be evaluating the change in the overall U-value for the column and checking to see if the position of the vapor barrier remains between the rigid insulation and the back-up support structure.

The original limestone façade describes its cladding system as such, going from the exterior to the interior: 3 ½" Limestone, 1 ½" Air Space, 2" Rigid Insulation with a minimum R-12, Air and Vapor Barrier, and finally the concrete/CMU Back-Up Wall. However, what is neglected to be mentioned is that there is a portion of the façade not adjacent to the concrete when it comes to thermal heat loss. Looking at Figure 2-7 (shown on the next page), there are two 5/8"-gypsum-on-metal-stud backing supports. These make up 14 in. of the frontage compared to the 21 in. width of the concrete column. This means that the gypsum accounts for 40% of the façade area when it comes to measuring the average U-value.

Figure 2-7: Highlighting of the gypsum backing supports for the façade with dimensions



Before the U-values for either the limestone column or the precast concrete column can be determined, the R-values for each component in the assembly need to be obtained. It was assumed that the atmospheric conditions during testing were 10°F (Winter) and the building is set to 70°F with 50% relative humidity (with a resulting dew point of 51°F). Research into various R-values for materials in the limestone façade column have been compiled into Table 2-2a:

Table 2-2a: R-values and overall U-value for components found in the limestone façade assembly.

	Concrete Backing	Gypsum Backing
Outside Air Film	0.17	0.17
3-1/2" Limestone	(0.111/in. * 3.5") = 0.39	0.39
1-1/2" Air Space	1.00	1.00
2" Rigid Insulation, R-12	12.00	12.00
Concrete Column	(0.08/in. * 42.5") = 3.40	
5/8" GWB		0.56
12" Air Space		1.00
5/8" GWB		0.56
Inside Air Film	0.68	0.68
Σ R-value	17.64	16.36
U-value = 1/(Σ R-value)	0.057	0.061

And finally, the average U-value for the limestone façade column is calculated using 60% of the concrete backing's U-value and 40% of the gypsum backing's U-value. This yields an average U-value of 0.586 for the limestone façade column.

Additionally, the various R-values for materials in the precast concrete façade have been compiled into Table 2-2b:

Table 2-2b: R-values and overall U-value for components found in the precast concrete façade assembly.

	Concrete Backing	Gypsum Backing
Outside Air Film	0.17	0.17
4” Concrete	(0.08/in. * 4”) = 0.32	0.32
1 Air Space	1.00	1.00
2” Rigid Insulation, R-12	12.00	12.00
Concrete Column	(0.08/in. * 42.5”) = 3.40	
5/8” GWB		0.56
12” Air Space		1.00
5/8” GWB		0.56
Inside Air Film	0.68	0.68
Σ R-value	17.57	16.29
U-value = 1/(Σ R-value)	0.057	0.061

The average U-value for the precast concrete façade column is 0.588, almost exactly the U-Value of the limestone façade. This bodes well for proving that the precast concrete façade is a viable option, but it still needs to be proven that nothing will impact the vapor barrier should this option be considered.

As mentioned in passing above, the dew point for the given conditions is 51°F. This means that if water is passing through the wall and the temperature in the fall falls below 51°F, then the water will condense and cause all sorts of problems. Using the given difference in temperature and the R-values for the assembly, the dew point can be identified which in turn dictates the location of the vapor barrier. For this case, the temperature across the gypsum will be measured as it has the lower total R-value and therefore is a worse case. In order to map out the progression of the temperature through the wall assembly , Equation 3 needs to be used:

$$T_x = T_o + (T_i - T_o)\left(\frac{\Sigma R_{o-x}}{\Sigma R_{o-i}}\right) \qquad (3)$$

where: T_x = the temperature at point X in the wall;
T_o = the temperature outside the column = 10°F;
T_i = the temperature inside the column = 70°F;
ΣR_{o-I} = the sum of the R-values for the whole wall = 16.29;
ΣR_{o-x} = the sum of the R-values to point X in the wall;

The points to be measured using Equation 3 are located at the face of each material (including the air space). The compiled results are found below in Table 2-3:

Table 2-3: Temperatures at material face locations within the precast concrete column

Description of location	Distance into Column Assembly	ΣR_{o-x}	T_x (°F)	Past Dew Point? (Y/N)
Precast Exterior Face	0”	0.17	10.63	N
B/w Precast and 1st Air Space	4”	0.49	11.80	N
B/w 1st Air Space and Insulation	5”	1.49	15.49	N
B/w Insulation and 1st GWB	7”	13.49	59.69	Y
B/W 1st GWB and 2nd Air Space	7-5/8”	14.05	61.75	Y
B/W 2nd Air Space and 2nd GWB	19-5/8”	15.05	65.43	Y
2nd GWB Interior Face	20-1/4”	15.61	67.50	Y

As this table shows, the temperature passes through the dew point at some point in the rigid insulation. Since water moves from the interior to the exterior, the vapor barrier will need to be placed on the inside face of the rigid insulation, which is where it was placed originally. Therefore, the precast concrete column assembly passes the mechanical analysis check.

Cost Analysis

Given that the architectural designs for the original and the precast facades are identical, I decided to directly compare the square foot costs of the two systems as opposed to doing a full façade takeoff. It also helps that the only thing that changes between the two façade systems is the exterior material along with their thicknesses; the rigid insulation, air and vapor barriers, relieving angles and concrete support systems have remained the same. For the cost data, I used RS Means Building Construction Costs 2015 although I did have to make some approximations since neither system had an explicit entry in the book.

For starters, I used the Limestone Veneer with a Sugarcube Finish to approximate the cost per square foot for the original façade. However, RS Means 2015 did not have an entry for 3 ½” thick limestone veneer, so I decided to take the cost data for the 3” thick veneer and average it with the cost data for the 4” thick veneer to get me at least somewhat close to what the costs for a 3 ½” thick limestone façade are. The results can be found below in Table 2-4:

Table 2-4: Square Foot Cost Data for Limestone Veneer Facades with 3", 3.5" and 4" Thick Courses

Thickness	*Material Cost / SF*	*Labor Cost / SF*	*Equipment Cost / SF*	*Total Cost / SF*
3"	$22.50	$5.35	$1.72	$29.57
3.5"	**$26.25**	**$5.35**	**$1.72**	**$33.32**
4"	$30.00	$5.35	$1.72	$37.07

The precast concrete was a little harder to quantify because there is no data for precast concrete sizes as small as the column is designed for. Eventually I settled on the precast architectural concrete with panel size 4'x8'x4" thick since it met the majority of the requirements I was looking for. The cost data for the precast concrete façade system can be found below in Table 2-5:

Table 2-5: Square Foot Cost Data for Precast Architectural Concrete, Uninsulated, Low-Rise Use, 4'x8'x4" Thick

Thickness	*Material Cost / SF*	*Labor Cost / SF*	*Equipment Cost / SF*	*Total Cost / SF*
4"	**$20.50**	**$11.70**	**$5.65**	**$37.85**

A direct comparison of the different costs between the two systems is as follows in Table 2-6, with the better option in each category in boldface:

Table 2-6: Comparison between the Limestone Veneer and the Precast Concrete for Material, Labor, Equipment and Total Costs

Façade System	*Material Cost / SF*	*Labor Cost / SF*	*Equipment Cost / SF*	*Total Cost / SF*
Limestone Course Veneer	$26.25	**$5.35**	**$1.72**	**$33.32**
Precast Architectural Concrete	**$20.50**	$11.70	$5.65	$37.85

Based on the above results, while the precast architectural concrete is a better choice in terms of material costs, the limestone façade is much cheaper in terms of labor and equipment usage. Overall, both systems are very close but the original limestone façade does edge out the precast concrete façade. This result is similar to an assessment made by Mr. Flynn, who commented that the costs for a prefabricated façade and a non-pre-fabricated façade are around the same. He mentioned that while a prefabricated façade might have lower material costs, the labor and equipment costs offset the savings from materials.

Conclusions

The purpose of this analysis will be to research different kinds of prefabricated façades and to propose a prefabricated column design with the intention that it maintains the architectural integrity of the original design while saving on-site time, reducing costs and increasing the quality of the assembly. Of all the materials and systems considered, the selected system was a bisected column design using precast concrete. This system successfully passed the structural check, the thermal check and the moisture check. However, the overall system cost for the precast concrete façade was a little over $4.50 more per square foot than the original limestone façade.

Based on the current information given, I cannot recommend using the precast concrete façade system. While it performs just as well as the limestone façade in terms of structure, thermal and moisture capabilities, the high labor and equipment costs unfortunately do not make it a viable option yet. What makes this conclusion interesting, however, is that prefabricated stone, concrete and metal panel facades have already been proven to be more efficient in the industry. Usually those kinds of façades are using larger panels, though, so more research will be needed to look into the viability of prefabricating long, narrow façade columns in addition to large panels.

Analysis #3 – 3D Coordination Execution Plan Development

Introduction

Building Information Modeling (BIM) is rapidly becoming the standard tool for owners, designers, and construction managers to collaborate on a construction project. BIM's abilities have gone beyond modeling the physical space to include being able to store cost and performance information, visualize the schedule's sequence of activities, and coordinate the designs of the engineers and architects. Construction Industry members have been incorporating BIM processes into their standard practices, and Penn State has been at the forefront of this movement.

On this project, BIM has been a very integral part from the start including Design Authoring, Design Reviews, Engineering Analysis and Record Model. One of the biggest areas in which it is being utilized is for 3D Coordination purposes (e.g., Clash Detection). The Steidle Building is getting new laboratories on all four main floors, which means that these spaces are very equipment intensive. As such, everything there (and the rest of the building for that matter) needs to be highly coordinated in order for everything to be included in the allotted space. However, when the project went out to bid, the BIM model contained about 42,000 unresolved clashes. Even though a higher number of clashes was expected due to the anticipated unforeseen existing conditions of the Steidle Building's structure, this is still an excessively high number of clashes for a project.

The purpose of the analysis will be to investigate the root causes for the issues that led to this excessive number of clashes and to propose a process that can help to remediate these issues on future BIM-integrated projects with an emphasis on 3D Coordination. It would benefit all three groups if they were aware of how to address the issues found on this project should they reoccur in the future.

This analysis will be focusing solely on how 3D coordination was implemented during pre-construction and the issues that arose from that implementation. Penn State, EYP and Mascaro are all well versed in running BIM software and using it as a collaborative tool, so it was safely assumed that there would no issues relating to insufficient competency or inadequate training. It was also assumed that the issues for 3D Coordination were independent of any other issues stemming from other planning activities.

A component of the Integrated Bachelor and Master Degree Program is the inclusion of a Masters level class as part of one of this thesis' analyses. This analysis fulfills that requirement as it is based off of the information learned in AE 597G: Building Information Modeling Execution Planning.

Analysis Process

1. Interview members of the project team and evaluate the original process designs to determine where issues could have potentially occurred

2. Research methods for implementing 3D Coordination activities on a BIM-integrated project by interviewing various BIM personnel from other successful BIM-integrated projects to see how 3D Coordination could have better implemented
3. Adjust the Level 1 process design and Level 2 process for 3D Coordination to incorporate improvements where deficiencies were identified.
4. Propose final adjusted process design as part of the final report

Issue Identification

In order to ascertain what the root issue or issues were, I interviewed the project manager from Mascaro, Mr. Matt Morris, and the project manager from Penn State. I also interviewed via email the lead architect for the project, Mr. Hacig Tacvorian. He also brought in Mr. Ervin Kulenica, the BIM Manager for EYP, to help answer questions. Once the interviews were completed, I reviewed the existing BIM process design diagram for the project (which can be found in Appendix 3-1) to evaluate where the root issue originated from.

Before I go into the negatives, however, I should mention all the parts that were considered successful by the project team. Everyone mentioned that a highly collaborative environment was created during construction. Furthermore, coordinating with the subcontractors went especially well for events like deliveries and pre-installation conferences. Mr. Tacvorian and Mr. Kulenica made a special note of how well coordination went for the underground utilities given Penn State's policies on tree protection. They and Mr. Morris believe that this is the kind of environment that ought to be strived for during the early onset of the project.

However, one theme that came up between all three interviews was the limited involvement on Penn State's part. When it comes to 3D Coordination, Penn State leaves that to the architects, engineers and construction managers to resolve clashes. The BIM Plan for the project seems to confirm this, as the process diagram shows that Penn State's only role in the early part of the project is for issuing the attribute list (refer to Figure 3-1 for details). Mr. Morris pointed out that this became a problem for Mascaro and EYP as this was both of their first times working with Penn State and as such didn't quite know who to talk to at OPP. He mentioned that it was difficult to navigate the staffing structure which led to a breakdown in communication between all three parties.

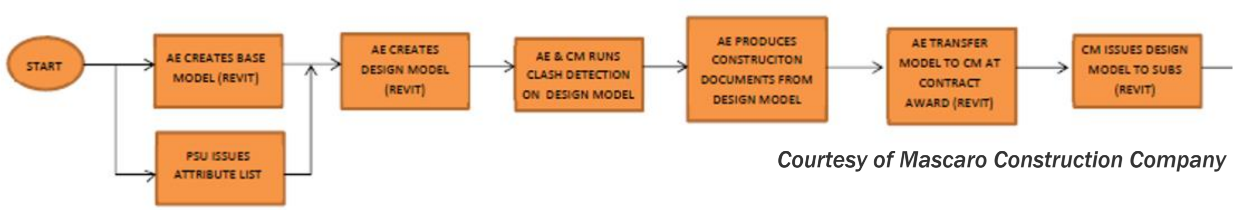


Figure 3-1: Early activities in the project's BIM process design diagram leading up to construction

It is this communication breakdown that seems to be chiefly responsible for the excessive number of clashes at the time the project went out to bid. EYP and Mascaro had successfully identified about 42,000 clashes, but unfortunately did not get them resolved in time. It didn't help that OPP didn't conduct their design review until the Construction Documents were 100% complete. This resulted in costly changes to the design and further added to the number of clashes.

The communication breakdown and its related factors are what will be addressed when developing a solution. Since the result of this breakdown in communication was that the subcontractors had to spend more time and money working with the project team to resolve these issues in the field, solving the communication issues would most likely yield the largest effect on improving the coordination process.

Industry Interviews

In order to develop the solution, additional information was required as to what other processes have been implemented for 3D Coordination and how they can be incorporated. To do this, I conducted interviews with two other project managers involved with BIM-integrated projects at Penn State.

The first one was with Mr. Jeremy Duckett from Barton Malow. He was involved with the Mueller Lab and South Frear Building renovations and is currently working on the Whitmore Lab renovation. BIM, and by extent 3D Coordination, was used primarily during construction for these projects by Barton Malow since a different firm was involved in the pre-construction activities. The process Barton Malow used for 3D Coordination on these projects was to take the original design models and coordinate them in the field before creating the means and methods models to be handed over to the subcontractors. Each sub would then make their own model as per the project's BIM execution plan. These models would be used by the designers to update the As-Built model.

The other project manager I interviewed was Mr. Matthew Baker from PJ Dick Construction. He was in charge of the Burrows Building renovation that is just wrapping up now. The vast majority of BIM's usage on that project was for 3D Coordination. Instead of doing a wholly coordinated model, PJ Dick's approach to coordination was to go through the building by floor and location (e.g. 1st Floor of the East Wing) and coordinate that area before sending the model out and moving on to the next area. They held meetings every two weeks with the trades' coordinators to perform the 3D Coordination.

Both project managers encountered a similar problem during coordination in regards to dealing with the existing conditions. Mr. Baker mentioned how the undocumented aspects of the structure presented many unknown challenges that hurt the schedule. Mr. Duckett talked about similar issues, but also mentioned how it wasn't just the undocumented conditions but also the unmodeled elements in the subcontractors' models presented difficulties for 3D Coordination. For example, the electrical subcontractor might have the larger conduit elements and the cable trays modeled but wouldn't include the lights. However, Mr. Duckett also specifically talked about how well the coordination process for the fume hoods in the lab spaces. These required a lot of service and had numerous clash issues associated with them, but since the project team got and early jump on solving these issues the coordination process went very smoothly.

Something interesting mentioned by both project managers was that the success of BIM is actually fairly independent of the project delivery method or the BIM execution plan. As long as the project team works well together and communication remains open, then it will be much easier to collaborate and resolve problems.

Evaluation

Based on the responses from Mr. Morris, Mr. Tacvorian and Mr. Kulenica, promoting communication between Penn State, EYP and Mascaro should be the focus of the proposed process design. This is backed up by how Mr. Duckett and Mr. Baker emphasized the importance of communication among the project team members in order to ensure that the coordination process goes over smoothly. Given that Mr. Rush, Mr. Morris, Mr. Tacvorian and Mr. Kulencia all agreed on how well coordination went with the trades during construction, I won't need to look at the process during that timeframe and can focus on 3D Coordination's implementation during the pre-construction phase.

What's also interesting is that the actual process design diagram in the BIM Execution Plan (refer to Appendix 3-1 for the full process design diagram) does have a fairly detailed process for overall execution. Each activity has an explicit responsible party and what is required of them at that stage. This is further backed up by the defined roles and responsibilities in the plan. However, it doesn't have any detailed process designs for each individual BIM activity. It also doesn't define communication procedures during planning, design, pre-construction, and construction. This lack of information seems to have contributed to the communication issues between the parties. While I am not sure of what communication practices Penn State usually employs on its projects, it would still be prudent to include the establishment of communication practices as part of the 3D Coordination process I will propose. This way the project team can select a method that is most conducive to the project type at hand.

It was also mentioned by Mr. Tacvorian and Mr. Kulenica that they would like to have seen Penn State have more influence during the clash detection process. I agree with them as Penn State having a more supportive role would definitely help the process run more smoothly. This would be especially beneficial during the early stages of the project when EYP and Mascaro were struggling with finding who at Penn State they needed to talk to. If Penn State can assist with that in addition to providing direction as needed, then that should prevent breakdowns in communication. However, direct collaboration should also be promoted between EYP and Mascaro during the actual coordination of the designs. Once that is completed, if clashes remain then Penn State can come in to support the project team in resolving the issues but should

Conclusion and Deliverable

The purpose of the analysis was to investigate the root causes for the issues that led to this excessive number of clashes and to propose a process that can help to remediate these issues. The issues were identified by interviewing members of the project team and evaluating the BIM process design for the project. The proposed process design was developed based on information provided by interviewed industry professionals and the feedback from the Steidle Building project team.

Overall, the issue that plagued the implementation of 3D Coordination on this project was a breakdown in communication between Penn State, EYP and Mascaro. This was caused by EYP and

Mascaro's unfamiliarity with Penn State's staffing structure as this was both of their first times working with Penn State. Furthermore, while the original BIM execution plan's process design documents the activity sequences very well, it doesn't provide details for the individual activities. In order to remedy this, the following requirements needed to be met for the proposed process design:

- Communication procedures must be defined at the start of the 3D Coordination process
- Penn State must act in a supporting role during the early stages of the process and should have more influence during the coordination of the model
- Direct communication between EYP and Mascaro is essential during the coordination of the models.

In creating the process design for this analysis, I decided to create a Level 2 process design specifically for 3D Coordination. Within the original Level 1 process design, this Level 2 process design would fall under the "AE and CM run clash detection on Design Model" activity. The full Level 2 process design for 3D Coordination can be found in Appendix 3-2.

The first section of the proposed Level 2 process design (seen at right in Figure 3-2a) focuses on setting up the coordination process by creating a meeting schedule, defining roles and responsibilities, and establishing communication methods. This is meant to create an open and collaborative atmosphere at the start of the project, similar to the atmosphere that evolved out of the project during the construction phase. During this phase, Penn State's BIM Manager shall take on the lead role for all of these activities, although EYP and Mascaro will be required to provide input for how roles and responsibilities are assigned and communication should be set up while the models are being coordinated. It should be noted, however, that this part of the process design is only necessary on this project and on similar ones where the architectural firm or construction manager is working with Penn State for the first time. If a firm has worked with Penn State in the past, then this section may not be necessary as the firm will have these items already established.

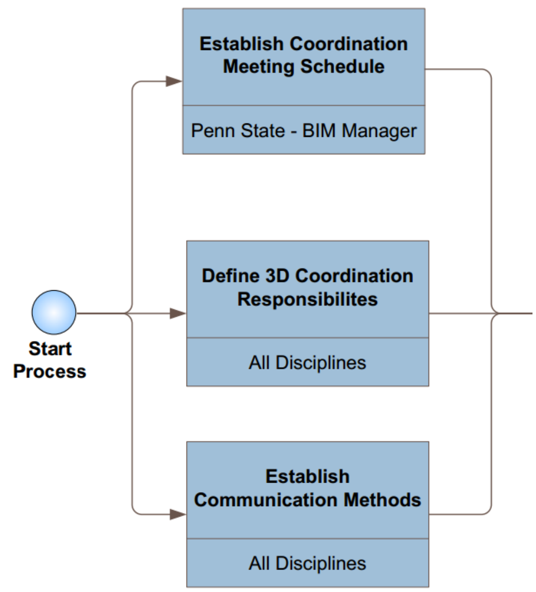


Figure 3-2a: Level 2 process design for 3D Coordination; coordination process set-up stage

The second section (seen below in Figure 3-2b) is the actual coordination process itself. Penn State has very limited involvement in this part of the process design. The only involvement from

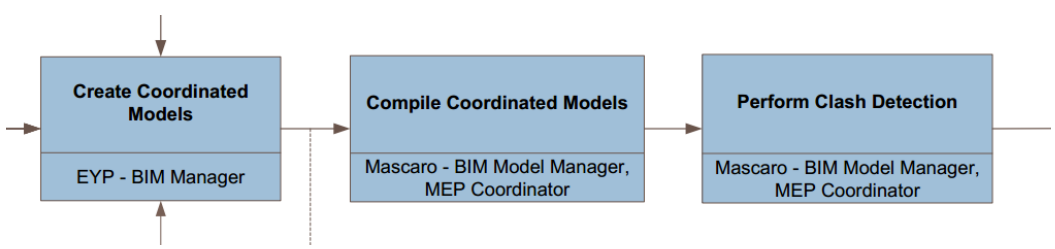
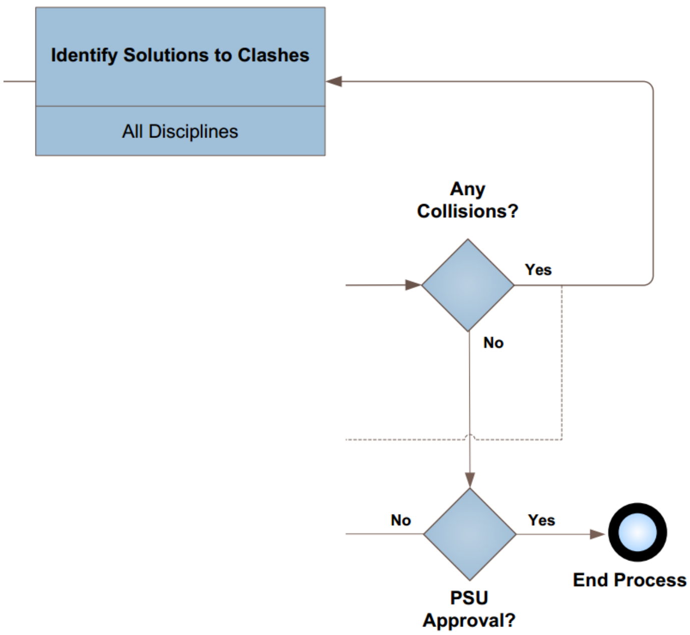


Figure 3-2a: Level 2 process design for 3D Coordination; coordination process

Penn State at this stage is managing the schedule for the coordination meetings as decided upon during the last stage. Instead, EYP and Mascaro work with a direct connection between them. The process itself is very straightforward. EYP's BIM Manager takes the designs created by the architects and creates the coordinated models that are to be handed over to Mascaro's BIM Model manager. Mascaro's BIM Model Manager will then compile the models and run clash detection with the assistance of the MEP Coordinator. It should be noted that for the first run through of the coordination process, EYP's BIM Manager won't need to alter much from the design models to the coordinated models. However, as subsequent passes are taken to fix resulting clashes, he will need to create new coordinated models to send to Mascaro's BIM Model Manager.



The final section (seen at left in Figure 3-2c) details the approval sequence for the coordinated models and the rework loops resulting from rejection of the models. In order for the coordinated models to be approved, they must meet two requirements: 1) is the model free of clashes and collisions, and 2) do the models meet Penn State's approval in terms of achieving its goals and standards? If the models still have clashes between them or new clashes have arisen from the design changes, then a clash detection report will be created. Then Penn State, EYP and Mascaro will be actively responsible for identifying solutions to the clashes listed in the report. While all three parties will be working together and communicating with each other, the lead should be taken by the one that is most capable of resolving the issues. This may change between the three parties as each one has different areas of expertise. It is here that the majority of work during the 3D Coordination process is expected to take place. On the other hand, if the coordinated models do not meet Penn State's requirements, then it will fall to EYP to make the necessary design changes. Once those changes are made, the models will continue to be coordinated. They will only be acceptable once they are free of clashes and are approved as designed, at which point drawings may be published and released for subcontractors to bid on.

Overall, this proposed Level 2 process design provides a foundation which should promote communication within the project team during pre-construction. This process design can also be used by Penn State on other BIM-integrated projects using 3D Coordination, specifically if it's a firm's first time working with Penn State. However, in the end communication is paramount regardless of what the plan is. No matter what, as long as communication is open between everyone then 3D Coordination will almost always run smoothly.

Industry Research Topic – Best Value Selection Criteria for MEP Subcontractors

Introduction

When selecting a subcontractor based on who has the lowest bid, there are several issues that could crop up during construction. For starters, the cheapest contractor at bid isn't necessarily the cheapest contractor overall (i.e. claims contractors). Furthermore, a contractor bidding the project may not be able to perform the required work due to insufficient capital or experience, and even if the contractor is affordable and competent they might be nearly impossible to work with. Therefore, owners are shifting their focus from choosing the lowest bidder to determining which contractors offer the best value for their price. So if an owner wants to find the best-value contractor, what methods and processes exist or are being developed that can help determine the most "valuable" contractor?

The purpose of this topic will be to conduct research into current best-value practices and to propose a set of criteria that Penn State can use on their construction projects. As Penn State is a publicly-funded institution, it is in both their interests and the public's interests that cost-saving methods such as Best-Value selection be utilized. As there are a near infinite number of criteria that could be considered during subcontractor selection, the research conducted will focus on areas that are more applicable to Penn State's Office of Physical Plant (OPP), which oversees all of Penn State's construction and facility operations.

There are many different aspects to evaluating contractors based on best-value, so this research will focus on the selection criteria specific to OPP. Furthermore, the scope will be narrowed to looking only at MEP subcontractors for projects being delivered with the CM at Risk, Design Assist, Integrated Project Delivery methods will be different for MEP subcontractors. As for the selection criteria, the conducted research will focus on a set of previously- developed criteria but will account for others that were unconsidered if enough.

Research Process

1. Perform initial research into Best-Value analysis and selection
2. Develop an initial questionnaire to determine what "value" OPP looks for in subcontractors
3. Conduct 3 to 4 interviews with OPP personnel to gain feedback on the questionnaire's content
4. Redevelop the questionnaire based on the obtained feedback
5. Distribute the questionnaire to approximately 30 members of OPP's staff involved with subcontractor selection
6. Collect and interpret the data from the returned forms.
7. Select and propose the weighted criteria that OPP could use for MEP subcontractor selection

Current Industry Methods

Best-Value selection is defined differently across the industry, especially in the differences between designers, constructors and owners. These definitions range from simplistic ones to very detailed requirements. A basic definition was proffered by Gransberg and Shane from the American Society of Civil Engineers: "selecting a contractor on the basis of something other than price alone." The Associated General Contractors of America and the National Association of State Facilities

Administrators built off of a similar definition when they published their requirements for Best-Value, which are as follows:

1. Contracts for design and construction are separate contracts
2. Total Construction Cost is a weighted criterion for final contractor selection
3. Final selection of contractor is based on a weighting of the total construction costs **and** other criteria
4. Design is assumed to be substantially complete

In addition to different definitions of Best-Value selection, there are several different methods that the industry has implemented that resemble Best-Value selection processes but have key differences. The most notable method is Qualifications Based Selection (QBS). Often, QBS is used on projects where the scope of the project or the designs have not been fully finished and therefore a full budget cannot be considered. This method focuses primarily on the capabilities and competencies of responding companies, although other factors can be taken into account. However, unlike Best-Value selection QBS doesn't take costs of construction into account since there is no developed budget. Another method that's regularly used is Pre-qualified Design-Bid-Build. Pre-qualified DBB analyzes much of the same criteria as Best-Value selection, but does it in a two-step process with the bid amount being the final determining factor, whereas Best-Value selection utilizes other factors as part of the final decision. Although Best-Value can be either done as a one or two step process, for the purpose of this topic Best-Value will be assumed to be a one-step process.

Penn State's Usage of Best-Value

Currently, Penn State uses a Best-Value selection processes on a limited basis for their projects. Since Best-Value selection isn't allowed on state-funded projects through the Department of General Services, Penn State can only use it on projects they are funding for themselves. However, on said projects Penn State has been very proactive in implementing project delivery methods other than the traditional Design-Bid-Build method with a competitive-sealed low-bid selection process. Penn State has used delivery methods like Design-Build, Construction Manager at Risk with Early Involvement, and Integrated Project Delivery on past and current projects. They have also been shifting towards the use of Best-Value Selection and QBS as opposed to strictly using low-bid.

For example, two of their projects utilizing a Best-Value approach within the past year were the Lasch Building Renovation and Beaver Stadium's Yearly Maintenance. The criteria for these projects included between them:

- The Bid Amount
- Past Project Experience
- MBE/WBE Participation Plan
- Safety Program
- Quality Program
- Proposed Project Team
- Team Interview

These criteria are designed to align with Penn State goals to project success, which can be found below in Figure 4-1.

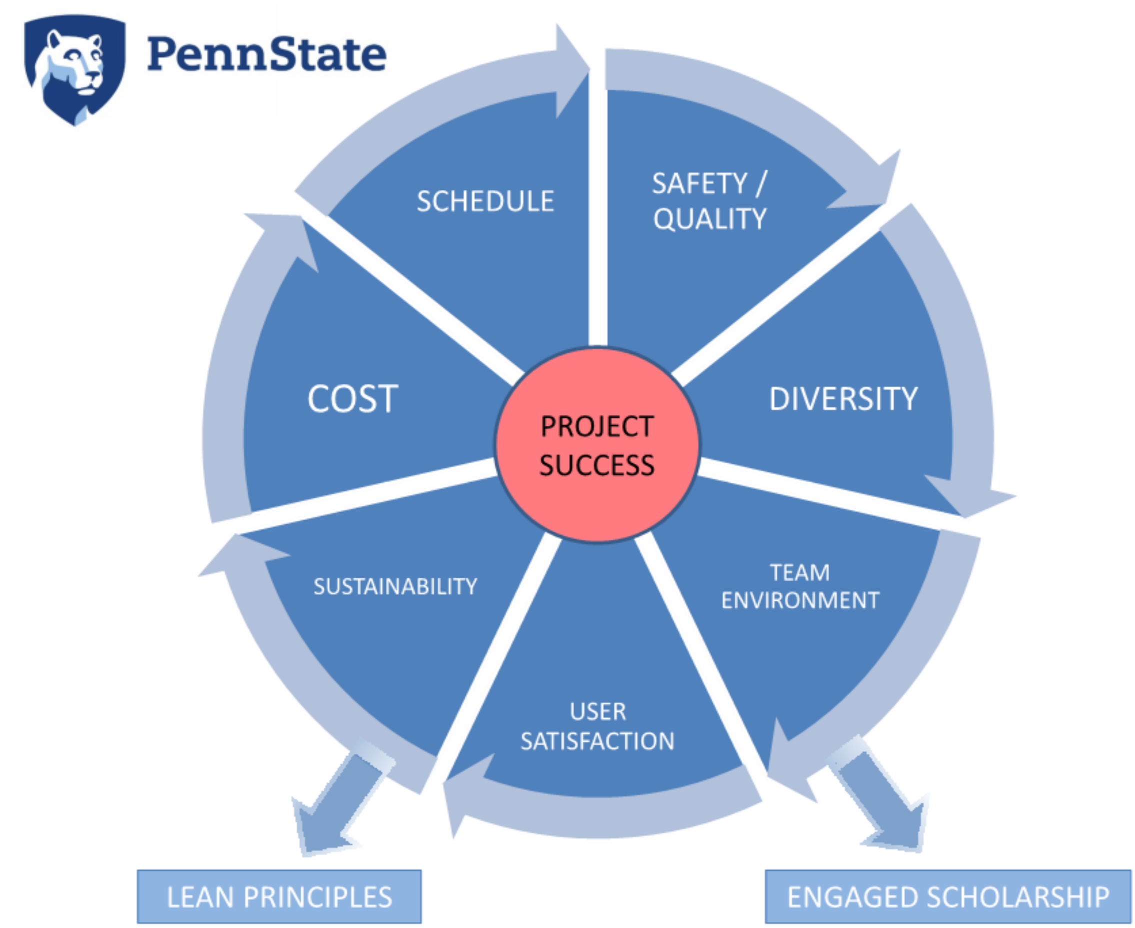


Figure 4-1: Elements of project success for OPP. Image provided by John Bechtel, Assistant Director of the Design and Construction Division at OPP

One of Penn State's most recent project that went out to bid is the Nursing School Clinic and Entrance construction project. The scope of this project is that a portion of one of the buildings floors will be remodeled into a medical clinic for Penn State staff (not for students) and the southeast corner of the building will have a new entrance constructed to increase accessibility while improving aesthetics. This project is being delivered through a Design-Build method, and I had the opportunity to sit in on the selection panel for the Design-Build Team. After the teams that had qualified made their presentations and finished with the interviews, the panel commenced with selecting the team for the project using a Best-Value process. The table that they used to make the selection can be found below.

Table 4-1: Best-Value Criteria Scorecard for the Nursing School Project

Company:										
Rate each criteria on a scale of 1 to 3										
	Weight	Panelists								Average Weighted Score
		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	
Ability to Provide Quality Entrance	25%									
Ability to Provide Quality Clinic	20%									
Meet the Schedule	10%									
Communication Skills/ Team/Budgeting	15%									
Safety Approach	5%									
MBE/WBE	5%									
Cost	20%									
Total Score										

Surveying OPP's personnel

In order to develop the set of criteria, I had to gauge what OPP's project managers and coordinators considered as valuable to their projects. Based on the lists from the three afore-mentioned projects and the conducted research, I identified the following thirteen criteria to compare between CM Selection, MEP subcontractor selection and overall project value:

- Personnel
- QA/QC Program
- Schedule
- Bid Amount
- Safety Record
- Reputation
- Past Experience
- Diversity
- Sustainable Practices
- LEAN Principles
- BIM Experience
- Risk Management
- Team Chemistry

The questionnaire would ask how much value each criteria has, with one being of low value and five being of high value. In addition to these criteria, I also decided to include a section where personnel responding to the questionnaire could write down their own criteria for CM firms and MEP subcontractors as well as what they define as value in a construction project. The full questionnaire can be found in Appendix 4-1.

Results

The questionnaire was distributed among approximately 30 members of OPP's project management staff, of which 17 responded. The returned values for the thirteen criteria's importance across CM selection, MEP subcontractor selection, and overall project value can be found below in Figures 4-2, 4-3, and 4-4 respectively.

Figure 4-2: Returned values for the thirteen criteria when applied to Construction Manager Selection

Figure 4-3: Returned values for the thirteen criteria when applied to MEP Subcontractor Selection

Figure 4-4: Returned values for the thirteen criteria when applied to overall project value

Once this data was consolidated, the values for each criteria's importance in each section was averaged to determine how each criteria compared to each both within each section and across the three sections. That comparison can be found below in Figure 4-5 and the actual values can be found in Table 4-2

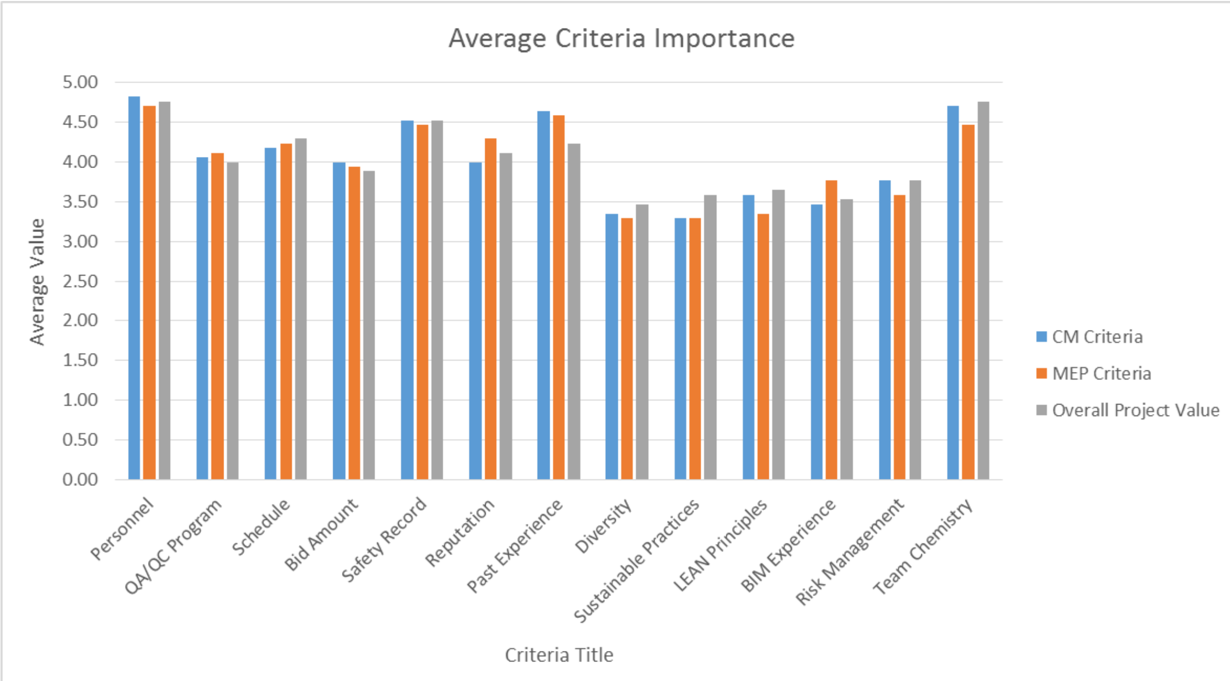


Figure 4-5: Average criteria's importance for CM selection, MEP subcontractor selection, and overall project value based on the returned questionnaires

Table 4-2: Numeric Values for Each Criteria's Importance

	Construction Manager Selection Criteria	MEP Subcontractor Selection Criteria	Overall Project Value
Personnel	4.82	4.71	4.76
QA/QC Program	4.06	4.12	4.00
Schedule	4.18	4.24	4.29
Bid Amount	4.00	3.94	3.88
Safety Record	4.53	4.47	4.53
Reputation	4.00	4.29	4.12
Past Experience	4.65	4.59	4.24
Diversity	3.35	3.29	3.47
Sustainable Practices	3.29	3.29	3.59
LEAN Principles	3.59	3.35	3.65
BIM Experience	3.47	3.76	3.53
Risk Management	3.76	3.59	3.76
Team Chemistry	4.71	4.47	4.76

There were also a few additional criteria mentioned by multiple members of the responding project management staff for CM selection and MEP subcontractor selection. The only shared criteria between the two was experience from working the Penn State on a previous project. For CM selection, this was expanded to include experience with similar project types. Highlighting key project personnel was also mentioned for CM selection. On the MEP selection side, there were two other criteria mentioned by the some of the responders: being knowledgeable about Building Automation Systems (BAS) and being familiar with the commissioning process. However, it should be noted that each of these criteria were only mentioned by two or three people, so they were not considered when developing the weighted list of Best-Value criteria.

Finally, the responders were fairly consistent in what they considered to be valuable to projects overall. The most heavily mentioned requirement was fulfilling the contract – specifically this included meeting or coming in under-schedule and under-budget, ensuring project safety, and delivering a high quality project. In addition to that, the other two requirements that were frequently mentioned were having a collaborative team and attaining a high end-user satisfaction rating.

Evaluation of the Results

It was surprising to see just how much value everyone placed in all of the listed criteria in the questionnaire. I had expected much broader range of averages – for example, I expected criteria like LEAN Principles and Risk Management to have averages between one and two – but instead all of the criteria attained an average higher than 3.0. Clearly OPP believes that all of these criteria, and perhaps even the ones added on in addition, ought to be considered when evaluating a project proposal. This also means that the initial assumption of using a one-step Best-Value selection method won't work as there would be too many factors to consider. That would dilute the importance of the criteria. Thus, a two-step Best-Value selection method will be designed for.

It should be noted that the results also go against the weighted that was used for the Nursing School Project. For that selection committee, Quality and Cost (Bid Amount) were the two highest criteria, whereas according to OPP's project management staff the two highest criteria should be the project team's Personnel and Team Chemistry. The other key difference is that safety is given only minimal consideration while the project management staff believe safety to be almost critical to the project's value. This may be due to the fact that the selection panel comprised of more than just OPP personnel, but it's still interesting to see how determining value is executed versus how it is viewed.

The final important point here is the difference between what the project management staff view as valuable to the project and how OPP defines project success (which is intrinsically tied to value since success is usually defined as how much value one gets out of the project compared to the cost). All of the items that the project management staff viewed as valuable are included in the project success diagram. However, two of the diagram's requirements for success – diversity and sustainability – were not seen as valuable. Additionally, the diagram's two sub-requirements – engaged scholarship and LEAN principles – were not part of what the project management staff valued. Whether this means that the project success diagram needs to be more refined or that the project managers need to learn about the value of those other elements is not within the scope of this research topic and shall be left for a future study.

When building the weighted criteria list, I only used the data from the MEP subcontractor selection section. I decided to cut the criteria that did not have an average importance rating of at least 3.50. Then, I subtracted 3.5 from the remaining criteria's average rating, with the results shown below:

- Personnel: 1.206
- QA/QC Program: 0.618
- Schedule: 0.735
- Bid Amount: 0.441
- Safety Record: 0.971
- Reputation: 0.794
- Past Experience: 1.088
- BIM Experience: 0.265
- Risk Management: 0.088
- Team Chemistry: 0.971

I then totaled these values and determined what percentage each criteria was worth of the total value. Each criteria was rounded to the nearest whole percent, with the results shown below:

- Personnel: 17%
- QA/QC Program: 9%
- Schedule: 10%
- Bid Amount: 6%
- Safety Record: 14%
- Reputation: 11%
- Past Experience: 15%
- BIM Experience: 4%
- Risk Management: 1%
- Team Chemistry: 14%

It should be noted that the total percentage above is 101%, which is understandable given the amount of rounding that had occurred but is unacceptable for the weighted criteria list. Given that OPP uses multiples of 5 when weighting criteria, I rounded each percentage to the nearest 5%, which also results in cutting the Risk Management Criteria from the list:

- Personnel: 15%
- QA/QC Program: 10%
- Schedule: 10%
- Bid Amount: 5%
- Safety Record: 15%
- Reputation: 10%
- Past Experience: 15%
- BIM Experience: 5%
- Team Chemistry: 15%

Conclusions and Recommendations

The purpose of this topic was to conduct research into current best-value practices and to propose a set of criteria that Penn State can use on their construction projects. That set of weighted criteria was based upon the collected results from a questionnaire distributed among OPP's project managers and coordinators.

Due to the amount of value placed on each of the listed criteria in the questionnaire, the one-step Best-Value selection process that was originally designed for cannot be recommended. Instead, a two-step Best-Value selection process is proposed based on the results from the questionnaire.

The first step will be to include any or all of the thirteen criteria listed in the questionnaire as part of the initial RFP or RFQ. The short-list of MEP subcontractors will be determined based on the RFP/RFQ. The second step will be to evaluate the short-listed firms based on the weighted criteria determined beforehand. I adapted the scorecard from the Nursing School Project selection process to show how the weighted criteria could be used for a selection committee. That scorecard is shown below in Table 4-3.

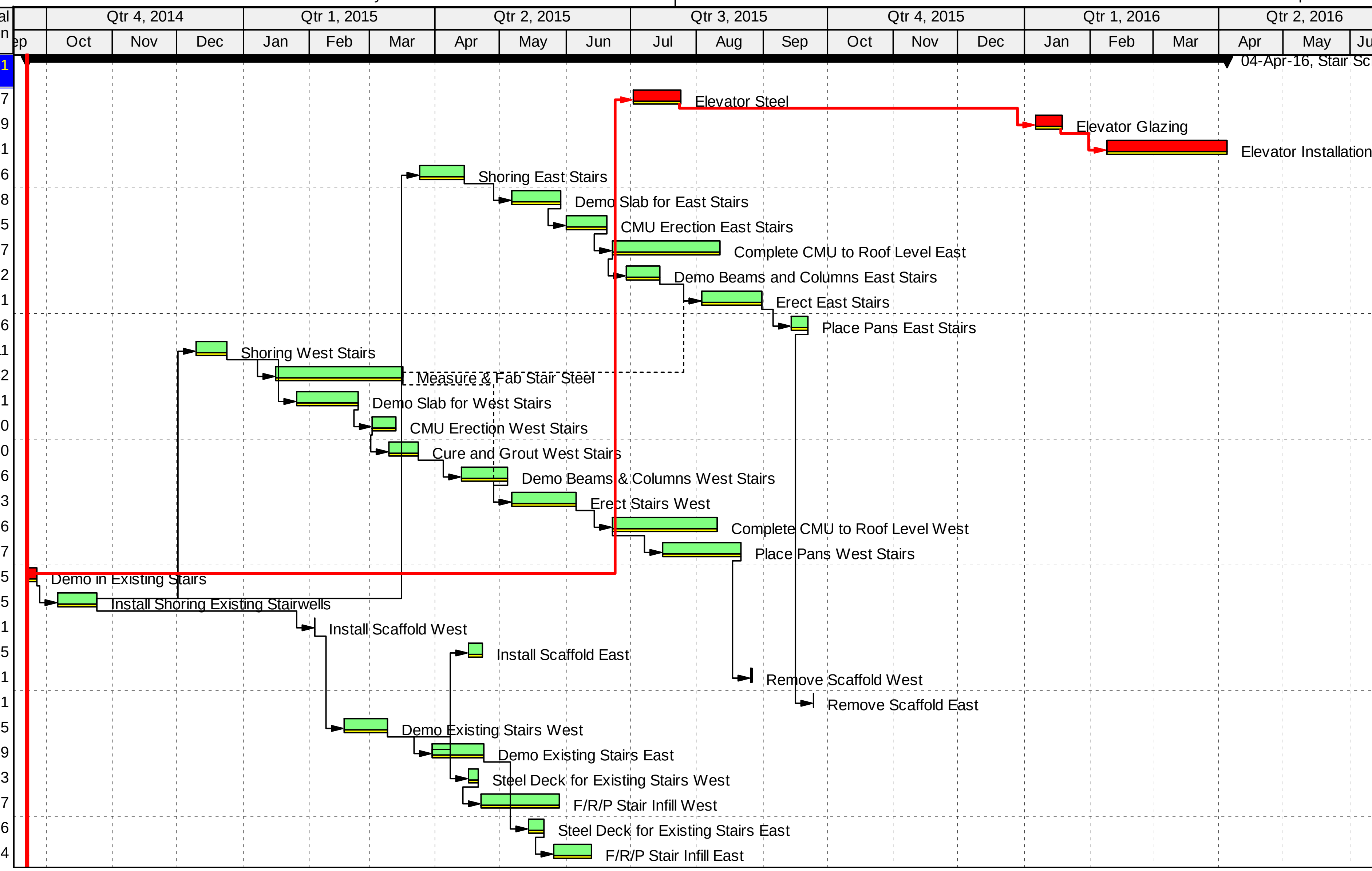
Table 4-3: Proposed Best-Value Criteria Scorecard for MEP subcontractors for Future OPP Projects

Company:										
Rate each criteria on a scale of 1 to 3										
	Weight	Panelists								Average Weighted Score
		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	
Personnel	15%									
Team Chemistry	15%									
Safety Record	15%									
Past Experience	15%									
QA/QC Program	10%									
Schedule	10%									
Reputation	10%									
Cost	5%									
BIM Experience	5%									
Total Score	100%									

However, it has to be said that the weights on this list, and by extend the list itself, is not fixed in place for use on every project. Each project has its own unique characteristics, and thus has its own needs and demands. Therefore, this set of weighted criteria should be used a starting for the selection of MEP subcontractors on OPP's projects, but does not have to look exactly like this.

Appendix 1-1: Schedules for the Alternate Vertical Transportation Analysis

#	Activity ID	Activity Name	BL Project Start	BL Project Finish	Original Duration
1		**Stair Sched #1 Demo First**	22-Sep-14	04-Apr-16	401
2	ELEV10	Elevator Steel	02-Jul-15	24-Jul-15	17
3	ELEV20	Elevator Glazing	06-Jan-16	18-Jan-16	9
4	ELEV30	Elevator Installation	08-Feb-16	04-Apr-16	41
5	ES110	Shoring East Stairs	24-Mar-15	14-Apr-15	16
6	ES120	Demo Slab for East Stairs	06-May-15	29-May-15	18
7	ES130	CMU Erection East Stairs	01-Jun-15	19-Jun-15	15
8	ES140	Complete CMU to Roof Level East	22-Jun-15	11-Aug-15	37
9	ES150	Demo Beams and Columns East Stairs	29-Jun-15	14-Jul-15	12
10	ES160	Erect East Stairs	03-Aug-15	31-Aug-15	21
11	ES170	Place Pans East Stairs	14-Sep-15	21-Sep-15	6
12	WS110	Shoring West Stairs	10-Dec-14	24-Dec-14	11
13	WS120	Measure & Fab Stair Steel	16-Jan-15	16-Mar-15	42
14	WS130	Demo Slab for West Stairs	26-Jan-15	23-Feb-15	21
15	WS140	CMU Erection West Stairs	02-Mar-15	13-Mar-15	10
16	WS150	Cure and Grout West Stairs	10-Mar-15	23-Mar-15	10
17	WS160	Demo Beams & Columns West Stairs	13-Apr-15	04-May-15	16
18	WS170	Erect Stairs West	06-May-15	05-Jun-15	23
19	WS180	Complete CMU to Roof Level West	22-Jun-15	10-Aug-15	36
20	WS190	Place Pans West Stairs	16-Jul-15	21-Aug-15	27
21	XS110	Demo in Existing Stairs	22-Sep-14	26-Sep-14	5
22	XS120	Install Shoring Existing Stairwells	06-Oct-14	24-Oct-14	15
23	XS121	Install Scaffold West	03-Feb-15	03-Feb-15	1
24	XS122	Install Scaffold East	16-Apr-15	22-Apr-15	5
25	XS123	Remove Scaffold West	26-Aug-15	26-Aug-15	1
26	XS124	Remove Scaffold East	24-Sep-15	24-Sep-15	1
27	XS130	Demo Existing Stairs West	17-Feb-15	09-Mar-15	15
28	XS140	Demo Existing Stairs East	30-Mar-15	23-Apr-15	19
29	XS150	Steel Deck for Existing Stairs West	16-Apr-15	20-Apr-15	3
30	XS160	F/R/P Stair Infill West	22-Apr-15	28-May-15	27
31	XS170	Steel Deck for Existing Stairs East	14-May-15	21-May-15	6
32	XS180	F/R/P Stair Infill East	26-May-15	12-Jun-15	14

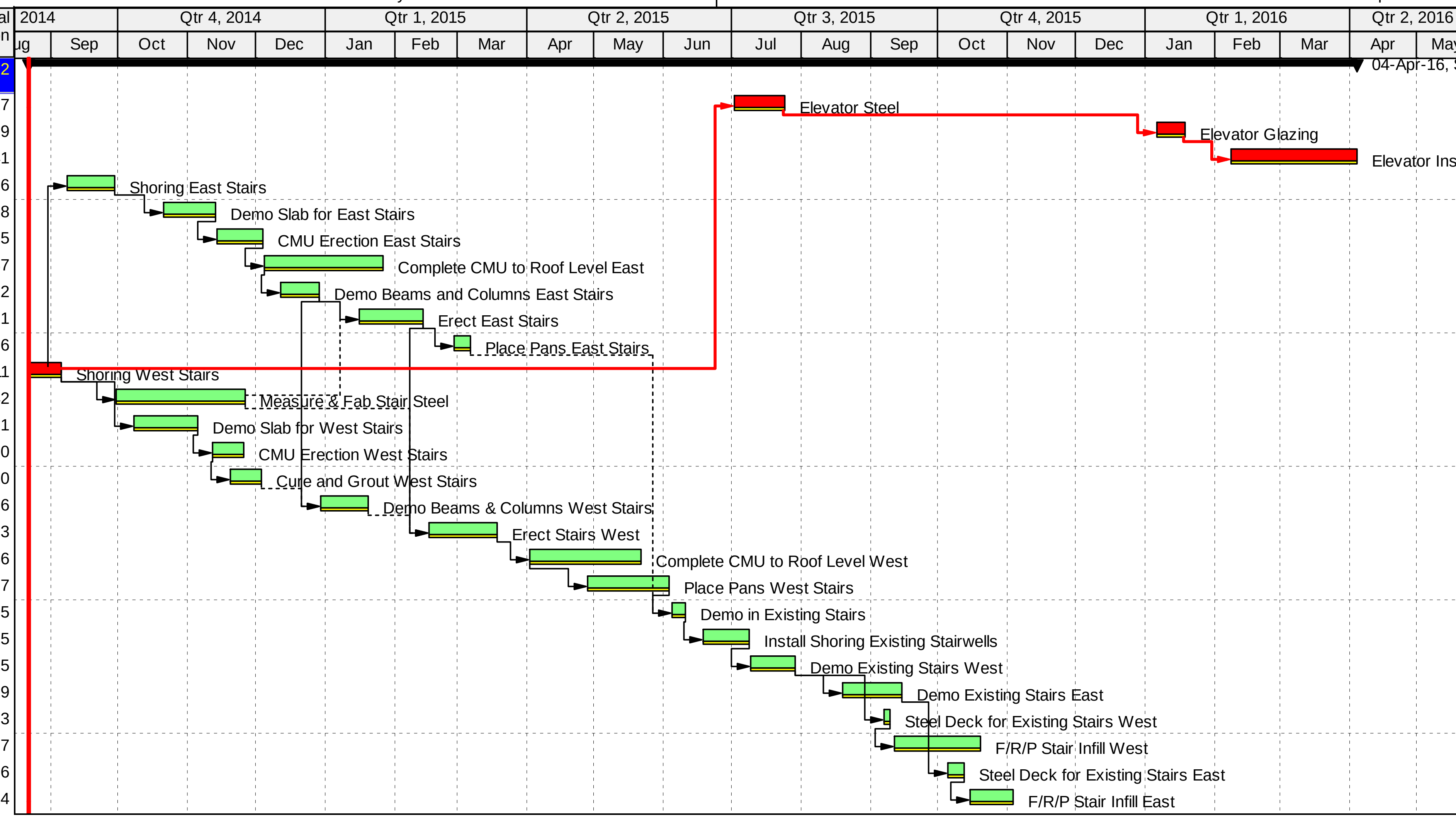


Actual Level of Effort | Actual Work | Critical Remaining Work
Primary Baseline | Remaining Work | Milestone

TASK filter: All Activities

New Stairs First	Classic Schedule Layout	08-Apr-16 00:12

#	Activity ID	Activity Name	BL Project Start	BL Project Finish	Original Duration
1		**Stair Sched #2 New Stairs First**	22-Aug-14	04-Apr-16	422
2	ELEV10	Elevator Steel	02-Jul-15	24-Jul-15	17
3	ELEV20	Elevator Glazing	06-Jan-16	18-Jan-16	9
4	ELEV30	Elevator Installation	08-Feb-16	04-Apr-16	41
5	ES110	Shoring East Stairs	08-Sep-14	29-Sep-14	16
6	ES120	Demo Slab for East Stairs	21-Oct-14	13-Nov-14	18
7	ES130	CMU Erection East Stairs	14-Nov-14	04-Dec-14	15
8	ES140	Complete CMU to Roof Level East	05-Dec-14	26-Jan-15	37
9	ES150	Demo Beams and Columns East Stairs	12-Dec-14	29-Dec-14	12
10	ES160	Erect East Stairs	16-Jan-15	13-Feb-15	21
11	ES170	Place Pans East Stairs	27-Feb-15	06-Mar-15	6
12	WS110	Shoring West Stairs	22-Aug-14	05-Sep-14	11
13	WS120	Measure & Fab Stair Steel	30-Sep-14	26-Nov-14	42
14	WS130	Demo Slab for West Stairs	08-Oct-14	05-Nov-14	21
15	WS140	CMU Erection West Stairs	12-Nov-14	25-Nov-14	10
16	WS150	Cure and Grout West Stairs	20-Nov-14	03-Dec-14	10
17	WS160	Demo Beams & Columns West Stairs	30-Dec-14	20-Jan-15	16
18	WS170	Erect Stairs West	16-Feb-15	18-Mar-15	23
19	WS180	Complete CMU to Roof Level West	02-Apr-15	21-May-15	36
20	WS190	Place Pans West Stairs	28-Apr-15	03-Jun-15	27
21	XS110	Demo in Existing Stairs	04-Jun-15	10-Jun-15	5
22	XS120	Install Shoring Existing Stairwells	18-Jun-15	08-Jul-15	15
23	XS130	Demo Existing Stairs West	09-Jul-15	29-Jul-15	15
24	XS140	Demo Existing Stairs East	19-Aug-15	14-Sep-15	19
25	XS150	Steel Deck for Existing Stairs West	07-Sep-15	09-Sep-15	3
26	XS160	F/R/P Stair Infill West	11-Sep-15	19-Oct-15	27
27	XS170	Steel Deck for Existing Stairs East	05-Oct-15	12-Oct-15	6
28	XS180	F/R/P Stair Infill East	15-Oct-15	03-Nov-15	14



Actual Level of Effort | Actual Work | Critical Remaining Work
Primary Baseline | Remaining Work ◆ | ◆ Milestone

TASK filter: All Activities

#	Activity ID	Activity Name	BL Project Start	BL Project Finish	Original Duration
1		**Stair Sched #3 Accelerated Eleva**	22-Sep-14	02-Nov-15	291
2	ELEV10	Elevator Steel	18-Jun-15	10-Jul-15	17
3	ELEV20	Elevator Glazing	17-Aug-15	27-Aug-15	9
4	ELEV30	Elevator Installation	07-Sep-15	02-Nov-15	41
5	ES110	Shoring East Stairs	24-Mar-15	14-Apr-15	16
6	ES120	Demo Slab for East Stairs	06-May-15	29-May-15	18
7	ES130	CMU Erection East Stairs	01-Jun-15	19-Jun-15	15
8	ES140	Complete CMU to Roof Level East	22-Jun-15	11-Aug-15	37
9	ES150	Demo Beams and Columns East Stairs	29-Jun-15	14-Jul-15	12
10	ES160	Erect East Stairs	03-Aug-15	31-Aug-15	21
11	ES170	Place Pans East Stairs	14-Sep-15	21-Sep-15	6
12	WS110	Shoring West Stairs	10-Dec-14	24-Dec-14	11
13	WS120	Measure & Fab Stair Steel	16-Jan-15	16-Mar-15	42
14	WS130	Demo Slab for West Stairs	26-Jan-15	23-Feb-15	21
15	WS140	CMU Erection West Stairs	02-Mar-15	13-Mar-15	10
16	WS150	Cure and Grout West Stairs	10-Mar-15	23-Mar-15	10
17	WS160	Demo Beams & Columns West Stairs	13-Apr-15	04-May-15	16
18	WS170	Erect Stairs West	06-May-15	05-Jun-15	23
19	WS180	Complete CMU to Roof Level West	22-Jun-15	10-Aug-15	36
20	WS190	Place Pans West Stairs	16-Jul-15	21-Aug-15	27
21	XS110	Demo in Existing Stairs	22-Sep-14	26-Sep-14	5
22	XS120	Install Shoring Existing Stairwells	06-Oct-14	24-Oct-14	15
23	XS121	Install Scaffold West	03-Feb-15	03-Feb-15	1
24	XS122	Install Scaffold East	16-Apr-15	22-Apr-15	5
25	XS123	Remove Scaffold West	26-Aug-15	26-Aug-15	1
26	XS124	Remove Scaffold East	24-Sep-15	24-Sep-15	1
27	XS130	Demo Existing Stairs West	17-Feb-15	09-Mar-15	15
28	XS140	Demo Existing Stairs East	30-Mar-15	23-Apr-15	19
29	XS150	Steel Deck for Existing Stairs West	16-Apr-15	20-Apr-15	3
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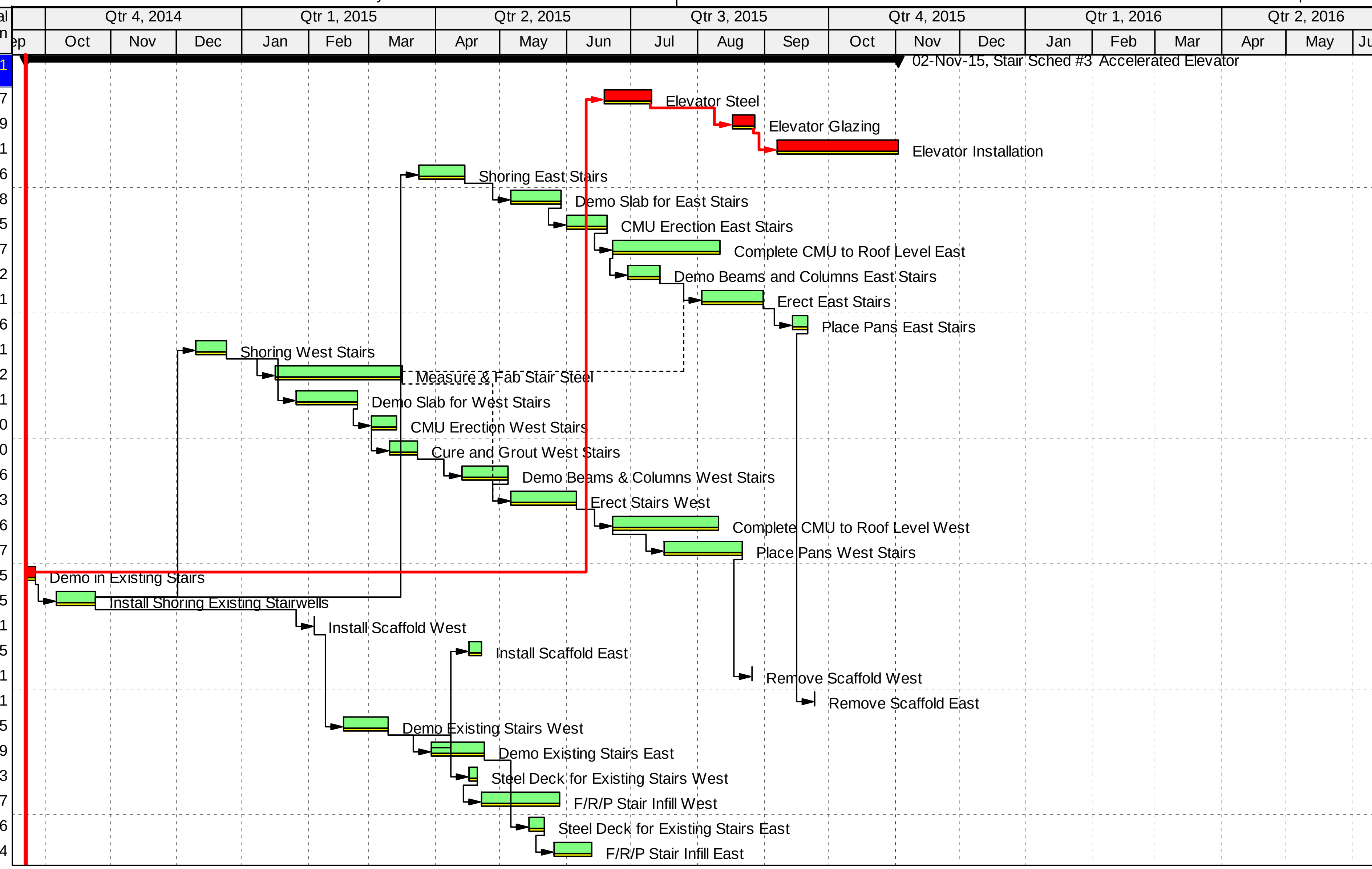
32	XS180	F/R/P Stair Infill East	26-May-15	12-Jun-15	14

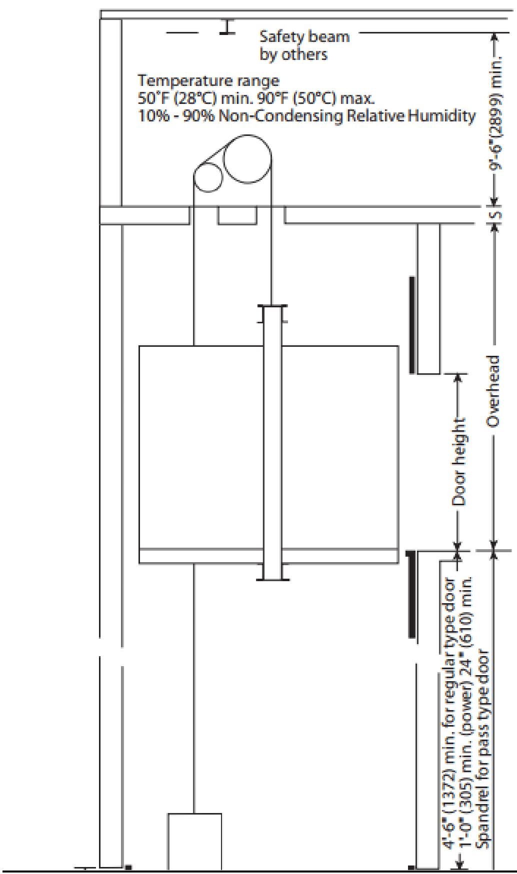


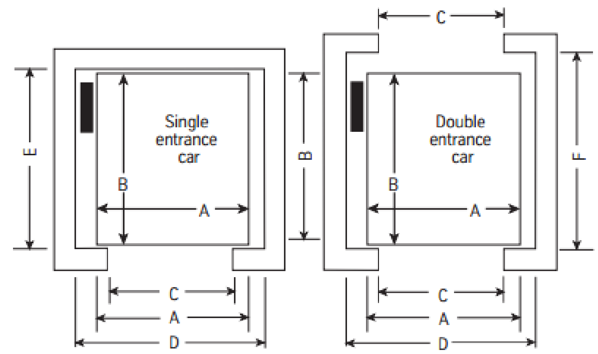
Actual Level of Effort | Actual Work | Critical Remaining Work
Primary Baseline | Remaining Work | Milestone

TASK filter: All Activities

Appendix 1-2: Elevator Sizes from ThyssenKrupp Elevator Company

Rugged, all-steel construction and custom engineering give our freight elevator the strength and power you need to get the job done day-after-day.





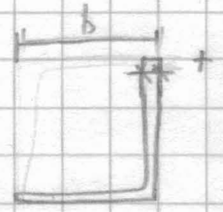
	Capacity in pounds			
	2500 (1134 kg)	**4000 (1814 kg) 5000 (2268 kg) 6000 (2722 kg)**	**8000 (3629 kg)**	**10,000 (4536 kg)**
A	5'-4" (1626)	8'-4" (2540)	8'-4" (2540)	8'-4" (2540)
B	7'-0" (2134)	10'-0" (3048)	12'-0" (3658)	14'-0" (4267)
C	5'-0" (1524)	8'-0" (2438)	8'-0" (2438)	8'-0" (2438)
D	7'-10" (2388)[1]	10'-10" (3302)[1]	11'-0" (3353)[2]	11'-0" (3353)[2]
E[3]	7'-8" (2337)	10'-8" (3251)	12'-8" (3861)	14'-8" (4470)
F[4]	7'-11" (2413)	10'-11" (3327)	12'-11" (3937)	14'-11" (4547)

1 Add 2" (51) for seismic.
2 Add 4" (102) for seismic.
3 Add 1¾" (44) if pass type doors are used.
4 Add 3½" (89) if pass type doors are used.

Appendix 2-1: Structural Analysis Notes and Calculations

Structural Analysis

Given: L 6" x 6" x 3/8"
assumed ↑



$E = 29E^6$ psi
$I = 15.4$ in^4 $b = 6"$
$S = 3.51$ in^3 $t = 3/8"$
$F_y = 36{,}000$ psi

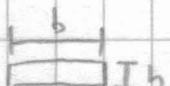
$$V_{capacity} = \tau_y\, b\, t = \left(f_y/\sqrt{3}\right) b t = \left(\frac{36{,}000 \text{ psi}}{\sqrt{3}}\right)(6 \text{ in})(3/8")$$

$$V_{capacity} = \underline{46{,}765.4 \text{ lb.}}$$

$$M_{capacity} = f_y S = (36{,}000 \text{ psi})(3.51 \text{ in}^3) = 126{,}360 \text{ in}\cdot\text{lb.}$$

$$M_{capacity} = \underline{10{,}530 \text{ ft}\cdot\text{lb.}}$$

Flange as a cantilever:



$b = 1"$ (unit length) $f_y = 36{,}000$ psi
$h = 3/8"$

$$I = \frac{bh^3}{12} = \frac{(1")(3/8")^3}{12} = 0.0044 \text{ in}^4$$

$$S = I/c = \frac{0.0044 \text{ in}^4}{3/16 \text{ in}} = 0.023 \text{ in}^3$$

$$V_{capacity} = \tau_y\, b\, t = \left(f_y/\sqrt{3}\right) b h = \left(\frac{36{,}000 \text{ psi}}{\sqrt{3}}\right)(1")(3/8")$$

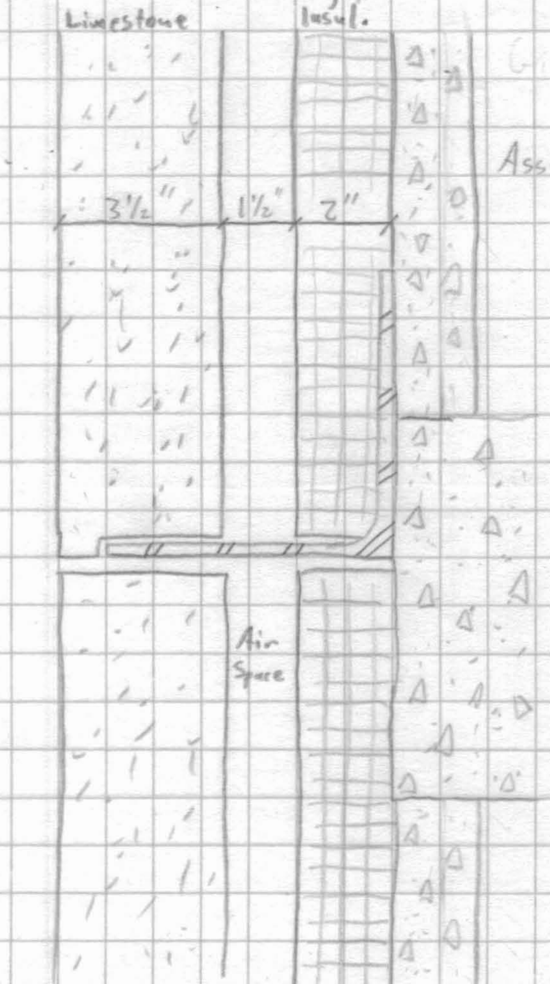
$$V_{capacity} = 7794 \text{ lb.}$$

$$M_{capacity} = f_y S = (36{,}000 \text{ psi})(0.023 \text{ in}^3) = 828 \text{ in}\cdot\text{lb.}$$

$$M_{capacity} = \underline{69 \text{ ft}\cdot\text{lb.}}$$

Structural Analysis

Original Limeston Facade:



Given: Height b/w Floors = 13'

Unit Wt. of Limestone = 156 pcf

Assumed: Mortar Net and Flashing have negligible weight

2" Rigid Insulation is attached to the concrete back-up structure

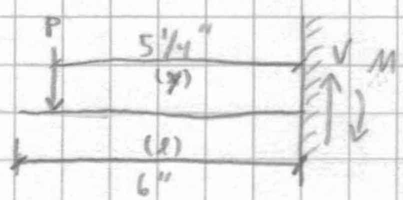
Relieving angles are found at the 2nd, 3rd, and 4th Floor Slabs

Breaks between Limestone courses (containing pins, wind anchors and caulking) will be counted as if the courses were continuous

Relieving angle is assumed to have a thickness of 3/8"

Angle is made from A36 Steel →
$E = 29e^6$ psi, $f_y = 36{,}000$ psi

Using Unit Inch



$$P = (156\text{ pcf})(1'')(3.5'')(13')\left(\frac{1\text{ ft}^2}{144\text{ in}^2}\right)$$

$$P = 49.3\text{ lb.}$$

$$V = P = 49.3\text{ lb.} \leq V_{cap} = 7794\text{ lb.} \checkmark$$

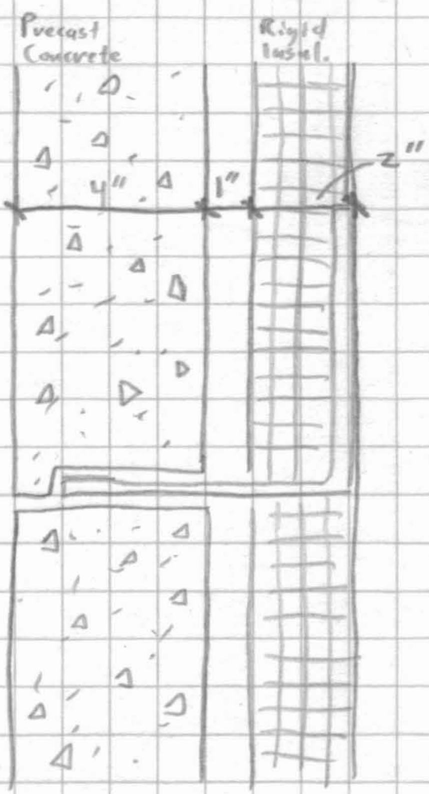
$$M = (49.3\text{ lb.})(5.25'')\left(\frac{1\text{ ft}}{12\text{ in}}\right)$$

$$M = 21.6\text{ ft}\cdot\text{lb.} \leq M_{cap} = 69\text{ ft}\cdot\text{lb.} \checkmark$$

$$\Delta_{max} = \frac{Py^2}{6EI}(3l - y) = \frac{(49.3\text{ lb.})(5.25\text{ in.})^2}{6(29e^6\text{ psi})(0.0049\text{ in}^4)}(3(6'') - 5.25'')$$

$$\Delta_{max} = 0.0043\text{ in.}$$

Structural Analysis: Precast Concrete Facade

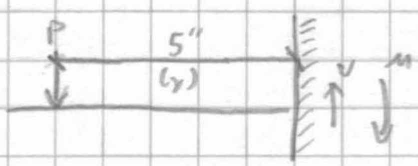


Given: Height of Precast Unit: 29.5'

Unit Wt. of Precast Concrete: 125 pcf

Assumed: All assumptions previously made

Precast Concrete Façade is made of lightweight concrete (125 pcf) and is colored using admixtures to match existing limestone



$$P = (125\ pcf)(1'')(4'')(29.5')\left(\frac{1\ ft^2}{144\ in^2}\right)$$

$$P = 102.4\ lb.$$

$$V = P = 102.4\ lb. \leq V_{cap} = 7794\ lb.\ \checkmark$$

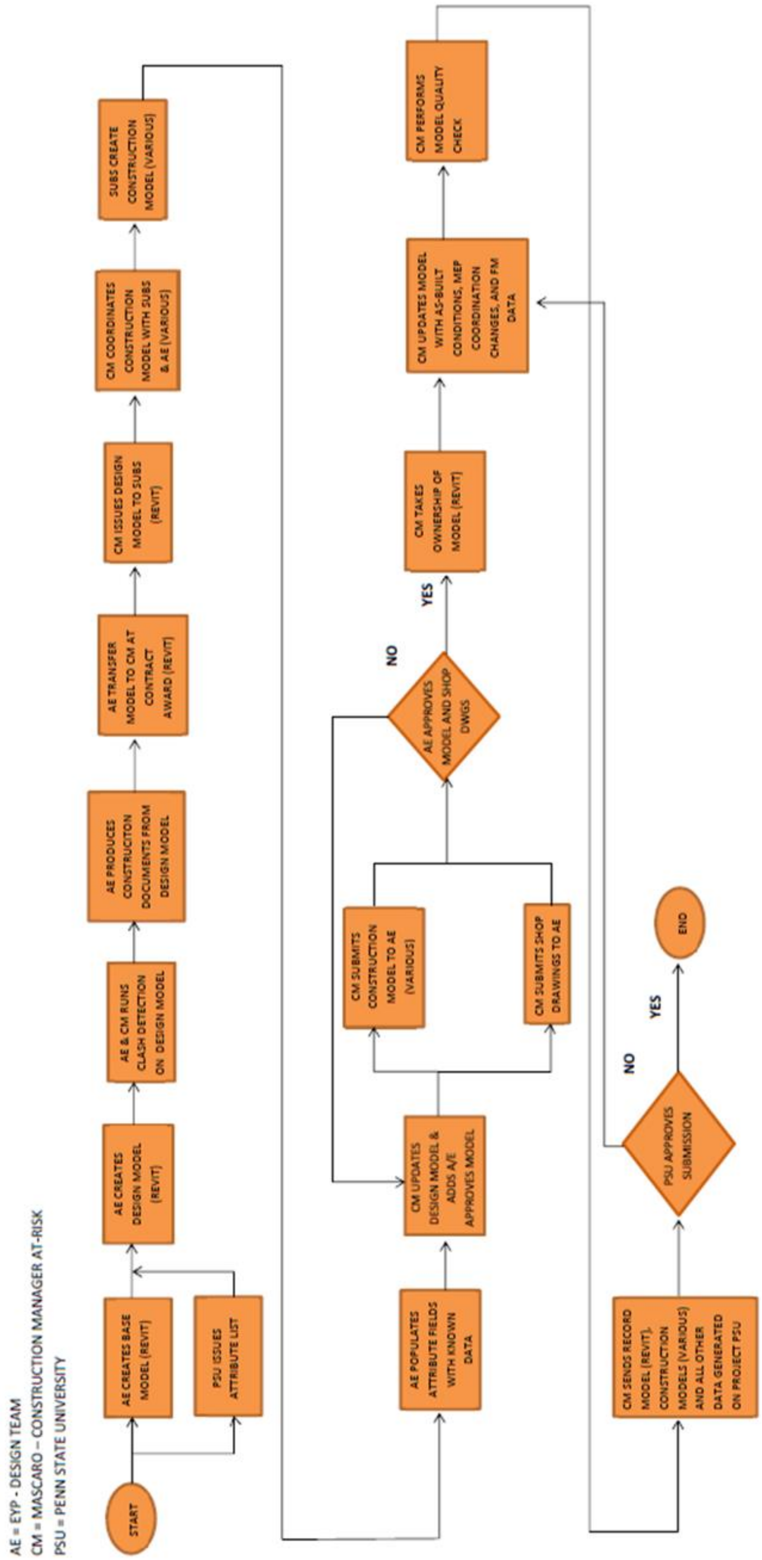
$$M = (102.4\ lb.)(5'')\left(\frac{1\ f}{12\ in}\right)$$

$$M = 42.7\ ft\cdot lb. \leq M_{cap} = 69\ ft\cdot lb.\ \checkmark$$

$$\Delta_{max} = \frac{Py^2}{6EI}(3l - y) = \frac{(102.4\ lb)(5'')^2}{6\,(29E^6\ psi)(0.0044\ in^4)}\,(3(6'') - 5'')$$

$$\Delta_{max} = 0.043\ in.$$

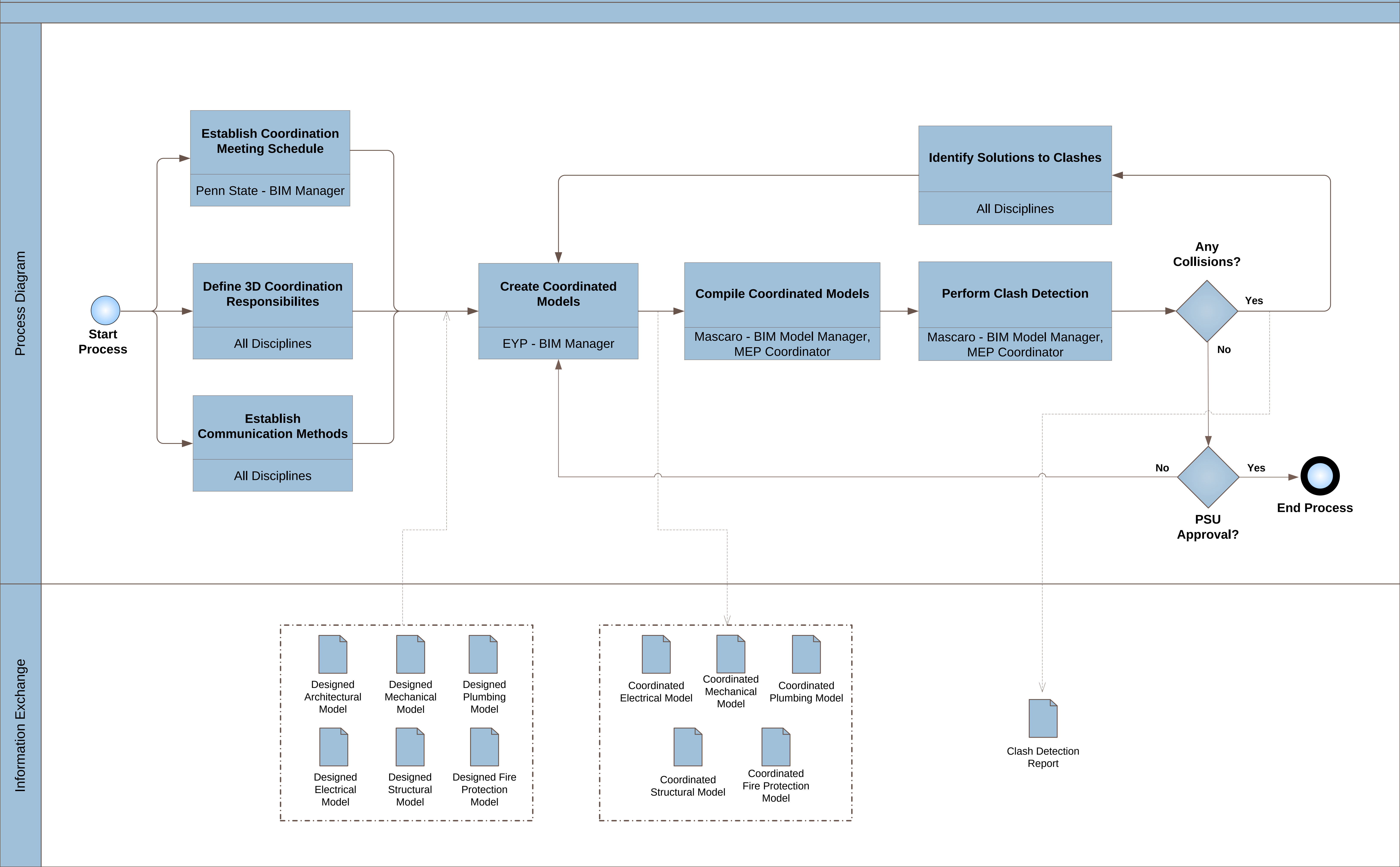
Appendix 3-1: Original Level 1 BIM Execution Process Design Diagram for the Steidle Building Renewal Project



Courtesy of Mascaro Construction Company

Appendix 3-2: Proposed Level 2 Process Design Diagram for 3D Coordination

Appendix 3-2: Developed Process Design for 3D Coordination



Appendix 4-1: Best Value Procedures Questionnaire

QUESTIONNAIRE REGARDING BEST-VALUE PRIME CONTRACTOR (OR SUBCONTRACTOR) SELECTION ON OPP MULTIPLE-PRIME PROJECTS ALLOWING FOR CONSIDERATIONS OTHER THAN COST

Background: Traditionally, prime contractors and subcontractors have been selected for projects based on two criteria: the responsiveness of the bid package and the total bid cost. However, it is also recognized that the lowest contractor at bid may not be the lowest at the end of the project. As such, other criteria may need to be considered in order to pick the contractor that will have the lowest final cost. This is believed to be tied to evaluating which contractors offer the most "value" to the project – how much can the contractor offer com- pared to their bid cost is.

Purpose: This questionnaire is being conducted as part of an Architectural Engineering Thesis Project to identify those criteria that are most applicable to the Office of Physical Plant when evaluating prime contractors or subcontractors for their "value". The end goal will be to propose a weighted list of criteria that OPP could use when they are able to select prime contractors or subcontractors.

Scope: Given how different the criteria can be for different contractors, the scope of this questionnaire is limited to the criteria for MEP prime contractors. Furthermore, these criteria are limited to multiple-prime projects where OPP directly holds the contracts or similar projects where OPP has a direct say in the selection of the contractors. Lastly, these criteria are only applicable to projects that aren't state and federally funded.

Participation: Your participation in this questionnaire is strictly voluntary and is not being compensated for. If you have any questions or concerns pertaining to this questionnaire, you may contact Jeffrey Duclos at jid5237@psu.edu. **Please submit no later than March 16th.**

Section 1: Personal Experience

Name: ______________________________

Job Title: ______________________________

Years of Construction Experience: ______________

Years working at Office of Physical Plant: __________

Email: ______________________________

Section 2: Current Best-Value Criteria for Construction Managers

Context: You are part of the project team selecting a construction management firm for a new laboratory on campus. As this is a privately funded project, your team is using a Best Value selection method for the responding firms.

When you review and evaluate a construction management firm's bid/proposal, **how much emphasis do you place on each of the following elements**, with 1 being the lowest and 5 being the highest:

Criteria	Low 1	2	3	4	High 5
Personnel	○	○	○	○	○
QA/QC Program	○	○	○	○	○
Schedule	○	○	○	○	○
Bid Amount	○	○	○	○	○
Safety Record	○	○	○	○	○
Reputation	○	○	○	○	○
Past Experience	○	○	○	○	○
Diversity	○	○	○	○	○
Sustainable Practices	○	○	○	○	○
LEAN Principles	○	○	○	○	○
BIM Experience	○	○	○	○	○
Risk Management	○	○	○	○	○
Team Chemistry	○	○	○	○	○

Are there other criteria that you think should be included specifically for a construction management firm that were not listed above:

____

____

____

____

[Continued on other side]

Section 3: Potential Best-Value Criteria for Prime Contractors and Subcontractors

Context: After selecting the construction manager for the project, the next step is to select the subcontractors for the project. Because of the complex scope of work on the MEP side, OPP has a direct say in selecting the MEP subcontractors and would like to use Best Value selection here as well for the responding companies.

When you review and evaluate an MEP subcontractor's bid/proposal, **how much emphasis would you like to place on each of the following elements**, with 1 being the lowest and 5 being the highest:

Criteria	Low 1	2	3	4	High 5
Personnel	○	○	○	○	○
QA/QC Program	○	○	○	○	○
Schedule	○	○	○	○	○
Bid Amount	○	○	○	○	○
Safety Record	○	○	○	○	○
Reputation	○	○	○	○	○
Past Experience	○	○	○	○	○
Diversity	○	○	○	○	○
Sustainable Practices	○	○	○	○	○
LEAN Principles	○	○	○	○	○
BIM Experience	○	○	○	○	○
Risk Management	○	○	○	○	○
Team Chemistry	○	○	○	○	○

Are there other criteria that you think should be included specifically for an MEP subcontractor that were not listed:

____
____
____
____

Section 4: General Best-Value Information

Context: After the laboratory project has been completed, you have been asked to reflect upon how considering value during the selection process impacted the project overall.

How do you define "value" in terms of what you seek to achieve during a project:

____
____
____
____

To what extent do you fell that **each of these elements add to the "value" of the project**, with 1 being of low priority and 5 being of high priority:

Criteria	Low 1	2	3	4	High 5
Personnel	○	○	○	○	○
QA/QC Program	○	○	○	○	○
Schedule	○	○	○	○	○
Bid Amount	○	○	○	○	○
Safety Record	○	○	○	○	○
Reputation	○	○	○	○	○
Past Experience	○	○	○	○	○
Diversity	○	○	○	○	○
Sustainable Practices	○	○	○	○	○
LEAN Principles	○	○	○	○	○
BIM Experience	○	○	○	○	○
Risk Management	○	○	○	○	○
Team Chemistry	○	○	○	○	○

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