

Environmental Studies Lab: Expansion

East coast, USA

4/9/2014
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Dr. Anumba



The Environmental Studies Lab: Expansion

East Coast, USA

Size: 72,000 GSF
Stories:
2 plus a penthouse
Delivery Method:
Design-Bid-Build
Contract Value:
\$39 million
Construction Dates:
6/1/11-10/7/13



Project team:
Architect/MEP Engineer:
Ewing Cole
General Contractor:
Hensel Phelps
Structural Engineer:
Woods Peacock
Civil Engineer:
Alpha Corporation



Structural system

- Cast-in-place concrete sub grade
- Steel frame above grade
- Composite metal decking

Mechanical system

- 250 Geothermal wells
- 12 water to water heat pumps
- 4 Outside air handling units all containing enthalpy wheels

Special Thanks to:

**EWING
COLE**



HENSEL PHELPS
Plan. Build. Manage.

Exterior system

- Brick veneer towards foundation
- 2' Section of fiber cement siding
- 2 sets of curtain wall systems
- Corrugated metal panels

Behind the Façade

- 4" insulated metal panels
- 6" cold form metal framing
- 6" metal stud

Electrical system

- Automated Transfer Switch
- Whole building on one generator
- Dimmable controls and Occupancy sensor
- New 480/277 transformer

Codi Shine | Construction Option

<http://www.engr.psu.edu/ae/thesis/portfolios/2014/cms5855/index.html>

Executive Summary

In **analysis 1**, there were a few reasonable assumptions made about what part of the schedule can be combined to incorporate the general contractor in earlier. The general contractor could come in at 35% of design development which will give enough time for the owner to input their ideas into the design before the design builder took over. Judging by the assumptions made, 315 days could be saved and construction could begin August 3, 2010 rather than October 31, 2011. This savings proves that the delivery method design build is a better option.

Analysis 2 demonstrated a SIPS of the overhead mechanical ductwork in the large labs. After creating a few different SIPS options, the most efficient schedule was decided on. The third SIPS saved the schedule 21 days, which is about a month of work. If the hourly rate was \$39.93 per sheet metal worker, then the original SIPS cost would have been \$829,703. SIPS 3 totaled \$896,924, which turned out to be the closest to the original cost and the lowest cost out of the three options. Using this SIPS for overhead mechanical rough-in would be recommended.

The façade study in **analysis 3** also produced savings in both cost and schedule. By changing the composite metal panels, corrugated metal panels, and non-operable louvers to fiber cement siding, saved 18 days. Changing the brick to cast in place concrete saves five days. The architectural breadth shows the changes being made and the justifications of them. A mechanical breadth verifies that the R-value will improve and that condensation will not get into the wall. The cost was a savings of \$293,630 and the total duration was reduced by 23 days. The proposed changes are recommended even though the aesthetics are changed a bit.

The **4th analysis** was on implementing BIM into the project. There were a few BIM uses that would have made planning, design, construction, and operation go smoother. 4D modeling, design review, construction system design, and coordination would have helped with all of these stages. Each of these BIM tools would have reduced the schedule in some way, especially if some of these were implemented before construction. The final part of this analysis was BIM focusing on facilities management. The software used to for asset management will help save time for the facilities manager.

By creating a new schedule out of these analyses, there is a great schedule reduction. The façade changes and SIPS save a total of 44 days, which is two months. With the alternative delivery method of design build, 315 days can be saved. These analyses bring the total scheduled savings to 359 days. This number can vary based on when construction actually starts. With these new durations, the construction for the Environmental Studies Lab: Expansion has the possibility of being turned over by November 15, 2011.

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My Family and Friends

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Project Introduction

Background

The Environmental Studies Lab is located on the East Coast of the United States of America. The construction consists of three phases; however this report focuses on Phase 1, the expansion. The existing lab leads the nation in research for land and water ecosystems. This area started out as farm land in the 1970s when it was later discovered to be a good source for wetland and a good area to study biology. The owner bought the land to protect it and later combined another research facility with the Environmental Studies Lab to make 2650 acres of land.

With the expansion, the scientist will have more adequate space and updated equipment to perform their research and experiments. Hensel Phelps was brought in as the General Contractor after being awarded the bid. The new expansion is a 3 story 72,000 gross square feet with the schedule duration being 22 months. The Environmental Studies Lab: Expansion was designed to be LEED Gold; however it has made LEED Platinum since then.

Building Systems Overview

Structural

The structural system for The Environmental Studies Lab: Expansion is mainly a structural steel system. Above grade it is structural steel. There are steel columns, beams and composite metal decking. Behind the façade, is a six inch cold form metal framing. The roof beams range from W12 to W24. Below grade is all concrete. The basement is all cast in place concrete. Most of the concrete is brought in by a pump and is contracted out to the general contractor, Hensel Phelps. The slab on grade is concrete as well as the spread footings. The slab on grade ranges from four to six inches thick depending on where it is located in the building. It is reinforced with welded wire fabric. All concrete footings and walls are reinforced with rebar ranging from #3 to #8. The composite metal decking has a concrete slab as well.

Mechanical

The Environmental Studies Lab: Expansion includes the construction of a central utility plant (CUP). In the CUP are twelve water-to-water heat pumps connected to a closed loop geothermal system. The new geothermal system consists of 250 wells drilled deep in the ground. The geothermal wells circulate the water which either rejects or takes heat from the ground and transfer it to the water-to-water heat pumps. The heat pumps then change the water to either hot or cold, depending on what is needed in the building. There are also four 100% outside air air handling units. Three of them are in the roof penthouse. All of the air handling units contain an enthalpy wheel which

transfers energy that would be lost from the exhaust stream to the supply stream. The small support labs contain one or two chemistry fume hoods with a dedicated exhaust system. The large labs contain snorkels that are connected to the exhaust system.

Plumbing

The plumbing work for the expansion will be new for the entire building. There will be new sanitary lines and pump station, new waste and vent lines. There is also the installation of a separate industrial waste system that contains an acid neutralization system and chemical resistant piping. In the CUP, there will be a hot water heater installed and a storage tank connected to the solar hot water system. This solar hot water system makes use of collector panels on the penthouse. In the expansion, there are several emergency eyewash and shower stations located throughout both floors. Since it is a lab, there needs to be a laboratory gas distribution system and a reverse osmosis/de-ionized water system. There are three cisterns to collect rainwater to distribute to the wetlands and therefore the geothermal wells.

Electrical/Lighting

The Environmental Studies Lab: Expansion includes a new 480/277 volt transformer that serves the entire building. There are seven automatic transfer switches (ATS) that switch between normal and emergency power. Unlike other buildings, this entire building operates on one generator. The power distribution system includes conduits, panelboards, and raceways. In the labs, there are multi-outlet raceways for both power and data. There are new fluorescent lights in the labs and mostly LED lights outside the building. Throughout the building, there are dimmable controls and occupancy sensors to help save on energy consumption.

Fire Protection

Fire protection for this building consists of fire rated walls and floors. There is a new wet pipe sprinkler system installed. Throughout the building, there are speakers, strobe notification devices and smoke detectors. The fire alarm system is connected to the sprinkler system, building automation system, smoke dampers, elevators and door controls. This is so in case of a fire, all systems will work together to get everyone out of the building safely.

Cost Summary

The cost of construction for The Environmental Studies Lab was about \$41,000,000 or \$570 per square foot. The mechanical/plumbing and control system was the most expensive because of how complex these systems were. These systems, which were all the same subcontractor, had a contract value of \$11,200,000. The electrical system was roughly \$2,800,000 while the structural system was \$3,500,000. These were initial contract values and they do not include change orders. The total construction cost of \$41,000,000 does include the change orders.

Schedule Summary

The overall duration for this project is 22 months from Notice to Proceed to Turnover. However, the project was extended due to constructability issues. Notice to Proceed was June 1, 2011 and Turnover on the Environmental Studies Lab was October 7, 2013. For the purpose of this thesis, the original end date of April 22, 2013 will be utilized. The critical path for this building occurs during excavation, steel erection, most MEP overhead rough-ins, and ceiling close-ins.

For easier, more manageable construction, the construction was phased into

sequences that broke up the building into two sections: S2 and S3. S2 is the east side of the building (green) while S3 was the west side (purple), as shown in **Figure 1**. The basement was only in S3 while the penthouse was mainly in S2, but entered a little bit into S3. The construction on the inside went from west to east while

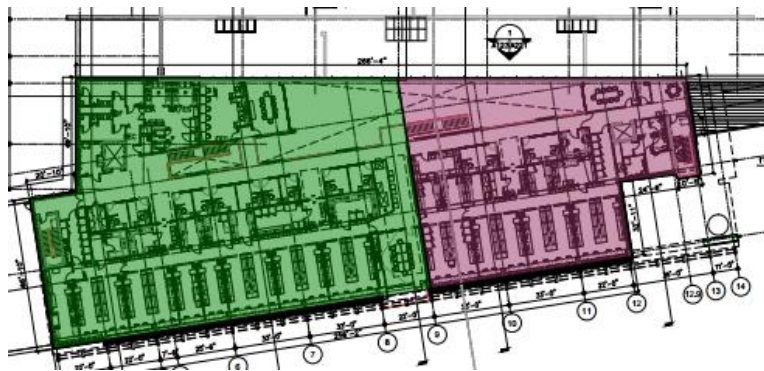


Figure 1 Sequencing

some of the outside construction went east to west. This may have been because certain subcontractors could finish an area without needing to wait on another subcontractor to finish first.

See Appendix A for sequencing and original project schedule

Earthwork

The earthwork on this schedule includes all excavation for the basement/foundation footings as well as for the weir walls, which plays a big factor in the wetlands.

Excavation for the footings started in November 2011 while the excavation for the landscaping did not start until seven months later.

Concrete

Immediately after the footings were dug, Hensel Phelps (the general contractor) started forming, reinforcing, and pouring the footings (FRP) for the basement. The retaining wall and slab on grade (SOG) came shortly after. The basement level only has a SOG for S3, while the first floor foundation occurs in S2. After the foundation in the basement is poured, the FRP of the slab on metal decking (SOMD) is completed for S3 on level 1. The building continues to be poured in the order of S3 and then S2. A couple months after placement is done in the building, the site work begins. This is so Hensel Phelps can use their craft efficiently and effectively.

Structural Steel

Structural steel includes the erecting of columns and beams as well as installing decking and details. Since the basement was slab on grade, there was only the erecting of columns and beams in S3. This was followed by the installation of the metal decking and detailing of S3 for level 1. Then the erecting of columns and beams in S2 on level 1 was next since there was just SOG on level 1 S2 followed by the erecting of columns and beams on S3. On level 2, erecting the columns for S3 and installing the decking and detailing occurred at the same time. This is to speed up the installation process so the building can be enclosed as soon as possible. The topping out occurred on April 13, 2012 when the columns and beams were erected in S2.

HVAC

The first activity that occurs on site is the excavation and drilling for the geothermal wells. This occurs on October 31, 2011 until January 11, 2012. The three vaults are immediately installed. After this, the excavation and the installation of the supply and return piping for the 250 geothermal wells occurred and took 70 days to complete. While the site work was happening, there were twelve water to water heat pumps being installed in the centralized utility plant (CUP). Most of the HVAC work in the basement happens in the CUP, including the installation of air handling unit four. Level 1 and level 2 were sequenced such that once one section was done the next section was started in both directions. For example, the installation of the ductwork on level 1 S3 started July 10, 2012 and ended August 6, 2012. On August 7, 2012 the installation for the ductwork in S2 began; and on August 2, 2012 the installation of ductwork on level 2 in S3 began. In the penthouse, air handling units 1A, 1B, 2A, and 2B were installed at the beginning of May.

Electrical

One of the new key electrical features to The Environmental Studies Lab was a new transformer that was installed in July 2012. There was electrical conduit that had to be installed in the basement slab. This had to be coordinated so the electrical contractor could rough-in the conduit before the slab was poured. This was also the case for the foundation slab in level 1. On each floor there were automated transfer switches that needed to be installed, set, and piped. The in wall (IW) rough-in branch electric was sequenced so that S3 was completed and immediately continued to S2. However, in the penthouse, S2 was completed on October 15, 2012 but S3 wasn't started until November 8, 2012.

Site Layout

Excavation was the first critical phase of construction for The Environmental Studies Lab: Expansion. The excavation of both the expansion and the geothermal wells occurred simultaneously. There were two excavators on site for this, one for the geothermal contractor and one for the general contractor, **Figure 2**. There was a haul road

created between the two excavated areas that was used by the excavators. The excavation went from the west end of the site to the east end of the site. The laydown and connex area was close to the fence and construction entrance for easy access.

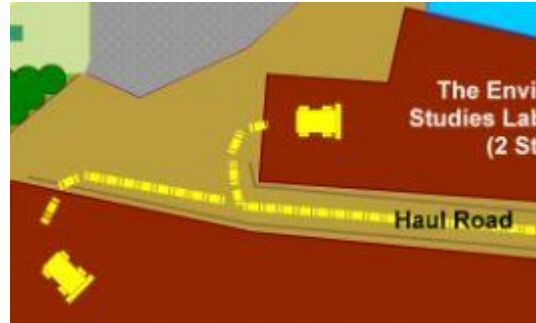


Figure 2 Excavation Site Plan

The next critical phase of construction was the superstructure. There were two crawler cranes on site for this phase. One crane was for steel and the other was for concrete.

The site only needed crawler cranes because it is only a two story building with a mechanical penthouse, **Figure 3**. Since concrete started this phase, there was a concrete washout area needed for the concrete trucks after a pour. The laydown area was extended and another entrance was added. This is because more subcontractors are starting to come on site in this phase and they



Figure 3 Superstructure Site Plan

need the space for their materials. There was also a loading dock added to the northwest end of the building. In order for the deliveries to get back there, they must go around the existing building. The soil from the excavation was moved to the edge of the site into stockpiles. Since the site is accommodating wetlands, the general contractor made a pond for the water to runoff into which runs off into a bigger body of water. There is an area of sediment rocks next to the pond that the water runs over. This is to collect any extra unwanted particles in the pond.

The final critical phase for this project was the finishes phase. In this phase, more of the site work itself was being developed and work had shifted to mainly inside the building. A parking lot was added for the subcontractors since there was need for different subcontractors. The haul road was moved more south of the building because construction started on the site, **Figure 4**.



Figure 4 Finishes Site Plan

There were concrete weir walls being poured on the site to assist with wetland runoff. Most of the construction traffic would enter through the southeast entry way, however when the entry porch was being poured, traffic had to be directed to the loading dock area. This lasted the day of the pour and then foot traffic went back to the front entry porch.

Throughout the project, the trailers and walkways did not have to be moved. There were times when there was construction done close to the pedestrian walkway. This problem was resolved by rerouting traffic for a few days or until that section was completed. Traffic flow is not heavy back in this area because it is strictly for the scientist and other unknown buildings that require clearance to gain access to.

See Appendix B for site layout plans

Analysis 1: Alternative Delivery Method

Problem Identification

The current delivery method, design bid build, is not the most ideal delivery method. With this delivery method, coordination and communication were not handled in the best way possible. The schedule was also delayed on this project. With a different delivery method, this all could have been prevented.

Research Goal

Changing the delivery method may improve certain aspects of the construction process. One of the main pushes here would be to get the general contractor involved early in the project. Since the architect and contractor are both involved in the design phase, there will be more coordination at the beginning of the project and throughout the project. If there is an issue with the design, the contractor will be able to see and fix the issue before it occurs in construction. By changing the delivery method to design bid build, the schedule will be affected as well. The schedule should accelerate considering construction can start when the design is not yet complete. Since there will be coordination in the design phase, there should be less conflicts and problems in the field during construction which will help accelerate the schedule as well.

Solution Method

- Research information from previous projects with similar aspects.
- Gather information and results of surveys conducted by the AE department.
 - Compare the different delivery methods on different projects.
 - Compare the different delivery methods by Hensel Phelps.
- Analyze the difference between getting the general contractor in early verses coming in after the design is complete.
- Recreate a schedule with an alternative delivery method.
- Determine which method is best for this project.

Background Research

With design bid build, there are a few problems that could be solved with a different delivery method. Design bid build goes through each phase which means one phase cannot start without finishing the previous one. There are multiple contacts in this delivery method as well. The owner acts a mediator for the contractor and the architect which can slow down the schedule. Another thing that slows down the process is that the owner has to find and interview each company. When the owner does find these parties, they usually do not have any association with each other until the bid, meaning they lack chemistry. This could hinder coordination and communication on the project since the architect and contractors do not have as close of a relationship as they could.

A better delivery method would be design build. The general contractor and the designer are in a joint venture with this method. This means both of these parties will be in the same unit making it easier to communicate. The general contractor is also involved earlier in the project. They can assist with the design phase by foreseeing any problems that may arise. This helps accelerate the schedule because it is faster than design bid build. It also is faster because the project can be started without the design fully finished eliminating the bidding process. Design build is a more cost effective method than design bid build because the designers have access to the construction cost as the project moves along. This could open up the possibility for value engineering.

With design build delivery is used, there will likely be bridging documents. By having bridging documents, the owner gives up some control over design but will be part of a collaborative process. Bridging has a way for the owner to include requirements into the request for proposal. This way the owner can say exactly what type of products and models that they want to use. However, by giving the owner more say in the matter, he assumes more risk. Therefore, bridging documents need to be composed with the designer input and the owner's requests. The owner can hire an architect and/or engineer to assist with initial design in order to have a say in the design and construction phases. The architect or engineer that the owner hires will contribute to the design development phase and also prepare scope of work documents. They will contribute about 30% to 50% of design to this phase. The scope of work documents includes aesthetics and the function of the building but leaves the constructability process to the contractor. However, the project team is in charge of the final design.

The delivery method on this project was design-bid-build with Hensel Phelps being the general contractor. All contracts were lump sum with direct communication between the architect and general contractor. The owner contracted Ewing Cole as the architect/MEP engineer. The owner then contracted a structural engineer and a civil engineer. After Hensel Phelps was awarded the bid, they contracted all the work to subcontractors except for concrete work. This relationship is shown in **Figure 5**.

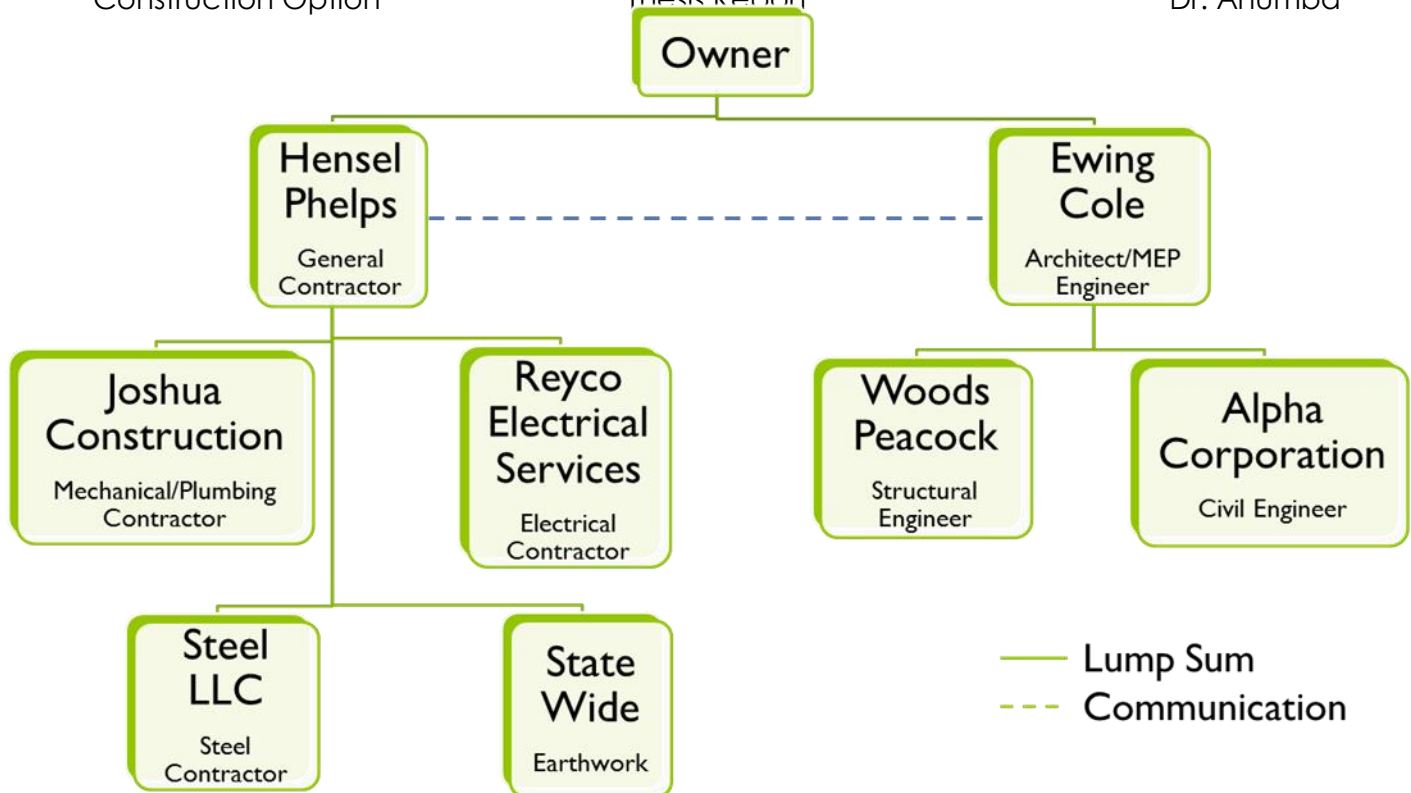


Figure 5. Contract relationship between project team members

Process

Researching other projects

In order to be able to perform a proper analysis, similar projects would need to be looked into. Through the Project Performance Questionnaire, which was accessed with assistance from Dr. Robert Leicht and Bryan Franz, it was decided that only Hensel Phelps projects should be considered since they were the general contractor. The Project Performance Questionnaire is a survey given to different companies all over the United States in order to perform research on delivery methods and project teams. One section of the Project Performance Questionnaire that was very applicable to this analysis was the project delivery system and the project team selection. These sections asked what kind of delivery system and when team members joined the project. In **Figure 6** below, is a side-by-side comparison of the Environmental Studies Lab: Expansion and the Commercial Hanger. The questionnaire was updated for the Environmental Studies Lab: Expansion, so there are a few differences in the questions. However both surveys are similar enough to compare them. Also included in this section was 'what factors were considered when selecting the project participant'.

See Appendix C for the full questionnaires

SECTION 2: PROJECT ORGANIZATION

Select the project delivery system best matching the delivery of your project:

Design-Bid-Build Design-Build (DB)
 Construction Manager at Risk (CM/GC) Integrated Project Delivery

Denote when each project participant was contracted for the project (timing as based on percent of overall design completion):

| | Pre-Design (0-15%) | Concept (15-30%) | SD (30-60%) | DD (60-90%) | CD (Full CD) | Bidding |
|------------------------|----------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------------------|
| Architect/Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| GC, CM/GC or DB | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| MEP Contractors | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| Structural Contractors | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |

Were specialty contractors involved before being contracted? Yes No

Relative to your expectations, evaluate the administrative burden you experienced (1=Low, 6=High):

Low 1 2 3 4 5 6 High

SECTION 8: TEAM PROCUREMENT & CONTRACTS

Indicate how proposals were solicited from each project participant:

| | Open Bid | Pre-Qualified Bid | 1-Stage RFP | 2-Stage RFP | Sole Source |
|------------------------|-----------------------|----------------------------------|----------------------------------|-----------------------|----------------------------------|
| Architect/Designer | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| GC, CM/GC or DB | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| MEP Contractors | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Structural Contractors | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> |

Which of the following factors were considered in the selection of each project participant (check all that apply)?

| | Price (Fee) | Price (Work) | Tech. Proposal | Design Concept | Similar Project Experience | Interview Performance |
|------------------------|--------------------------|-------------------------------------|--------------------------|-------------------------------------|----------------------------|--------------------------|
| Architect/Designer | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| GC, CM/GC or DB | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| MEP Contractors | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Structural Contractors | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Select the commercial terms used for the following project participants:

| | Lump Sum | OMP | Unit Price | Cost Plus |
|------------------------|----------------------------------|-----------------------|-----------------------|---|
| Architect/Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| GC, CM/GC or DB | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| MEP Contractors | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| Structural Contractors | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |

Were performance-based incentives used in any contracts? Yes No

Was the operation and maintenance of the facility included in the contract scope of any team member or members? Yes No

Did the project team use a formal partnering agreement? Yes No

SECTION II: PROJECT DELIVERY SYSTEM

Select the project delivery system best matching the delivery of your project:

Design-Bid-Build Design-Build
 Construction Manager at Risk (CM/GC) Integrated Project Delivery

Select the contractual terms used for the following project participants:

| | Lump Sum | OMP | Unit Price | Cost Plus | N/A |
|----------------|----------------------------------|-----------------------|-----------------------|---|----------------------------------|
| Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee | <input type="radio"/> |
| Contractor | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee | <input checked="" type="radio"/> |
| Design-Builder | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee | <input type="radio"/> |
| Const. Manager | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee | <input checked="" type="radio"/> |

Were performance-based incentives used in any contracts? Yes No

SECTION III: PROJECT TEAM SELECTION

Denote when each project participant was contracted for the project (timing as based on percent of overall design completion):

| | Pre-Design (0-15%) | Conceptual (15-30%) | SD (30-60%) | DD (60-90%) | CD (Full CD) | Bidding | N/A |
|----------------|----------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------------------|
| Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Contractor | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| Design-Builder | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Const. Manager | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |

Were specialty contractors involved before design completion? Yes No

Indicate how proposals were solicited from each project participant:

| | Open Bid | Pre-Qualified Bid | 1-Stage RFP | 2-Stage RFP | Sole Source | N/A |
|----------------|-----------------------|----------------------------------|----------------------------------|-----------------------|-----------------------|----------------------------------|
| Designer | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Contractor | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| Design-Builder | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Const. Manager | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |

Which of the following factors were considered in the selection of each project participant (check all that apply):

| | Price (GC/ Fee) | Price (Work) | Technical Proposal | Design Aesthetics | Similar Project Experience | Interview Performance |
|----------------|--------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|--------------------------|
| Designer | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Contractor | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Design-Builder | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| Const. Manager | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |

Was the operation and maintenance (O&M) of the facility included in the contract scope of any team member or members? Yes No

Figure 6. Environmental Studies Lab: Expansion survey vs. Commercial Hanger survey

Ten projects were compared and two of the ten were found to be very close to the Environmental Studies Lab: Expansion.

| Building Name | Square Foot | Cost/Sq Ft | Intensity | Construction Speed | Delivery Duration |
|--------------------------|-------------|------------|-------------|--------------------|-------------------|
| Environmental Studies | 72,000 | \$491 | \$1,756,192 | 3576 | 3473 |
| Technical Monitoring Hub | 71,336 | \$460 | \$2,218,444 | 4820 | -- |
| Commercial Hanger | 60,000 | \$329 | \$1,768,125 | -- | 3947 |

Table 1. Comparison of Environmental Studies Lab: Expansion vs. the Technical Monitoring Hub and Commercial Hanger

The Technical Monitoring Hub and Commercial Hanger were both design build. The Technical Monitoring Hub was a project related to transportation while the Commercial Hanger was obviously a commercial hanger. As you can see in **TABLE 1**, the buildings were compared by square foot, cost per square foot, intensity, construction speed, and

delivery duration. In order to determine these values, some basic information was needed about the project. In the questionnaires, there were questions about the construction project and the construction process as well as the teams that were on the project. The information needed for these calculations includes: square foot, notice to proceed, project end date, construction start date, construction contract finish date, actual finish date, initial and final construction costs. Notice to proceed and project end dates were used to determine the project duration. This was used to determine the delivery duration. Intensity was determined by using the final construction cost and the construction duration. Construction speed was determined by the square footage and the construction duration.

See APPENDIX D for full calculations on how these were completed.

Talking with the project teams

The best way to find out how the teams collaborated during the projects was to talk to the project managers and find out how everything was handled. This way, it will be a more accurate determination of whether or not it was more beneficial to have the general contractor come in during the design phase.

On the Technical Monitoring Hub, the project manager claims that having a design build delivery method was the best choice especially for this owner. The owner was very open to letting Hensel Phelps take control of design due to their understanding of what the owner wanted. This often happens since they were a repeat client. For their design build project, as soon as the subcontractors signed the contract they would have them check the schedule to ensure they were capable of performing the tasks on time. The mechanical, electrical, and fire protection subcontractors were brought in early to assist with design. This worked out well because they designed it per the owner's requirements and to their standards. These design build subcontractors started building before their design was approved which helped accelerate the schedule. When doing this, they were able to determine sizes and be comfortable with taking the risk of fabricating before approval because they knew the owners requirements. Another thing that helped accelerate the schedule was off-site prefabrication of the mechanical and electrical work. Hensel Phelps also had a few design assist subcontractors start early to input design in order to match their supply. Throughout the project, they continued to collaborate well with the subcontractors through weekly meetings. During these, they would discuss what was going on in the next time period to ensure the schedule was on track.

While all packages overlapped throughout the project, there were three packages that were fast track packages: foundation, early site, and steel. The structural steel design was released early in order to shorten procurement and fabrication times. The early site work was released early in order to start constructing the building pad

surcharge. The site work was approved as soon as possible allowing it to begin quickly. There was also work being performed concurrently on site that was not impacted by the surcharge. All of this helped accelerate the schedule and would not have been possible with a less collaborative delivery method.

Another big item that impacted the schedule was called shared racking. Shared racking are prefab duct and pipe runs. The duct and pipe runs were unitized assemblies of 20 foot long runs that were brought on site and quickly put into place. The project manager said that constructing the shared racking was a collaborative effort that was able to be achieved because of the design build method.

The Commercial Hanger was a government project so it was done a bit differently per the contract. The government has 30 days to review all of the documents which makes this a fast track design. They broke the package into two phases: site, civil, and foundation, and then everything above grade and build out. This was done so the site work could be in progress while the rest of the scheduling and design for the building was being completed. The delivery method was design build for this project as well so they contracted a few design assist subcontractors such as structural steel, mechanical, electrical, plumbing, and fire protection. The design assist subcontractors brought in a scope within their budget while keeping the owners needs in mind. During the document review period, they were able to provide sequencing, constructability advice and review within their trade. During construction they continued to collaborate in an effective manner. This was a very dynamic and fluid process because they were in constant contact with each other asking for the other subcontractor's input on that particular item.

Throughout the project, the owner was very accessible. There were two "over the shoulder" reviews prior to submission. This is where everybody would sit down with the owner, who in this case is the government, and flip through each sheet in order to take their input and feedback. The contractors would work on the changes as the government reviewed it in order to not fall behind schedule. Overall, this delivery method was the best for the owner because there was only one point of contact and the risk was shared with all team members.

Using design build as the delivery method worked out very well for this project. Hensel Phelps was able to control the design. This meant procuring the subcontractors early which also led to ordering the material early. Since the subcontractors were on board, the pre-planning of construction was able to begin during design.

Comparing the projects

When comparing the Environmental Studies Lab: Expansion with the Technical Monitoring Hub, there are obvious differences in collaboration. Since the Environmental Studies Lab: Expansion is design bid build, there was no input at all from the

subcontractors, or even Hensel Phelps for that matter, in the design phase. The input that the subcontractors could have contributed to the design would have saved a lot of time, especially since there were a few clashes and design issues that were discovered after the items were put into place. Although they did have weekly subcontractor meetings at the Environmental Studies Lab: Expansion to coordinate the activities being completed in the field, this did not save the time it could have during the design phase.

In the Commercial Hanger, the fast track design with the 30 day government review is a good idea. If this is achievable in the first place, why not use it in more projects? It is beneficial to both the project teams and the owner. The “over the shoulder” reviews were also very beneficial in coordination and schedule reduction. The project team avoided a lot of issues because of these meetings, which would have been beneficial to the Environmental Studies Lab: Expansion as well.

In both projects the site work was approved as early as possible in order to start working on the site while other design aspects were being completed. Since the Environmental Studies Lab: Expansion had extensive site work, this would have been very helpful. In both projects there was also room for innovation in the design phase that sped up the schedule. This may not have been able to be considered at all if it had been a delivery method such as design bid build.

Schedule Reduction

After a conversation with both project managers, some key assumptions were made. They were to incorporate the following: early collaboration, fast track designing, early site work approval, and more innovation. A reasonable duration was also determined that could help reduce the schedule.

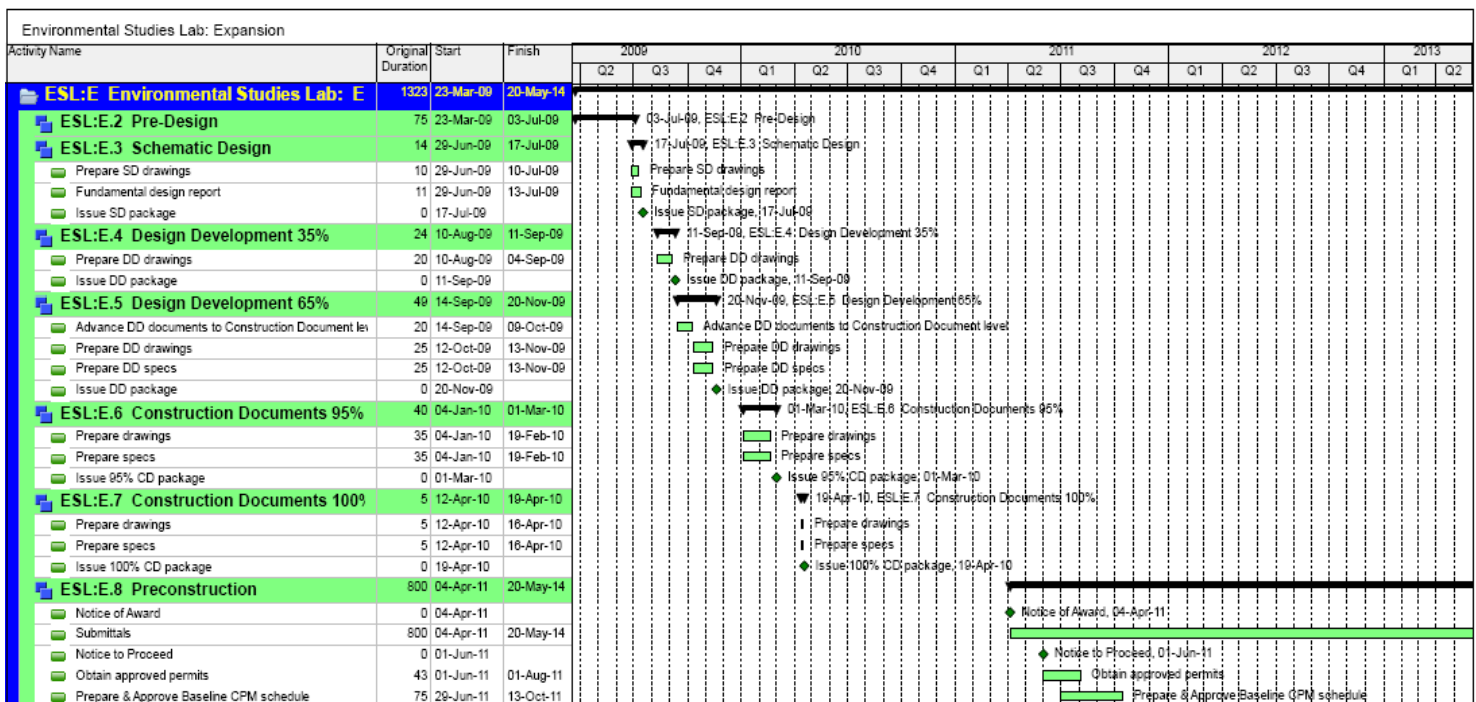
According to “AGC Project Delivery Systems for Construction”, in a typical design build contract, the contractor is involved around 15% of the design is complete. According to “The Design-Build Bridging Method”, the hired architect or engineer has a say in up to 50% of the design. The architect provided a design/document schedule that had Design Development of 35% being issued on September 11, 2009. If the 35% of design development is completed by this time, then it meets both of the sources requirements. By getting the contractor in this early, they would have a great effect on the design as well as fast tracking it and early subcontractor involvement. There are a few subcontractors that could be brought in early or be design assist subcontractors. The MEP subcontractors could definitely be brought in as design assist subcontractors. Since this is a lab, there are a lot of plumbing and mechanical equipment and pipe lines that have to be considered when designing and testing for clashes. Hensel Phelps self-performed the concrete as well as most of the doors and hardware. These subcontractors that would start early do not even have to be design assist; just getting them in early could help with issues such as value engineering. If the subcontractors

are only responsible for value engineering, they do not assume any of the design responsibility. If they are involved earlier in the project, it could be just early enough to be there for shop drawings and drawing review in the construction document phase. This phase is where preconstruction could start. At 95% construction documents, the specifications and construction drawings are being prepared. The subcontractors include their input and experience with the equipment being designed for the system. This would allow for submittals to start being approved and therefore, speeding along the fabrication and delivery.

Along with subcontractors becoming involved early, there are certain packages that would benefit from being fast tracked. The items that are long lead items should be fast tracked in order to move the project along quicker. The structural steel package was an item that is commonly fast tracked. It is a total of 86 days between the submittal development, review and approval, and fabrication and delivery. This number is not accounting for mistakes or problems that are possible. Air Handling Units (AHU) were also long lead items. Both submittal development, and submittal review and approval are 15 days. However, fabrication and delivery is 110 days for each of the four AHUs. Elevators are another long lead item that should be fast tracked. Although they take 30 days total for the submittal development and the review, it takes 120 days for fabrication and delivery. There are a few other items with long lead times, but these few mentioned are the more significant ones on this project

Conclusion

In **Figure 7**, the schedule for design was originally 639 days long. Below it has a revised



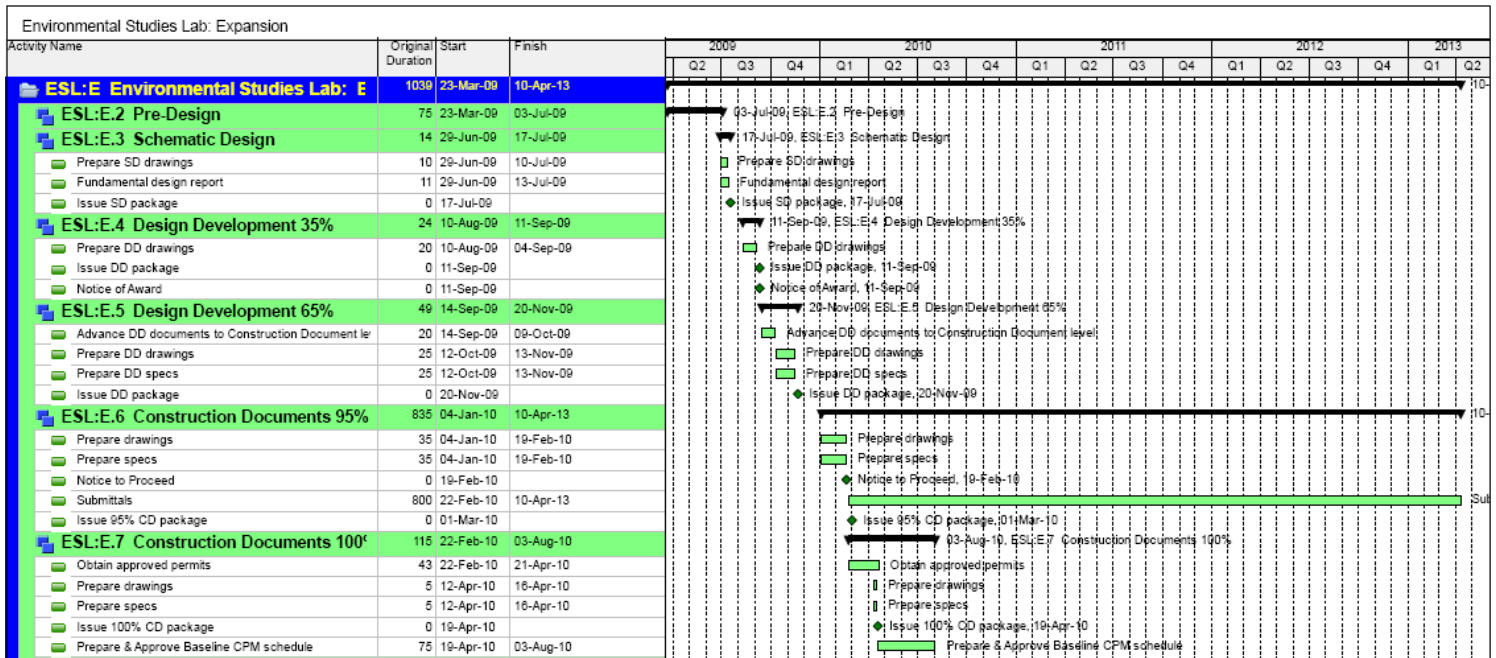


Figure 7. Original design schedule (Top) vs. proposed design schedule with design build (Bottom)

schedule which involves bringing in the contractor earlier as well as the subcontractors.

With this new schedule, some assumptions were made based on talking to the other project teams. The Pre-construction section was integrated into the other phases of design. The notice of award for Hensel Phelps would occur at 35% of design development. This way, Hensel Phelps will have input on design. The subcontractors would become involved after the drawings and specifications are prepared at 95% completion of construction documents. This way they can include their input on equipment and coordination. Preparing and approving the baseline CPM schedule would be a collaborative effort that could either go at 95% construction documents or 100% completion of construction documents.

From these assumptions, the design phases were completed in 339 days, which is a savings of 300 days. Construction could possibly start August 3, 2010, when the schedule would be completed. However, there were ideas mentioned above from the other project teams about phasing. If the site work was phased differently or started during design, obviously this would put construction as starting earlier. If coordination and fast tracking were accounted for, the schedule could have been reduced even more.

The fact that the schedule was reduced this much from just getting the contractor involved earlier shows that having a design build delivery method would be beneficial in that way. When it comes to coordination, design build is better than design bid build because of all the parties involved earlier in the design phase. This creates a good chemistry that can last throughout the project. The communication and design assist

subcontractors that comes from this delivery method would also help out the project. The subcontractor's input are important and they can also help develop the schedule to match their abilities. Design bid build being the current delivery method has hindered coordination and communication for the whole project team. Per this analysis, the best way to go would be to have used a design build delivery method. However, this is ultimately the owner's decision but they need to consider all pros and cons from each delivery method.

Analysis 2 – Short Interval Production Schedule (SIPS)

Problem Identification

Since the Short Interval Production Schedule (SIPS) helps with efficiency, this will accelerate the schedule and improve the quality of the project overall. There are 18 large labs in the Environmental Studies Lab: Expansion. These labs have the same layout and items in it. There are a few different options on which trades could perform a SIPS. The casework trade, the finishes trades, or the MEP trades are all options for those labs. The mechanical overhead rough-in would be very useful to have a SIPS.

Research Goals

The main goal for this analysis is schedule acceleration. Even though there is a learning curve at the beginning of the project, once the crews get accustomed to the process, this portion of the project will speed up. Since there will be a different crew for each activity, each crew will hopefully have the same amount of time for the learning curve.

Solution Method

- Gather a better understanding of the SIPS method
- Develop a sequence of work and crew for very specific tasks
- Create a SIPS in order to see how much the schedule could be reduced
- Analyze the difference in schedules and create a recommendation

Background Research

The goal for this analysis is to accelerate the schedule through SIPS. SIPS is a very detailed form of scheduling that helps with efficiency out in the field. Each activity is assigned a duration that may be so precise it is down to the minute. It is critical to have good communication between all parties involved to avoid delays throughout each activity. Initially, there is a learning curve on each process. This will be there until the field workers familiarize themselves with the process.

There are 18 large labs in the Environmental Studies Lab: Expansion, nine on the first floor and nine on the second floor. The overhead rough-in for the mechanical ductwork is the same in all these labs so it would be beneficial to explore a SIPS with this trade.

Process

Sequencing and Crews

In order to produce a SIPS, a scope package was chosen that was typical in all of the labs. The mechanical ductwork that was present was the same in every lab and there was a good majority of it. This package is a good opportunity for a SIPS because of the recurrence in the labs. The first thing that needed to be done was to figure out the

sequence. The construction was going east to west so this process was kept the same. After discussing the process with the project team, a short sequence was put together:

- First floor (Labs 1-9):
 - Layout
 - Install Sleeves
 - Install Hangers/Anchors
 - Layout/Rough-in
 - Unload and Distribute Duct Sections
 - Hang Trunk Lines
 - Install Medium Pressure Branch
 - Install SACs and EACs
 - Install Low Pressure Branch
 - Hard Duct (Exhaust)
 - Install Registers, Grilles, and Diffusers (RGD)
- Second floor (Labs 10-18):
 - Layout/Rough-in
 - Install Sleeves
 - Install Hangers/Anchors
 - Unload and Distribute Duct Sections
 - Hang Trunk Lines
 - Install Medium Pressure Branch
 - Install SACs and EACs
 - Install Low Pressure Branch
 - Hard Duct (Exhaust)
 - Install Registers, Grilles, and Diffusers (RGD)

The process was a little different on the first floor than on the second floor. There are two different times that layout was performed for the first floor. In order to save time, some of the layout was done before the concrete slab for the second floor was

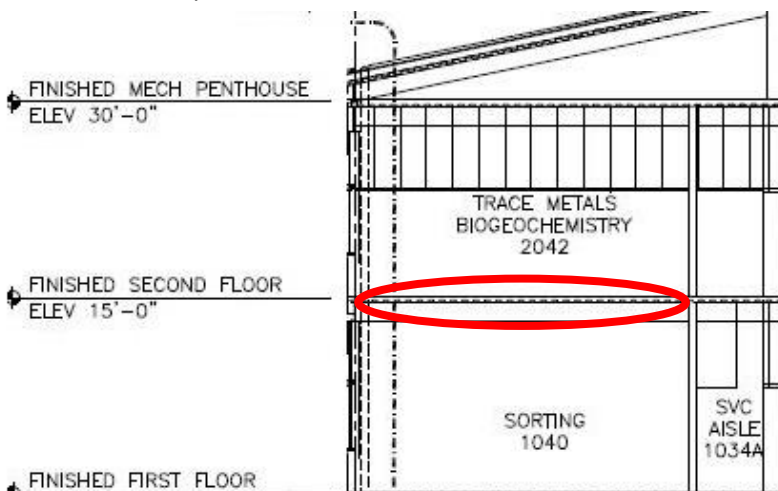


Figure 8. Location of first 'Layout' activity for the first floor

poured. The subcontractor would stand on the second floor while performing some of the layout in the first floor ceiling. This location is shown in **Figure 8**. This actually made it so the time was cut in half on the first floor. However, this same process was not performed for the second floor ceiling.

For a SIPS, each activity is assigned its own crew and color. Below in **Figure 9**, you can see the actual crew members used for each activity. **Figure 10** shows a lab in plan-view in order to see what colors apply to what mechanical equipment.

| Activity | Crew |
|-------------------------------------|---|
| Layout | 1 Sheet Metal Layout |
| Install sleeves | 1 Sheet Metal Worker |
| Install Hangers/anchors | 1 Sheet Metal Worker 1 Sheet Metal Apprentice |
| Layout/Rough-in | 1 Sheet Metal Layout |
| Unload and distribute duct sections | 2 Sheet Metal Workers |
| Hang trunk lines | 2 Sheet Metal Workers 1 Sheet Metal Apprentice |
| Install medium pressure branch | 2 Sheet Metal Workers 1 Sheet Metal Apprentice |
| Install SACs, EACs | 1 Sheet Metal Worker 1 Sheet Metal Apprentice |
| Install Low Pressure Branch | 2 Sheet Metal Workers 1 Sheet Metal Apprentice |
| Hard Duct Taps (Exhaust) | 2 Sheet Metal Workers 1 Sheet Metal Apprentice |
| Install RGD | 1 Sheet Metal Worker |

Figure 9. Each activity with its assigned color and crew sizes.

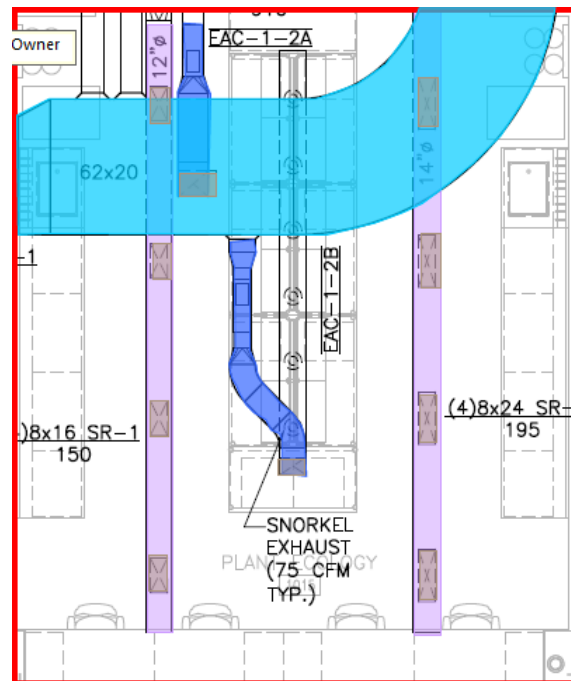


Figure 10. Plan-view of the overhead mechanical equipment with its assigned color.

After discussing the actual duration with the project team, it was determined how long each activity took per floor. All days were assumed to be an eight hour work day. All of the activities were broken out into days per floor except for "Install SACs and EACs." There were eight SACs and EACs installed per day, however this was not how many was in each lab. There was one SAC and two EACs in each lab, which makes 27 on each floor since there are nine labs. Since there are 27 SACs and EACS per floor and eight installed per day, this activity took three and a half days per floor to complete. There were ten RGDs per lab, however these were easier to install and only take two days per floor. From these durations, hours per day and then hours per lab were able to be determined. If each activity was performed in a Finish Start manner, it would take 50 hours and 13 minutes to complete one lab on the first floor and 57 hours and 20 minutes to complete one lab on the second floor. Between the number of crew members and the hours per lab, the hours per worker were able to be determined.

Appendix E shows calculations of the workers and activities

A SIPS was not performed on this project, but judging by the information provided by the project team, a SIPS was developed based on what could have happened. It was assumed that each activity was performed right after the other one was finished in a Finish Start relationship. The only activities that were performed concurrently were

“Install Sleeves” and “Install Hangers/Anchors.” It was also assumed there was a set crew assignment and it dragged out the schedule. Labs 1 and 2 and labs 10 and 11 are shown in **Figure 11**. From this, you can see how each activity followed one another on both the first floor and the second floor. The schedule is broken down into hour increments. The way that this SIPS was designed was that each activity was finished in one lab before it was started in another. The longest duration was the “Hang Trunk Lines” at nine hours. This was the only activity in which one lab was finished and the crew moved on directly to the next lab. By finishing the schedule in this manner, the final activity in lab 18 was completed on Day 33 on the third hour.

Appendix F shows a complete SIPS of the original durations

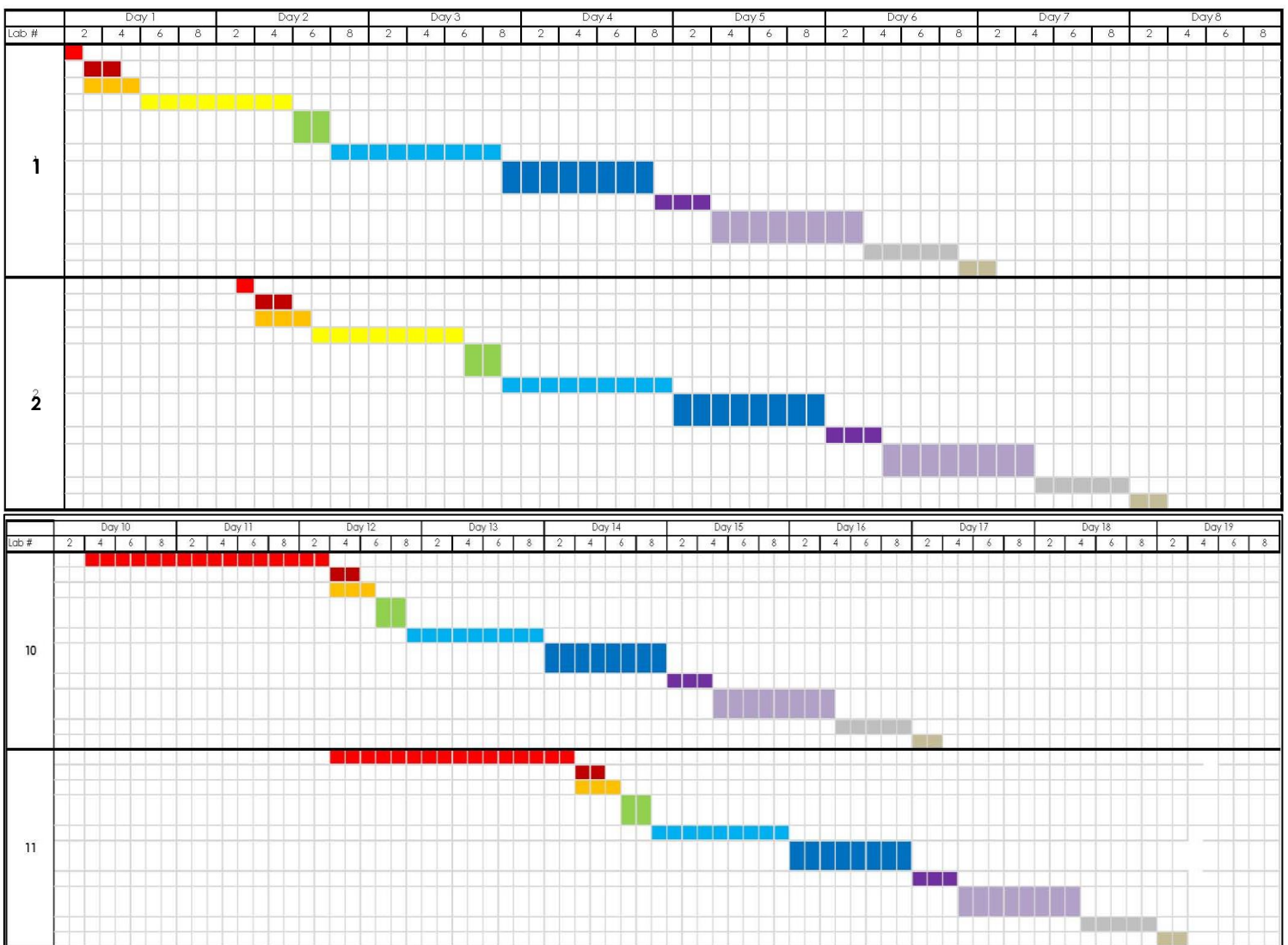


Figure 11. Original SIPS labs 1 and 2 on the first floor and labs 10 and 11 on the second floor

Constructing the SIPS

When recreating a SIPS, there were several different factors to consider. The first was if the sequence made sense. Layout/Rough-in was switched with Unload and Distribute Duct Sections because some of the material may have been needed for the layout/rough-in. This would save time for the workers so they would not have to go back and forth getting the supplies they need. It is also important that unloading and distributing of the duct sections be finished before the trunk lines are hung so time is not wasted waiting on the parts needed. The next factor to consider was what activities could be done concurrently. Most of the activities need to have a Finish Start relationship because they rely on the activity in front of them for the connection. The only other activities that made sense to be performed concurrently were the "Hard Duct Taps" and "Install RGDs." This could happen since the taps, or holes, were being cut for the RGDs. However, this activity was made into a Finish Finish relationship because as soon as the last hole is cut, the RGD can be installed.

Another big factor that needed to be considered was the crew sizes. Crew sizes that needed to be changed were determined by looking at the longest durations. Hang Trunk Lines had the longest duration for the first floor at nine hours per lab while Layout/Rough-in, Install Medium Pressure Branch, and Install Low Pressure Branch were all eight hours per lab. One worker was added to each of these activities which decreased the number of hours per lab. The new total was 40 hours per lab on the first floor. The second floor was different since the 'Layout/Rough-in' took more time to complete on the second floor than it did on the first floor. Layout/Rough-in took sixteen hours to complete on the second floor with one crew member, therefore the number of workers needed to be increased to three in order to make it five hours per lab. "Hang Trunk Lines," "Install Medium Pressure Branch," and "Install Low Pressure Branch" also added a worker. The new total for the second floor became 40 hours and 26 minutes. The hours per lab were determined using a ratio:

$$\frac{\text{Adjusted Crew Members}}{\text{Actual Crew Members}} = \frac{\text{Actual Hours/Lab}}{X}$$

with X being the adjusted hours per lab. By adjusting the crew sizes and decreasing the amount of time needed to complete an activity, there was float included into those activities. The float is there for the learning curve from SIPS. It also allows for overlap in activities.

These calculations can be found in Appendix E

SIPS Options

After multiple attempts at a schedule, it was determined that there may have to be multiple crews for each activity. The activities that were having the most trouble lining up were the "Layout/Rough-in" and "Hang Trunk Lines." It was decided that these two

activities should have multiple crew members. The odd lab numbers would have the same crews and the even labs numbers would have the same crews for those activities. The second floor only needed the activity “Hang Trunk Lines” to have multiple crews so the odds and evens crews continued through the second floor for that activity. The extra crew for “Layout/Rough-in” was able to be dropped because of the crew size needed. After the first “Layout” in Lab nine was completed, that one crew member would go to Lab ten to start “Layout/Rough-in.” When Lab eight finishes “Layout/Rough-in,” those two crew members join the other layout worker in Lab ten. The first schedule, shown in **Figure 12**, ended up being the shortest schedule with the last activity on the second floor being finished on Day 12 at the third hour of the day.

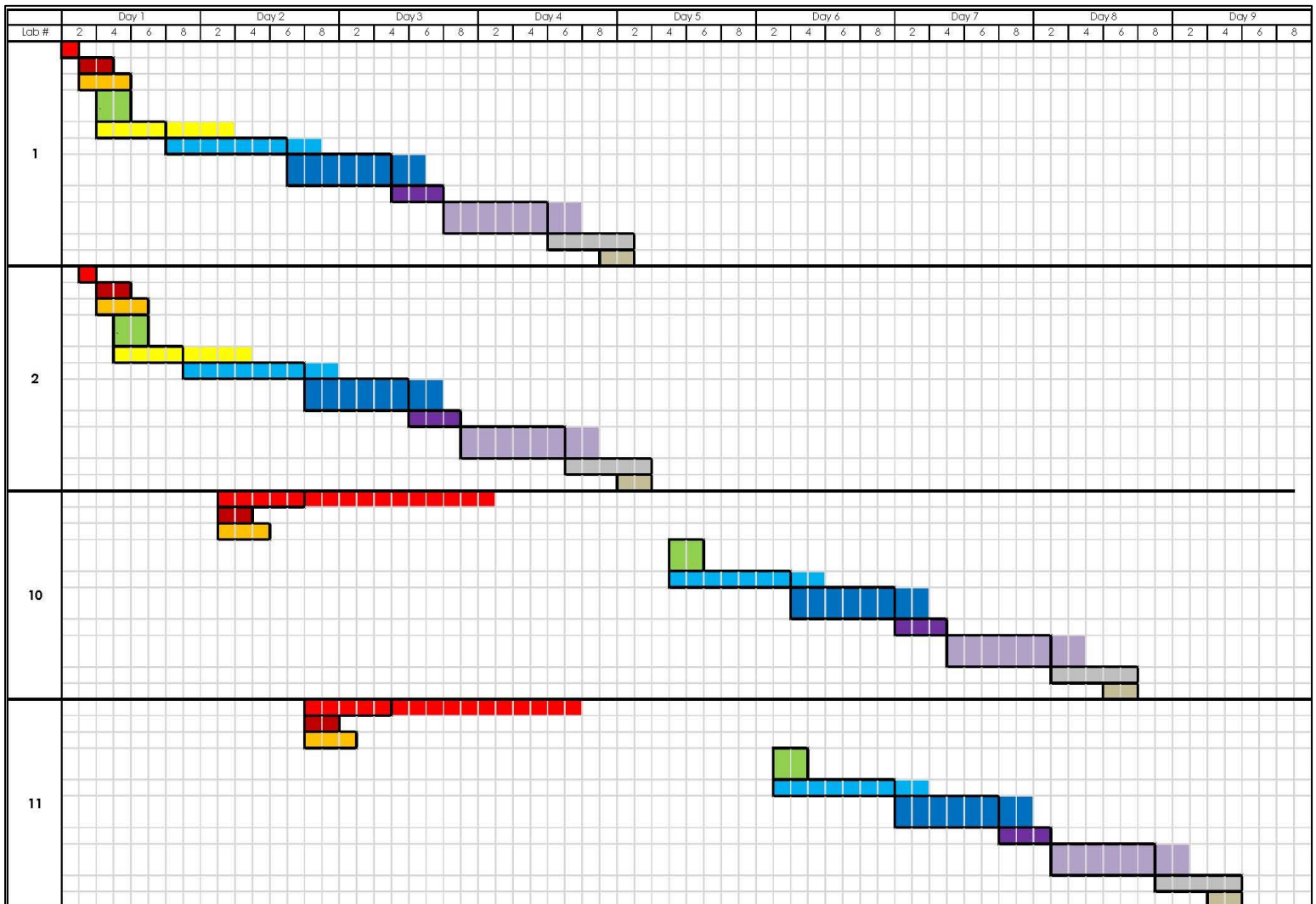


Figure 12. SIPS 1, Labs 1 and 2 on the first floor and Labs 10 and 11 on the second floor.

When this schedule was finished, it showed all the activities, starting with “Layout/Rough-in,” following the multiple crew pattern for each activity. There were 26 crew members per lab on the first and second floor without multiple crews for the floor.

With this schedule, that number doubles to 52 crew members per lab on each floor giving a total of 104 crew members. This would make labor double. With this many people, production may decrease because of people getting in each other's way, even though the schedule says it will only be twelve days. In **Figure 12** above, the durations are outlined in black. The colored boxes after the outline are showing the float available for that activity. This is shown throughout the rest of the SIPS.

The next schedule attempt to make a SIPS spread the schedule out a lot more. In this schedule, there were multiple crews used again. However, it was only for the activities "Layout/Rough-in" and "Hang Trunk Lines" on the first floor and "Hang Trunk Lines" for the second floor. The other activities all had a Finish Start relationship. With the Finish Start relationship, it caused the schedule to extend out further than the first schedule. The final activity on the second floor would finish on Day 17 at the seventh hour of the day. The problem with this schedule is that the activity "Install Medium Pressure Branch" and all the activities that follow it, progressively get further away from its predecessor, as shown in **Figure 13**. This is not a big problem, however it is inconvenient to have hours, even days between these two activities.

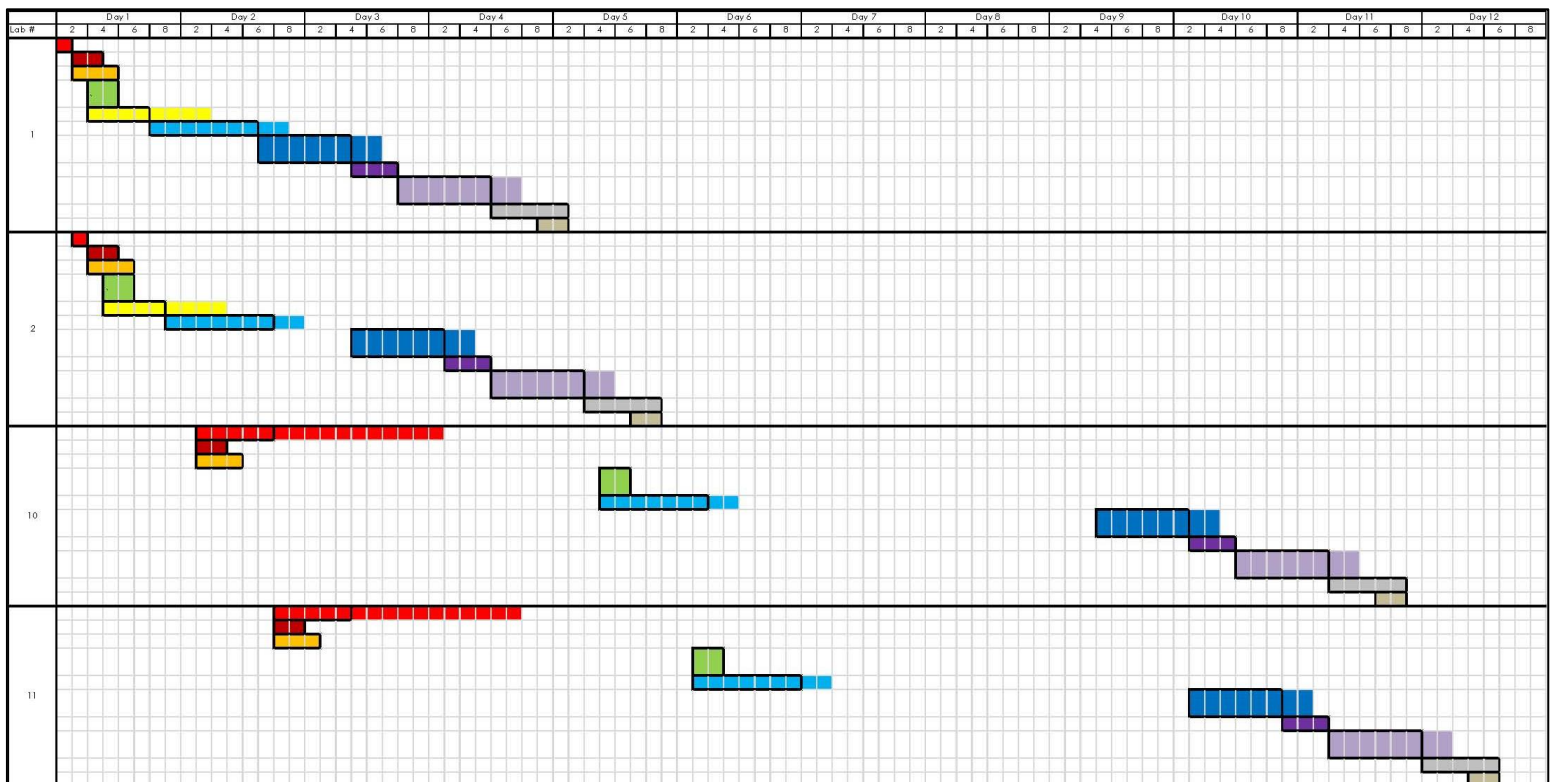


Figure 13. SIPS 2, Labs 1 and 2 on the first floor and Labs 10 and 11 on the second floor.

The crew for this schedule is not near as much as it was for schedule one. With the multiple crews only being for the activities "Layout/Rough-in" and "Hang Trunk Lines" on the first floor and "Hang Trunk Lines" for the second floor, the number of crews becomes 32 and 30, respectively.

The final schedule attempt made was a combination of SIPS attempts one and two. There were still multiple crews, but it still was only on activities "Layout/Rough-in" and "Hang Trunk Lines" on the first floor and "Hang Trunk Lines" for the second floor. In order for a Finish Start relationship to work while trying to reduce the schedule further, crew sizes needed to be adjusted. The activities "Install Medium Pressure Branch" and "Install Low Pressure Branch" were the next longest durations at eight hours per lab. There were originally three crew members on each of these activities. The first two attempts had the crew sizes of four crew members; however this attempt had these activities having five crew members. This crew size cuts the hours per lab in half for those activities on both floors. The total crew size for the first floor was 34 crew members per lab and 32 for the second floor per lab, which is less than both previous schedule attempts. **Figure 14** shows how this new factor affects the schedule. All activities were Finish Start, except for those activities that were to be performed concurrently, as previously decided. There was also float left on this SIPS to compensate for the learning curve and any overlapping needed. This schedule ends on Day 13 in the first hour of

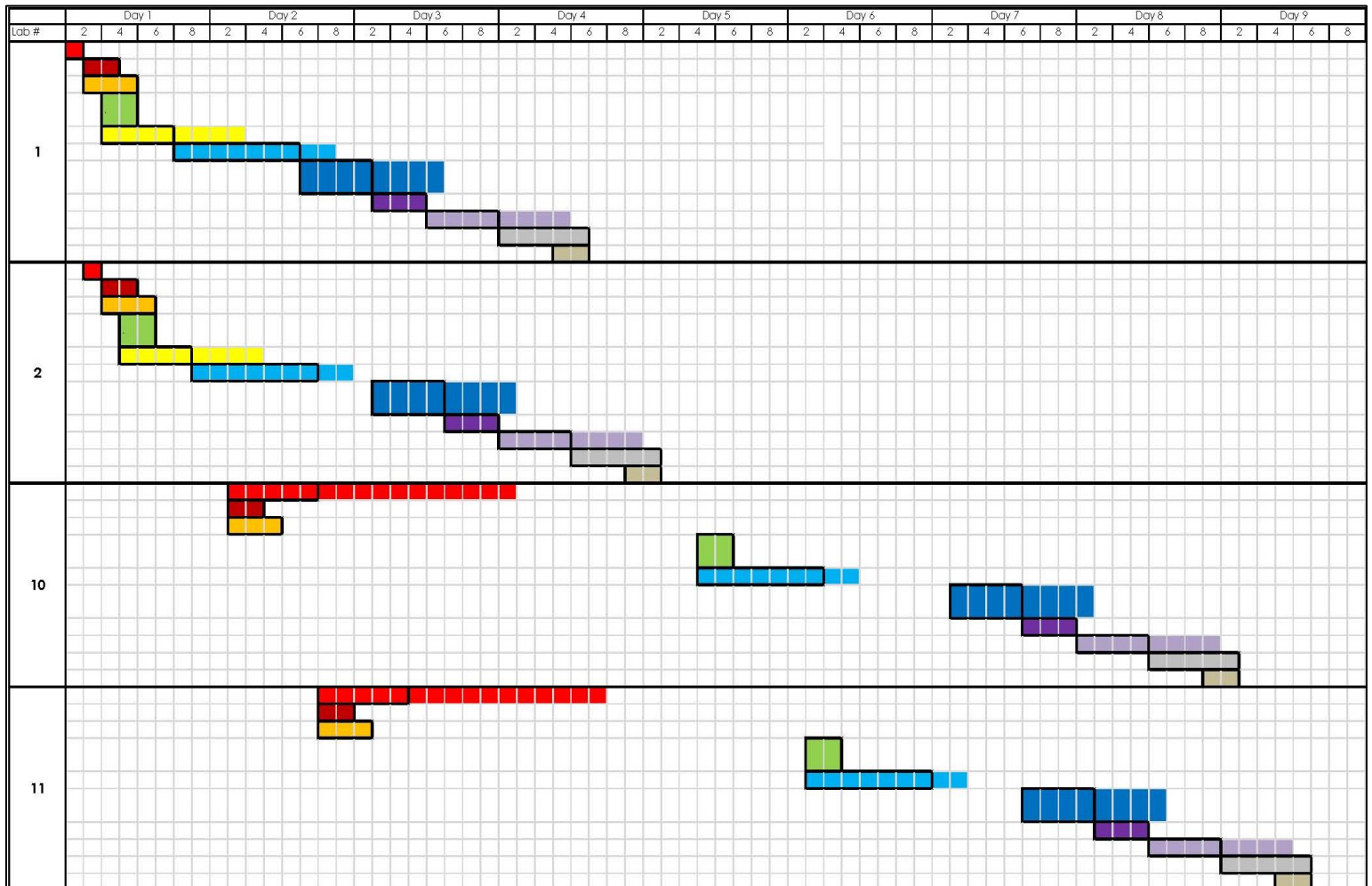


Figure 14. SIPS 3, Labs 1 and 2 on the first floor and Labs 10 and 11 on the second floor.

the day. Even though this is not an ideal time to end, with all the float available, the last lab could be completed at the end of Day 12.

A detailed breakdown of labs 1 and 10 are shown in **Figure 15**. These are broken down into fifteen minute intervals in order to show how much into an hour the activity goes. This also makes the durations more precise.

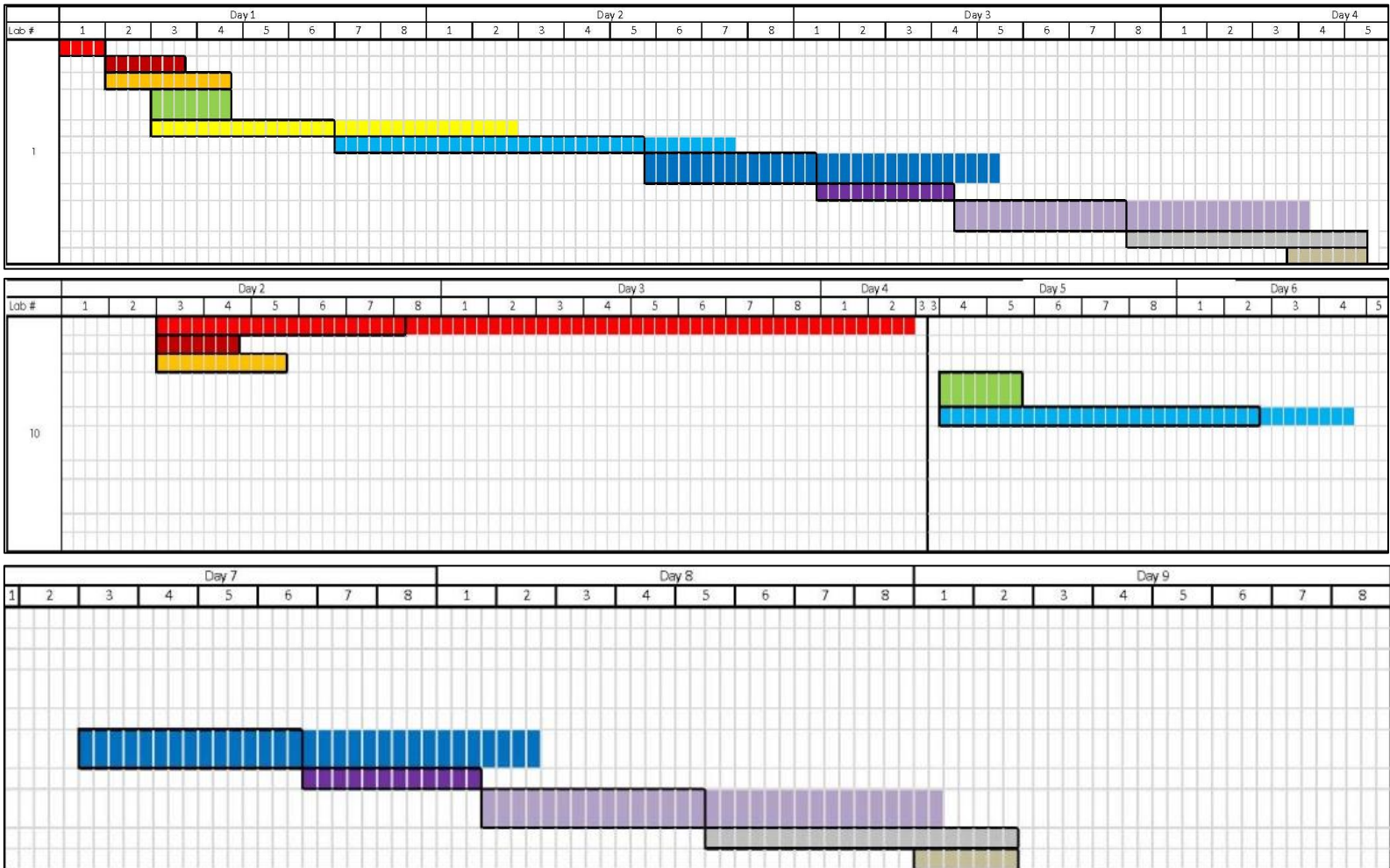


Figure 15. Detailed SIPS of Labs 1 and 10.

All full SIPS options can be found in Appendix G

Conclusion

In order to make a proper conclusion, a cost analysis needed to be performed to see how the change in schedule would affect labor costs. According to the Department of Labor, Licensing and Regulation, the hourly prevailing wage for a sheet metal worker is \$39.93. Using this number, the total cost for each schedule was able to be calculated. Below in **Table 2** is a cost break down of the cost of the Original SIPS and the other SIPS.

As you can see, the total for the Original SIPS was \$829,703. The closest SIPS to this was SIPS 3 at \$896,924.

| Schedule 1st | Crew/Lab | Hourly Rate | Hours/lab | Total Cost/lab | Total cost |
|--------------|----------|-------------|-----------|----------------|-------------|
| Original | 22 | \$39.93 | 50.22 | 44,116 | \$397,046 |
| SIPS 1 | 48 | \$39.93 | 40.00 | 76,666 | \$689,990 |
| SIPS 2 | 32 | \$39.93 | 40.00 | 51,110 | \$459,994 |
| SIPS 3 | 34 | \$39.93 | 37.60 | 51,047 | \$459,419 |
| Schedule 2nd | Crew/Lab | Hourly Rate | Hours/lab | Total Cost/lab | Total cost |
| Original | 21 | \$39.93 | 57.33 | 48,073 | \$432,656 |
| SIPS 1 | 44 | \$39.93 | 40.44 | 71,050 | \$639,449 |
| SIPS 2 | 32 | \$39.93 | 40.44 | 51,673 | \$465,054 |
| SIPS 3 | 32 | \$39.93 | 38.04 | 48,612 | \$437,505 |
| TOTAL | | | | | Total cost |
| Original | | | | | \$829,703 |
| SIPS 1 | | | | | \$1,329,439 |
| SIPS 2 | | | | | \$925,047 |
| SIPS 3 | | | | | \$896,924 |

Table 2. Cost breakdown of labor

All of these schedules are similar in that they all have multiple crews and they try to follow a Finish Start relationship. In SIPS one, the last activity on the second floor ends on Day 12 at the third hour of the day. This is a 21 day schedule reduction since the original schedule is 33 days. SIPS two has a 16 day schedule reduction since it ends at the end of Day 17. The last schedule ends on Day 13 in the first hour of the day, which is a 20 day schedule reduction.

The objective for this analysis is to reduce the schedule as much as possible. This would mean that SIPS One would be the best option. However, this option has a large number of crew members per lab which increases labor costs as shown in **Table 2**, above. SIPS Two is also labor intensive, while not reducing the schedule as much as the other two options. Therefore, with only a day difference, I believe SIPS Three is the best schedule. This is because it is the best ratio of schedule improvement to increases in necessary labor.

Figure 16 shows a comparison of the new duration with SIPS three and the original, less detailed duration of the HVAC schedule. As you can see, the original duration of the HVAC was 275 days. With SIPS three, the new duration is 254 days. This is a 21 day savings as calculated previously.

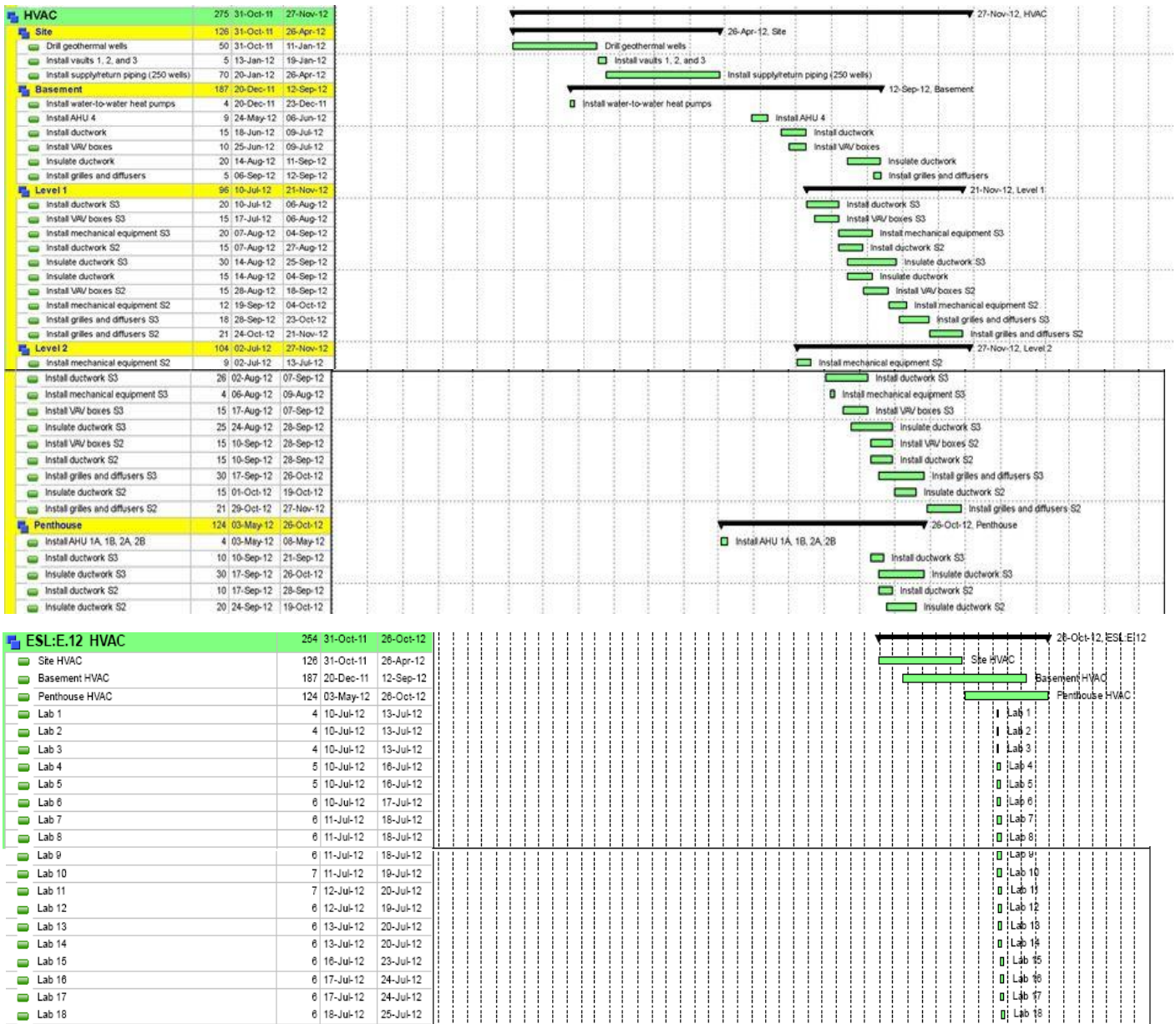


Figure 16. Comparison of original schedules (Top) vs. the SIP 3 implemented into the schedule (Bottom)

Analysis 3 – Façade Study

Problem Identification

The façade is very intricate with many different materials. These different materials mean multiple subcontractors and with multiple subcontractors, there are more contracts and more people to coordinate with. The different trades would be stacked on each other which could hinder productivity and quality. There are also a few materials that are very expensive. However, the architect's design intentions with this façade should not be compromised.

Research Goal

Without compromising the architect's intentions, different materials may improve on a few different aspects of the façade. The materials may be more cost effective or they might be easier to install resulting in a faster completion time. Another possibility would be to use fewer materials that are more similar in composition. This would mean fewer subcontractors and with fewer subcontractors, there could be in fewer problems with coordination. Along with the façade study, an architectural breadth and a mechanical breadth will be performed. The architectural breadth will discuss the redesign, installation, and fabrication sequence of this new material. The mechanical breadth will ensure that the new material does not affect the insulation properties through the use of R-values and that there is no condensation in the wall system.

Solution Method

- Contact the architect in order to determine what their intent was for the façade
- Research different materials that still meet the architects intentions
 - a. Research the function of the materials
- Perform a square foot estimate to determine cost difference of new the façade verse the current façade
- Critique the study to determine if this alternate façade is an improvement over the current façade

Background Research

The main façade materials are: brick veneer, corrugated metal panels, composite metal panels, fiber cement siding, and a curtain wall system. Between the façade and the whole exterior skin, there are 47 different materials. The exterior skin is very complex and it took a while to solve problems concerning it. There were many subcontractors involved in the coordination meeting that went into solving these problems. The main materials of the exterior skin are: 4" insulated metal panels, 6" cold form metal framing, and metal studs. These materials, along with others, made the building structurally sound. The four inch insulated metal panels were suppose to be vertical, however for this construction, they turned it on its side and it sealed the structure. It made the

building weather resistant. It was also a good material to work with according to the architect. The exterior skin made it so the façade materials acted only as a rain screen.

The Materials

There are multiple different materials on each façade elevation. The main ones are: brick veneer, corrugated metal panels, composite metal panels, fiber cement siding, louvers, and a curtain wall system, as shown in **Figure 17** below. However, for this analysis, the curtain wall system will not be considered. None of the materials being discussed in this analysis serve a structural purpose; they are just considered a rain screen.

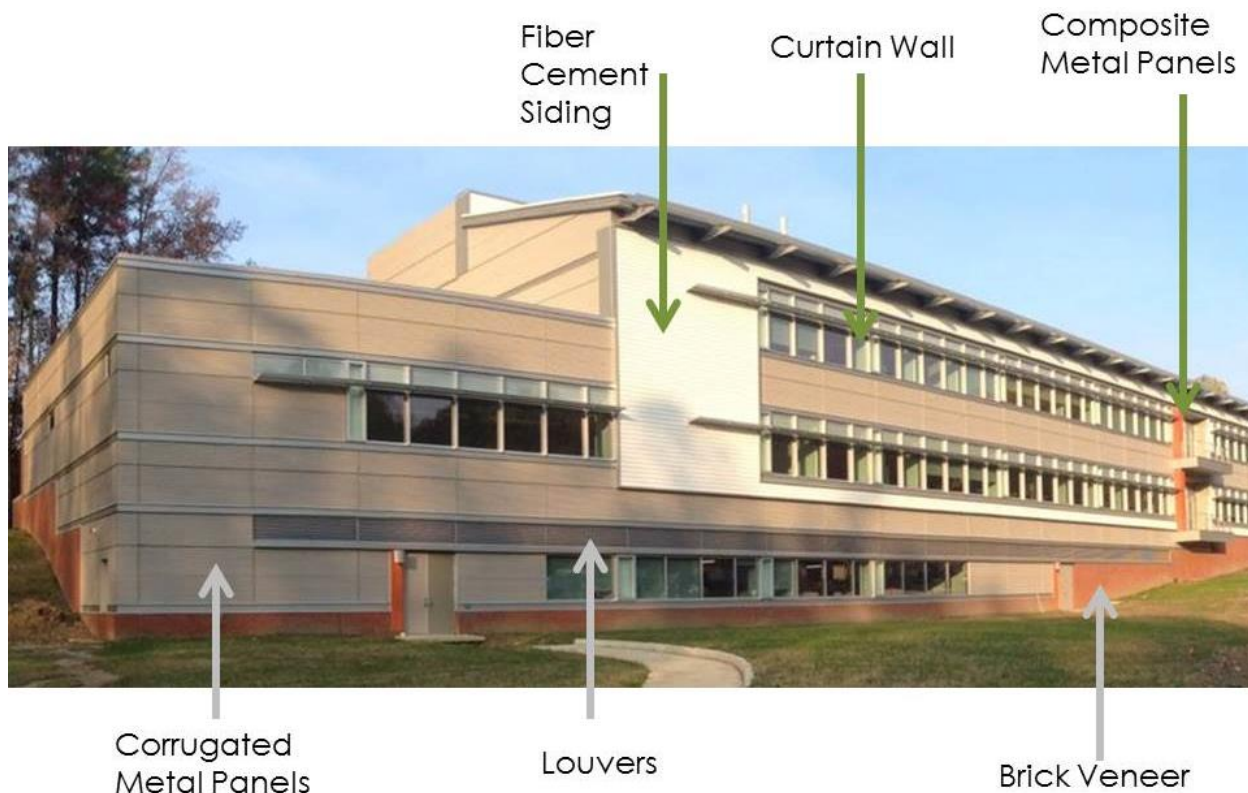


Figure 17. Labeled façade materials. (Image courtesy of Hensel Phelps)

| Expansion | | | | | | |
|-----------|------------|--------------------|---------------------|---------|--------------|----------------------|
| Elevation | Corrugated | Composite (orange) | Fiber Cement Siding | Louvers | Brick Veneer | Total Square Footage |
| North | 2,307 | 0 | 992 | 0 | 818 | 4,117 |
| South | 14,769 | 2,412 | 8,146 | 1,833 | 5,737 | 32,897 |
| East | 490 | 0 | 0 | 0 | 0 | 490 |
| West | 3,846 | 0 | 0 | 0 | 959 | 4,805 |
| Total | 19,105 | 2,412 | 9,138 | 1,833 | 7,514 | 40,002 |

Table 3. Current square footage of the façade materials

Table 3 above shows the current square footages on phase one of the building. As you can see, the main façade is on the south side. This is because the rest of the façade is going to be renovated in phase two, which is not included in the scope of this thesis.

Brick Veneer

Brick veneer has many good benefits other than aesthetically pleasing. Since there is just one layer of brick, it is not very difficult to install. However, the level of difficulty can depend on the type of brick and what the pattern is on the building. Installation can also be performed any time after the exterior skin is constructed. The single layer of brick also makes it more affordable than a brick that is integral to the structural system. There is a two inch air cavity between the brick veneer and the building that helps prevent moisture from

getting inside the wall and the building. This air cavity acts as insulation along with the four inch rigid insulation, which is especially beneficial since the brick is mainly exposed at the basement level. The majority of the brick was on the south side. There was 5,737 square feet on the south side, 959 square feet and 818 square feet on the west and north sides, respectively. This

construction is shown in **Figure 18**.

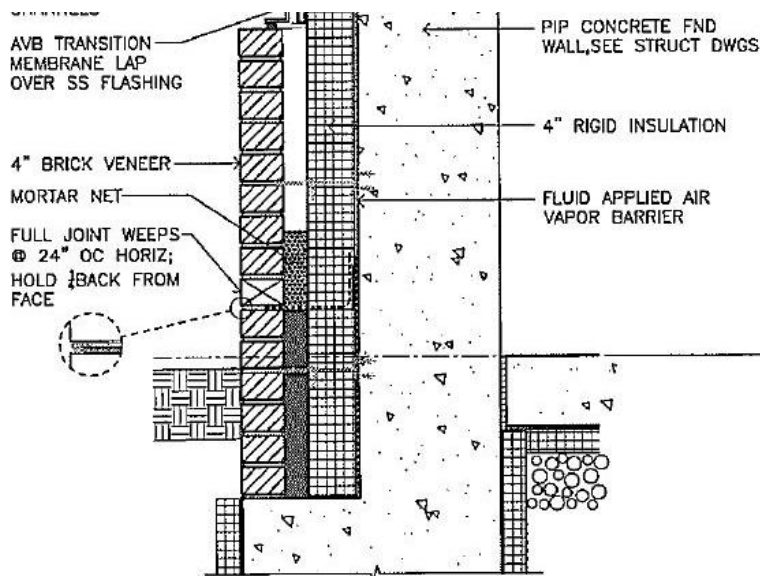


Figure 18. Brick Veneer section

Corrugated Metal Panels



Figure 19. Corrugated metal panels

The corrugated metal panels are on all sides of the building covering about 19,000 square feet. There is about 14,700 square feet on just the south façade. This material is versatile and easily installed. It can be installed horizontally or vertically, but for this project it was installed horizontally as shown in **Figure 19**. It is flexible and is ribbed with different sizes and shapes of ribs. This is to accommodate whatever aesthetic look the architect is aiming for. On the Environmental

Studies Lab: Expansion, the ribs are rounded with $\frac{3}{4}$ inch spacing. The panels are stainless steel and are painted to match the panel bonded washer.

Composite Metal Panels

The composite metal panels on the Environmental Studies Lab: Expansion are orange and serve as an accent panel. They are only at the balconies and beside the main entrance. Since the panels only accent key areas of the building, they only cover 2,412 square feet of the façade. The panels on this project are aluminum; however they can

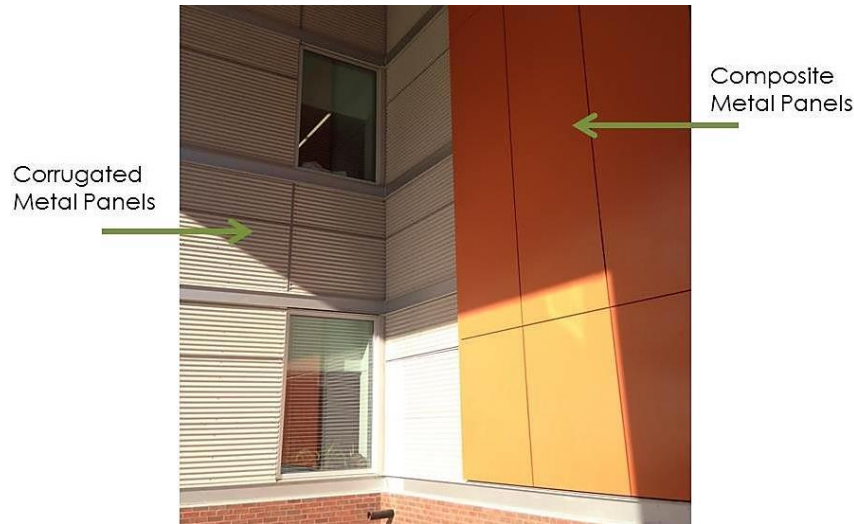


Figure 20. Composite metal panels

be many different types of materials such as copper, zinc, or stainless steel. The manufacturer for this project for these panels was Centria. After speaking with a representative from there, he informed me that they are a very popular material because of their aesthetics. Although this may be true, they are expensive and

challenging to install. They have a smooth appearance which makes them look more sophisticated. **Figure 20** shows the corrugated metal panels and the orange composite metal panels at the main entrance.

Fiber Cement Siding

Fiber cement siding was a material that was different than the rest of the materials on this building. This material was added to tie in the administration building located next to the Environmental Studies Lab: Expansion. Fiber cement siding is made out of cement, sand, and cellulose fiber and then mixed and pressed with wood grain or stucco. This material is easy to install because it can be cut onsite and nailed or fastened. The manufacturer was James Hardie. After it is installed there is little-to-no maintenance required, due to a typical 50 year warranty for this material. This siding can be painted any color because the paint bonds well with the material.



Figure 21. Fiber Cement Siding.
(Image courtesy of Hensel Phelps)

For this building, white was chosen because it matches the administration building next door. **Figure 21** shows its contrast to the rest of the building. The material covers 9,138 square feet, since its purpose is to contrast the rest of the building and tie in the other building on site.

Louvers

The louvers are not a big part of the façade, but for this analysis, they will be considered. There is only 1,800 square feet of louvers on the south façade. These louvers were resistant when installing. The only working louver on the south façade is above the basement doors. The rest of the louvers have flat panel installed behind them in order to give the appearance of working louvers, to maintain the aesthetic, without having them actually work. These louvers have little gutters on each blade that collect water and prevent it from going on the inside of the louver.

The main goal of this thesis is to reduce the schedule so for this analysis, I will start by trying to reduce the amount of materials and in turn reducing the amount of subcontractors. With the current materials, there are three different subcontractors. The more subcontractors there are, the more coordination issues, workers, safety concerns, and contracts there are. Coordination issues can delay that part of a project by a little or a lot depending on how big the issue is. With more workers, there is more training and more of a learning curve to get over. Safety is always a concern on every project. When there are different subcontractors working around one another, the issue becomes being aware of your surroundings. Safety can affect the schedule as well if there is an accident. Contracts can be more of a money concern rather than a schedule concern. However, it does take time to negotiate, create, review, and sign a contract.

Architectural Breadth

As previously mentioned with the façade study, there will be a redesign of the materials on the Environmental Studies Lab: Expansion. This architectural breadth will provide the research and explanation of the redesign as well as how each material is installed and the fabrication sequence. The goal for this breadth is to justify why this redesign is a more efficient design for the Environmental Studies Lab: Expansion. The redesign will discuss the aesthetics of the new design. The fastening of each material will explore how each material is installed and what is the easiest method. The fabrication sequence is the last research item that will be considered for this breadth.

The Redesign

Considerations

When considering the redesign of the façade, it was necessary to talk to the architect to understand why certain materials were chosen. First of all, none of these materials needed to have a structural function because the exterior skin was structurally sound without the façade materials. The metal wrap was a four inch panel that is usually constructed vertically, was turned on its side and wrapped around the building. This sealed the exterior skin and made it weather resistant. The façade itself just acts a rain screen. Is this true for brick veneer? The composite metal panels were part of the façade to act as an accent material. The architect wanted a smooth, high-tech look and this material fit that profile. The corrugated metal panels were a good metal material that kept the smooth look like the composite panels while incorporating a similar look to the fiber cement siding. The fiber cement siding was to tie into the surrounding building, as previously mentioned. The fiber cement siding was also a local material which helped with LEED. The brick veneer was incorporated in order to tie into the onsite court yard that was also made of brick. The louvers were needed over the doors so the fake louvers were extended out in order to make it not look out of place.

The architect recommended possibly changing the brick and the louvers to a different material. His recommendations were possibly changing the brick to a ground face block to match the high gloss finish that the metals have. It was also suggested to change it to cast in place concrete. For the fake louvers, he suggested to just use a metal panel or some linear metal material. After taking his suggestions into consideration, and researching each of the materials and manufacturers, I had some ideas of my own.

First Change

The material that seemed to be the easiest and quickest to install was the fiber cement siding (this will be shown later in the Production and Cost section of Analysis 3). The first change to make would be to replace the composite metal panels with fiber cement siding. The first thing to do was to make sure there was a fiber cement siding

manufacturer that could be manufactured to be similar to that material. James Hardie produces this type of vertical panel which is convenient since the siding is the same manufacturer. In **Figure 22**, you can see an example from the James Hardie projects beside the composite metal panels on the Environmental Studies Lab: Expansion.

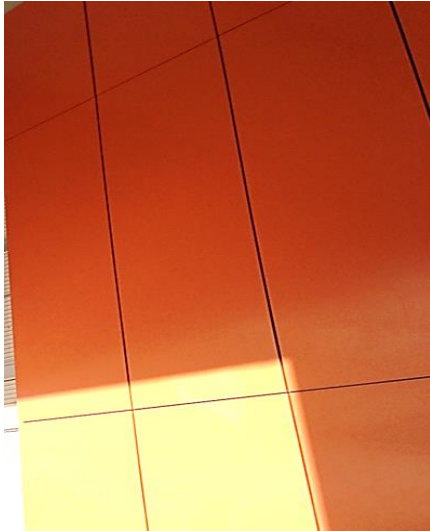


Figure 22. Current composite metal panels vs. James Hardie vertical fiber cement siding (Image courtesy of the James Hardie website)

The James Hardie vertical panels come in many different colors, so it would be easy to find an accent color appropriate for this building. The smooth texture is the closest to the fabricated metal look of the styles of panels that are available. There would be a change in aesthetics since this is a different material, however from a distance, which is how most of this material will be perceived, it is difficult to tell the difference. The James Hardie vertical panels come in sections of 4 foot by 10 foot but the sizes needed for the project were 5 foot and 20 foot sections. The panels will have to be cut, but since they are easy to cut onsite, this will not be a long and difficult process.

Second Change

Since fiber cement siding was the easiest to manage and install, it made sense to try to replace the material that had the most square footage on the façade, which was corrugated metal panels. This material was more difficult to find something similar to because of the ribs instead of overlapping panels. James Hardie was found to have something that could work as a replacement for the corrugate metal panels, shown in **Figure 23**. The Smooth Lap Siding by James Hardie has similar features to the vertical panels that would replace the composite



Figure 23. Corrugated metal panel. (Image courtesy of Centria website)

metal panels. The finish would not be the glossy metal look, however it will still be smooth and tie into the rest of the building. James Hardie also offers different colors for the siding therefore, it would be easy to find a similar color to what is already being used. The fiber cement siding exposes about seven inches of itself, which is the maximum. However, for the fiber cement siding replacing the corrugated metal panels, the exposure can be at four inches minimum. The rib length for each rib is 2.5 inches, which is half of what the fiber cement siding minimum would be. This is an obvious aesthetic difference that will be similar to the ribs from the original corrugated metal panels.

Third Change

The louvers that were not positioned over the doors are fake louvers meaning they have a flat metal panel behind them. They do not serve the same purpose that the actual louvers do. They were installed in order to keep the same look as the real louvers consistent. This look can still be maintained by replacing them with fiber cement siding or, as the architect suggested, replace them with a flat metal panel. If they are replaced by fiber cement siding, the look will be more consistent with the real louvers. The exposure of the real louvers are four inches and the fiber cement siding's minimum amount of exposure for a panel is four inches. This shows that they can have a similar look as shown in **Figure 24**.

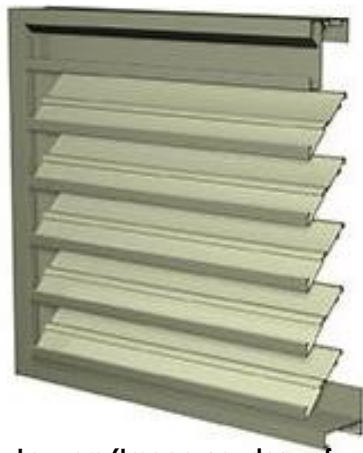


Figure 24. Louvers (Image courtesy of airolite website)

vs.



Fiber cement siding (Image courtesy of the James Hardie website)

Fourth Change

Changing the brick veneer to cast in place concrete aligns best with the architect's suggestion of changing the brick. Even though the brick was added to tie into the courtyard, concrete incorporates into the site as well. On the south-facing side of the building, there are concrete weir walls to help with the wet lands. These weir walls are connected to a concrete runnel which is connected to the building. By changing the material to concrete, the runnels and weir walls could look like they are an extension of

this wall. **Figure 25** shows a current section of the wall with the brick veneer verse a typical section of what the concrete wall could look like. By changing this material, it would get rid of a subcontractor rather than just change a subcontractor. Hensel Phelps self-performs concrete so they could place the wall themselves. As you can see, there will also be less material since it is just concrete, insulation, and drywall that is furred out.

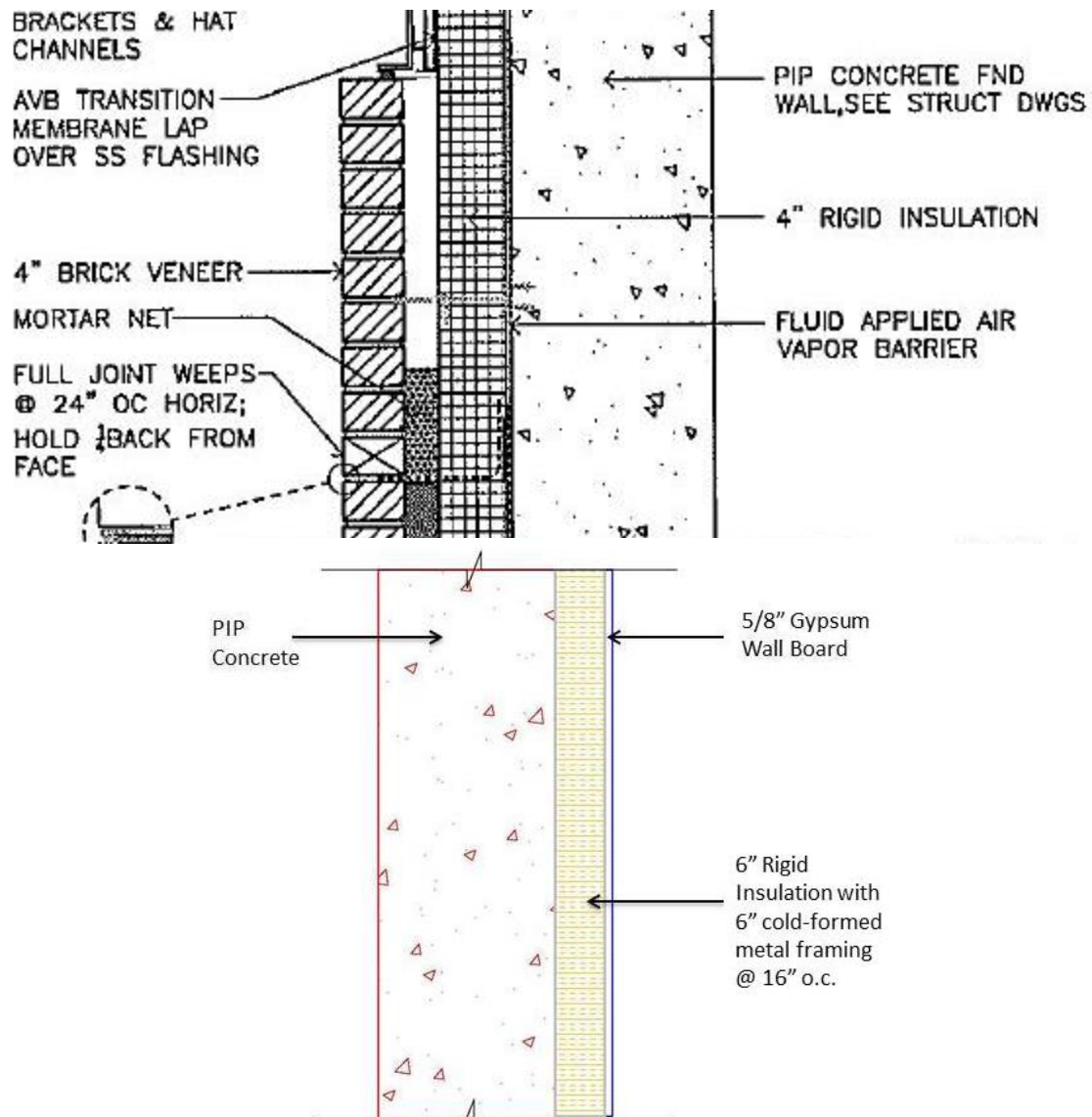


Figure 25. Brick veneer section vs. concrete redesign (not to scale)

Total Changes

Below shows the comparison on the actual façade versus the model of the change in façade in **Figure 26**. As you can see, the panels are different sizes so there is a distinct difference. Even though this is just a model and the definitive lines are not as visible, it is a good representation of what the material could look like. However, the model does demonstrate how the concrete façade ties into the site.

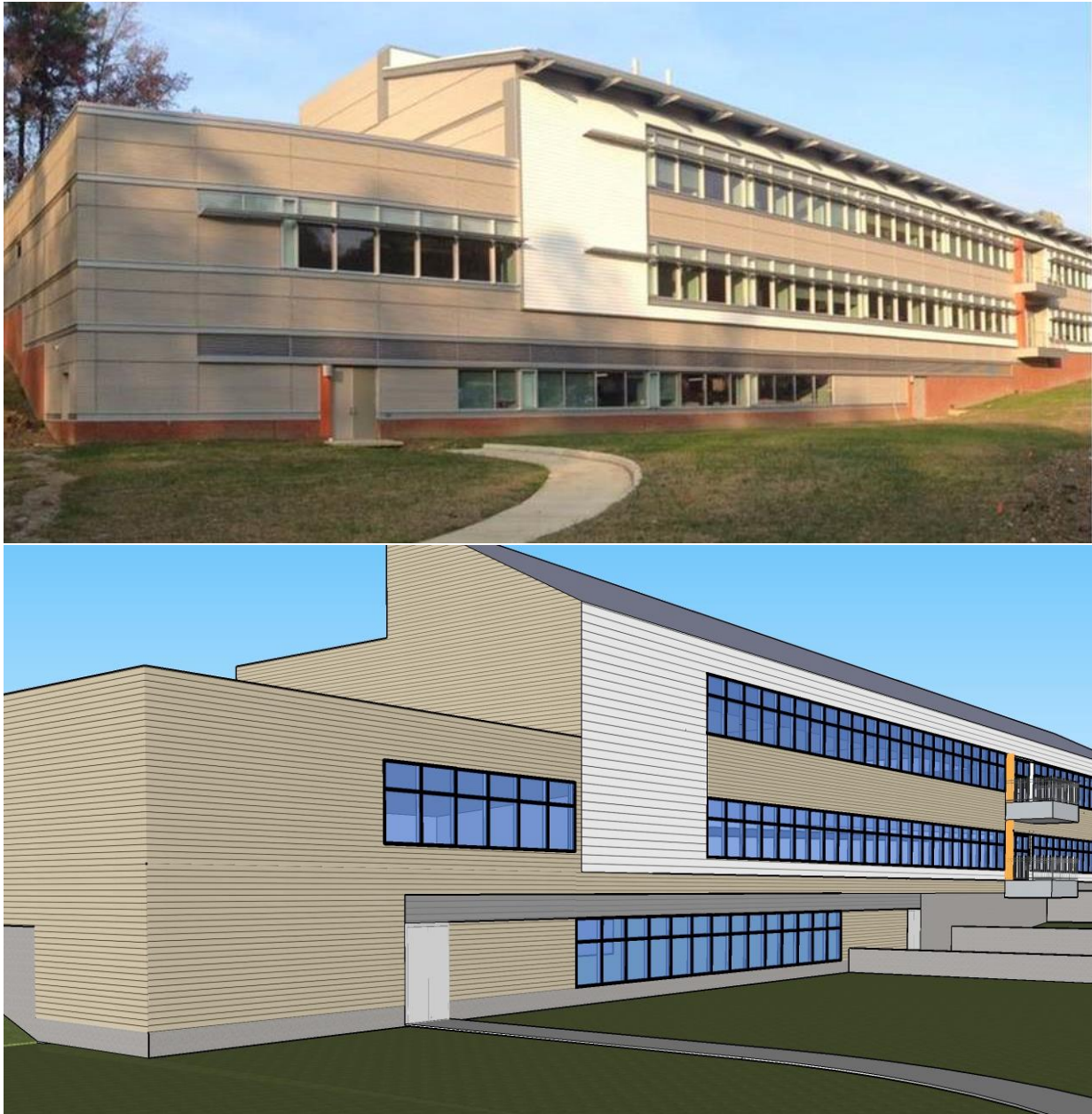


Figure 26. Actual façade (Top) vs. Model of proposed changes (Bottom)

Areas where these changes were made are shown in Appendix H

Fastening

The composite metal panels are the most difficult to install. This is verified from the calculations previously mentioned where the composite metal panels have 161 square feet installed per day. These panels are mounted on metal zee's over top of the corrugated metal panels. An example of what the zee clips look like is shown in **Figure 27** (sizes shown are not for this project).

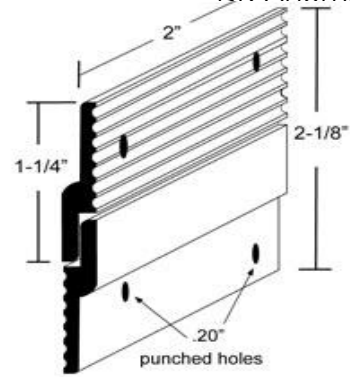


Figure 27. Zee clips (Image courtesy of eagle-aluminum)

The corrugated metal panels are easier to install than the composite metal panels because they are installed at 940 square feet per day. They are installed over the cold-formed metal framing and cover about 35 inches. Each panel's edges lap the adjacent panel and fasten to each

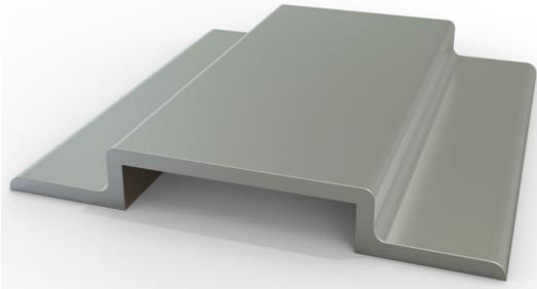


Figure 28. Hat channels (Image courtesy of eagle-aluminum)

other using the exposed fasteners. Since this is a coastal area, the fasteners are stainless-steel so they will not rust. The fasteners should be screwed into predrilled holes and connected the cold-formed metal framing behind it. There are also 3/4" vertical hat channels placed two feet on center. An example of a hat channel is shown in **Figure 28**.

The louvers are not that complex to fasten and install. They are fastened by Philip's flathead stainless-steel screws. The louvers are welded to the frames with a fillet weld. The wall behind them is different than the rest of the structure. There is three inch rigid insulation against a metal stud and gypsum wall board, as shown in **Figure 29**. The backing for the fake louvers are attached with sheet metal screws for a simple installation.

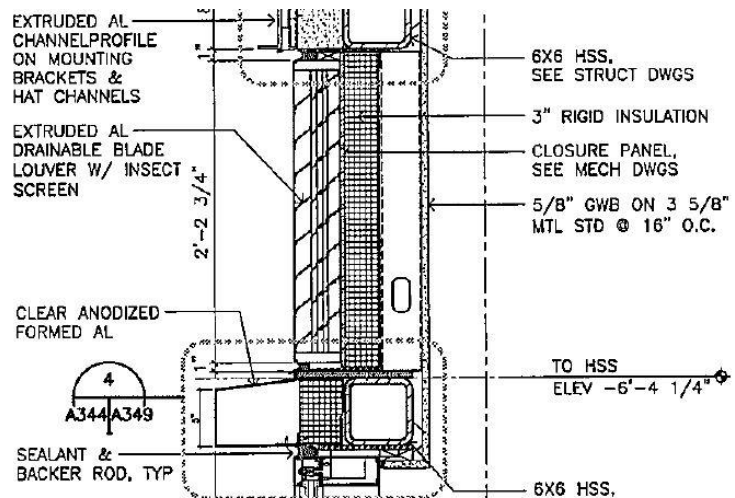


Figure 29. Louver connection detail

All of these materials will be replaced by fiber cement siding. Fiber cement siding was the quickest to install at 979 square feet per day, as previously mentioned. Unlike the rest of the structure, the fiber cement siding is attached to a 3/4" sheet of plywood with

hot dipped galvanized fasteners. These fasteners are nails that are every 24 inches on center. These fasteners should be long enough to penetrate one inch into the substrate, as shown in **Figure 30**. It is recommended that a pneumatic fastening tool is used in order for the nail to be flush with the siding. There is even a nail line shown on the board to make installation easier. The plywood that the fiber cement siding is fastened to, is anchored to the cold form framing at 16 inches on center. Since there is plywood behind this material in order to fasten it, it would have to be on just about the entire building when fiber cement siding replaces the other building materials.

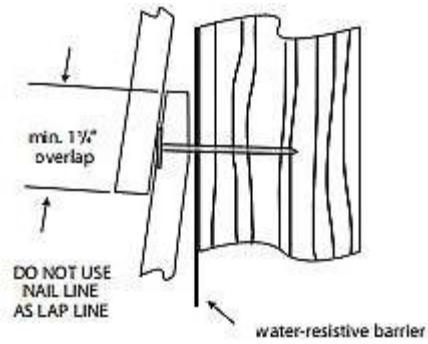


Figure 30. Fiber cement siding fastening
(Image courtesy of James Hardie website)

The brick veneer does not serve a structural function so it is just fastened to the cast in place concrete behind it. The difficult thing about installing brick is the weather conditions have to be right. If it is too hot, there is a code to follow as well as if it is too cold. The bricks can also only be installed when they are dry. In the area of the Environmental Studies Lab: Expansion, it rains a lot so it was difficult to find a good time of when the masons could lay the brick.

For this project, the brick needs to be laid in a running bond configuration. There is a two inch cavity between the brick veneer and the insulation that cannot have any mortar in it. That's why there is a mortar net in between the two materials. The brick is anchored into place with anchor ties. The ties are secured with dovetail anchors. Shown in **Figure 31**, the dovetail is locked into place in the cast in place concrete, which then secures the anchor ties. The anchor ties rest on the bricks but are then mortared in. These ties should be embedded every 16 inches on center for both the vertical and horizontal directions.

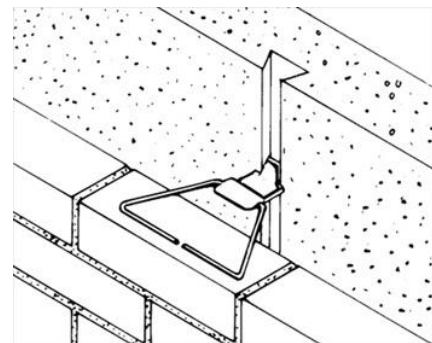


Figure 31. Brick dovetail connection
(Image courtesy of mason contractors)

The concrete that will replace the brick veneer is just cast in place concrete. The new design will consist of concrete, rigid insulation, and then drywall furred out by 6" metal studs. The concrete will be formed, reinforced, and poured by Hensel Phelps.

Fabrication

Another part of this architectural breadth is fabrication. It is important to consider the fabrication of the items and how long it takes to do this.

The composite metal panels come in sizes of up to 180 inches in length and 60 inches in width. They have a 20 year warranty to them as well. The face of the composite metal

panels are two sheets of aluminum about 0.032 inches thick. These two sheets are bonded to reaction injected polymeric core. They are also fabricated with dry seals, horizontal joinery, and extruded aluminum stiffeners. Between fabrication and delivery, composite metal panels will take 70 days to arrive on site.

The corrugated metal panels are factory formed as well. For the Environmental Studies Lab: Expansion, the corrugated spacing is about 2.5 inches. When it is factory formed, it is ensured that there will be no condensation on the interior or the panels as well as in the joints. The joints are fabricated with the gaskets in place to provide a tight seal. This tight seal will help with making it weather tight as well as reducing the metal to metal contact. The metal to metal contact is not wanted because there would be too much noise if there was contact. The warranty and the fabrication and delivery are the same as the composite metal panels: 20 years and 70 days respectively.

The louvers are factory assembled, however they can be disassembled for delivery. Each of the fins are fabricated to be four inches deep. The backing for the fake louvers is an inch thick. There are mullions along the edge of the louvers. When these mullions get too long, there are interlocking splits in order to connect them. The louvers take 30 days for fabrication and delivery.

There is not much to the fiber cement siding since it is stick built on the building. There is only a delivery time, however since this is a local material, it was delivered in a few days. Since fiber cement siding is installed in pieces, it will save 170 days of fabrication and delivery by replacing the materials. It is important to consider that the material supplier might not have all this material in the warehouse since 32,488 square feet of the fiber cement siding would be needed.

There was no fabrication of brick since it was laid on site, it was only delivery. However, the brick needed to be stored in a dry location off of the ground so it would not get wet. The brick could only be laid if it was dry and with the correct weather conditions, as previously mentioned. The only fabrication that would have needed to be done would be cutting the brick for it to fit in a certain location, which would have been done on site. The mortar arrives on the site premixed, so no additional steps were required. The delivery day for this material was 20 days.

By replacing the brick with concrete, a lot of time would be saved. With cast in place concrete, an order is called to a concrete company who delivers and pours the concrete. The strength (in psi), mixture requirements, and a delivery date are certain details the concrete company needs to know. When they show up on site, there is a slump test performed and a cylinder test to have on record. Then the concrete is poured that day. There will need to be time for the laborers to set the form and the rebar before the pour.

Conclusion

The changes to be made in analysis 3 are broken down in this architectural breadth. The redesign of the building will consist of changing the composite metal panels, corrugated metal panels, and louvers to fiber cement siding. This fiber cement siding will not have the smooth, factory formed metal look, however it will be similar enough that the difference is only recognizable close up. The concrete that replaces the brick veneer will help tie into the actual site, which could have a better appearance and make more sense. Both of these replacement materials are quicker and easier to install as well as get onto the site. By changing the materials to fiber cement siding and concrete, the schedule would be affected in a positive way. **Figure 32** is another angle of the model of the proposed changes.

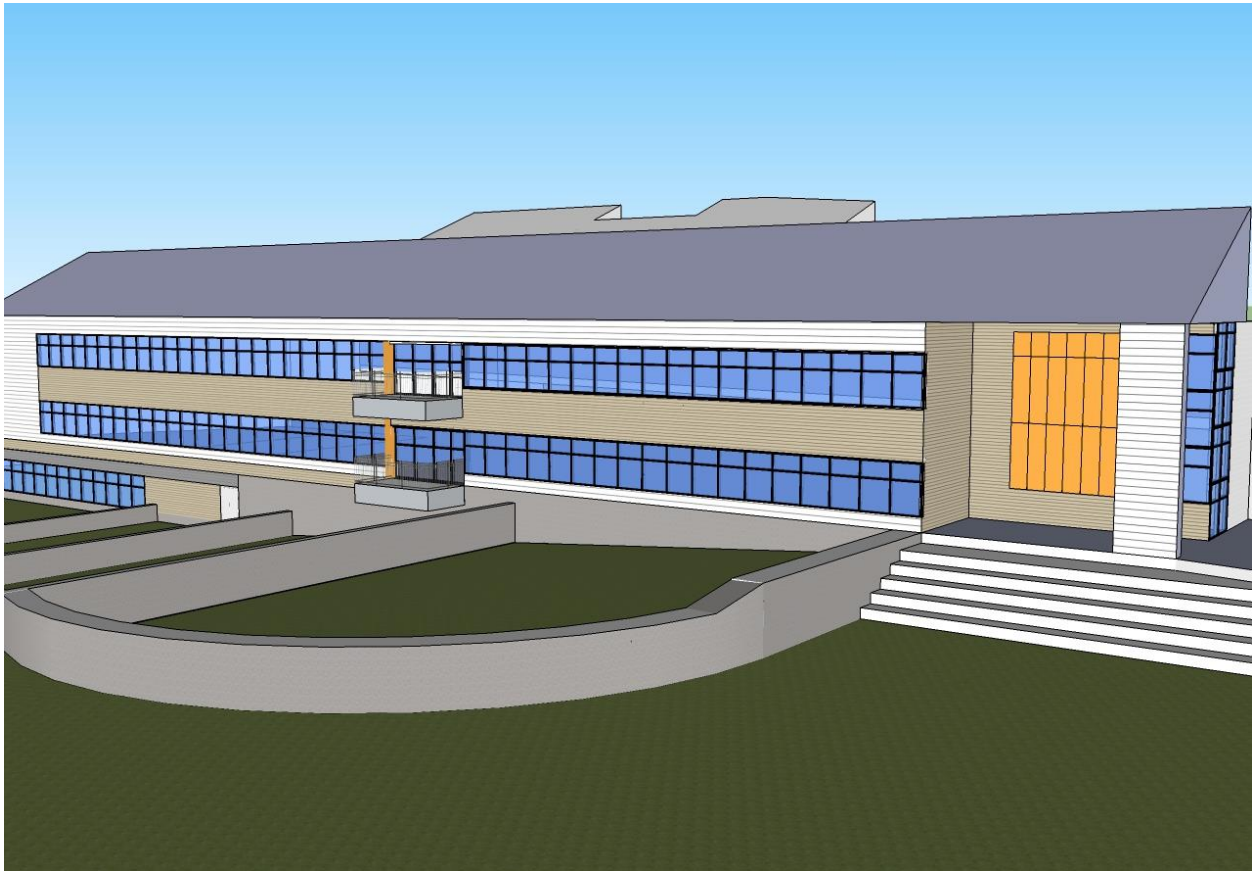


Figure 32. Model of proposed changes

Mechanical Breadth

Since analysis 3 and the architectural breadth were concerned with changing the materials of the façade, the mechanical breadth will verify that this will not change the R-value and condensation. The program IES Virtual Environment 2013 (IES) will be used in order to determine these values. In regards to condensation, if there is vapor pressure through the surface of the wall, it will be determined what needs to be done to prevent this. The R-value could be affected in a negative way and this program will determine that.

The R-value is dependent upon thickness. Therefore a thicker material has a greater R-value due to its ability to conduct and dissipate more heat through a greater length. The thicker wall also decreases conductance but increases resistance, which is a good thing.

IES Virtual Environment 2013

When using this program, there are a few things needed in order to make an accurate reading. The first thing needed is an average of the temperature both inside and outside of the building. Inside the building, it is recommended to be between 68 and 72 degrees Fahrenheit. It is important to design for the worst conditions in order to prevent designing a faulty system. According to weather.com, the average high of this area is 90 degrees while the average low is 29 degrees. Another thing that had to be known and inputted into the program was the materials. Since the R-values were being compared, both old and new materials were tested. For this area, the R-value is supposed to be an R-30. For this to be okay, the designers of the building likely used the ASHRAE Performance Rating Method (PRM). The PRM proves that the building consumes less energy than the ASHRAE 90.1 Baseline, which has the R-30 walls.

Since the building is a laboratory, the mechanical system is 100% outside air. Therefore, it can be assumed that there will be no humidity being recycled through the building because of the people. This means, between sensible heat and latent heat, sensible will increase, but only in the winter. With this building, the design for interior humidity should be 50%. According to the psychometric chart, the exterior humidity is 50% as well.

R-value and Condensation

In order to compare the R-values in IES, I needed to input all the materials from a data base. Some of the materials from the data base were not exact, however they were similar. The original materials selected include: corrugated metal panels, 4" insulated metal panels, 6" cold-formed metal frame, metal studs, and 5/8" gypsum wall board. It was assumed in this program that the corrugated metal panels were steel siding. After this was inputted, the thicknesses of the material were corrected and the condensation was graphed and the R-value was calculated. The R-value for this wall system is 35.64.

Shown in **Figure 33** is the condensation chart for summer condensation. The red line is nowhere near the blue line in this chart. When the red and blue line meet is where there is condensation.

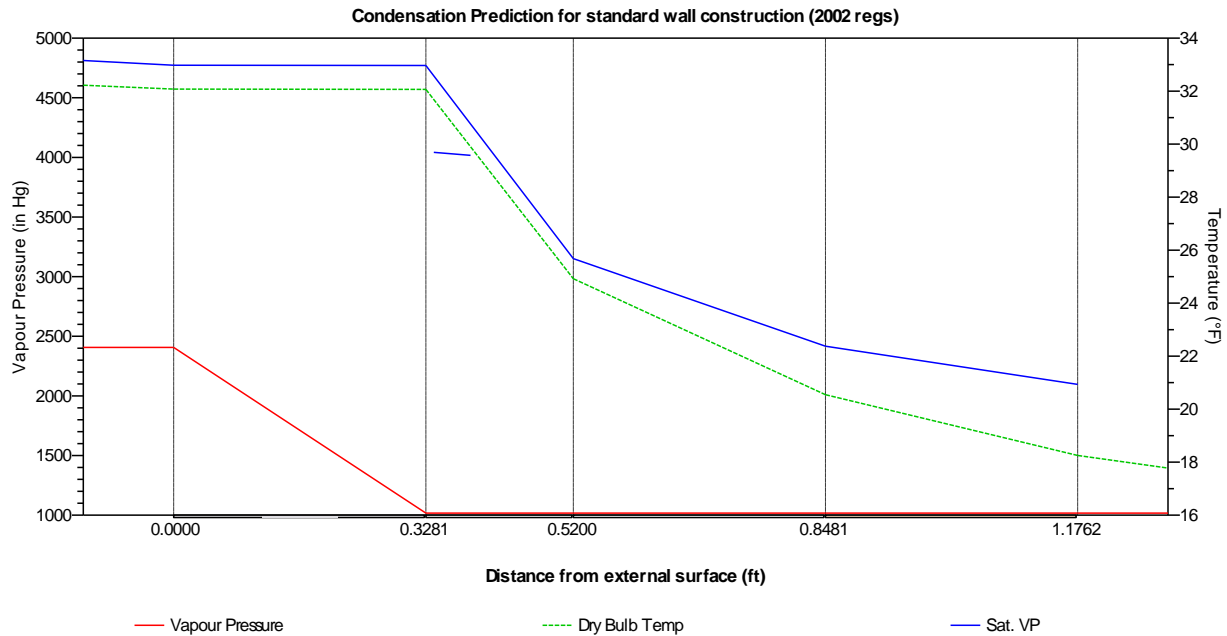


Figure 33. Original wall system condensation chart for the summer

When testing the new wall system, the only material that needed to be changed was the façade material. The materials for the new wall system were: fiber cement siding, 3/4" exterior grade plywood, 4" insulated metal panels, 6" cold-formed metal frame, metal studs, and 5/8" gypsum wall board. The thickness needed to be changed for this as well so once that was completed, the calculated R-value was 43.33. As mentioned before, the outside humidity would be 50% for the most part. The exterior humidity was adjusted to see how high it would get before condensation would start to form in the wall. It was discovered that at 99% relative humidity, the wall system is still good. In **Figure 34** it graphically shows that the condensation line does not meet the saturation line.

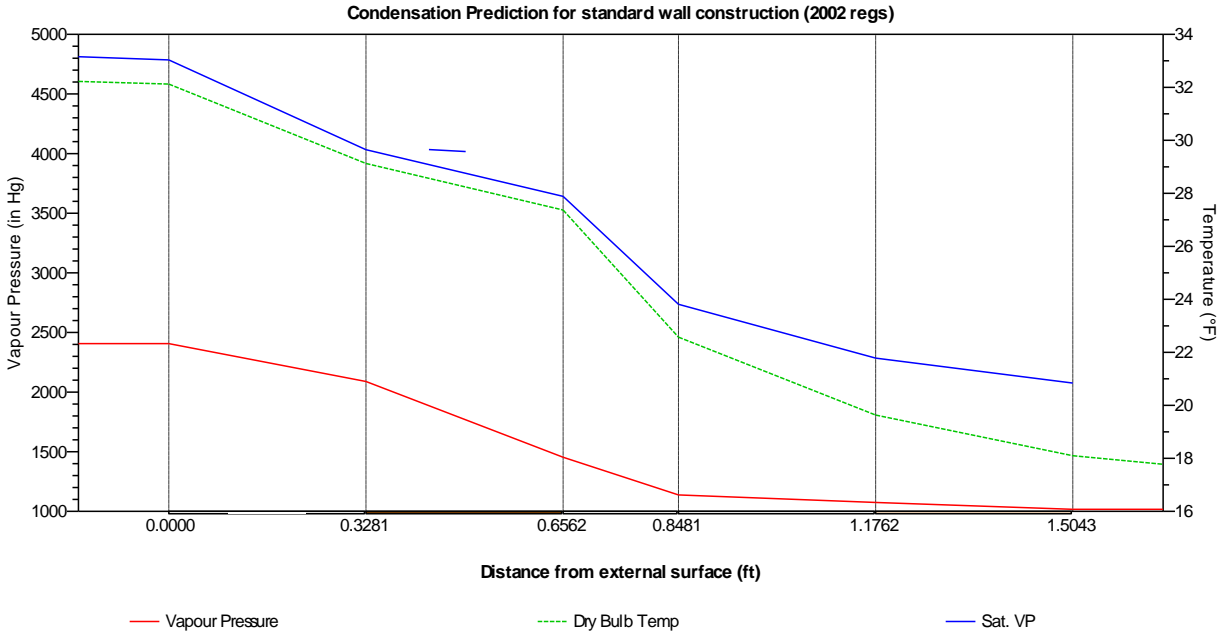


Figure 34. New wall system condensation chart for the summer

Since the winter is not humid in this area, there was not a whole lot of concern for condensation build up in the new wall system. The graphical representation is shown in **Figure 35**.

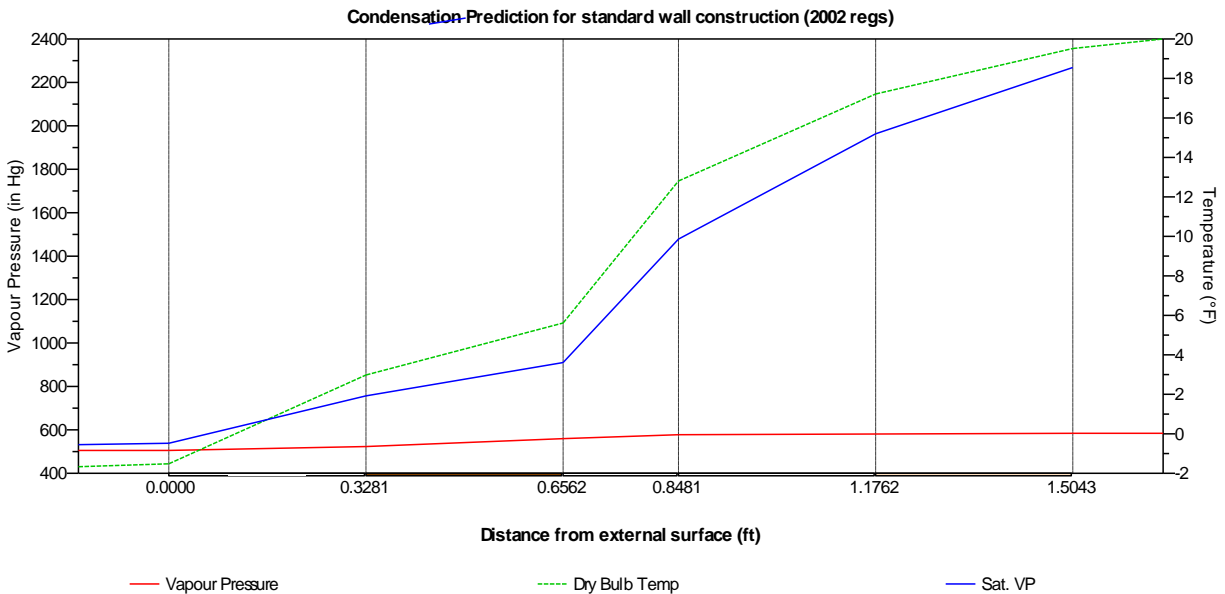


Figure 35. New wall system condensation chart for the winter

The last change that needed to be checked was the brick to concrete change. The composition of the new concrete wall is cast in place concrete, 6" rigid insulation with 6" metal studs @ 16" on center, and 5/8" gypsum wall board. The R-value for this was determined to be 31.68 in the summer. **Figure 36** shows the condensation chart for this condition.

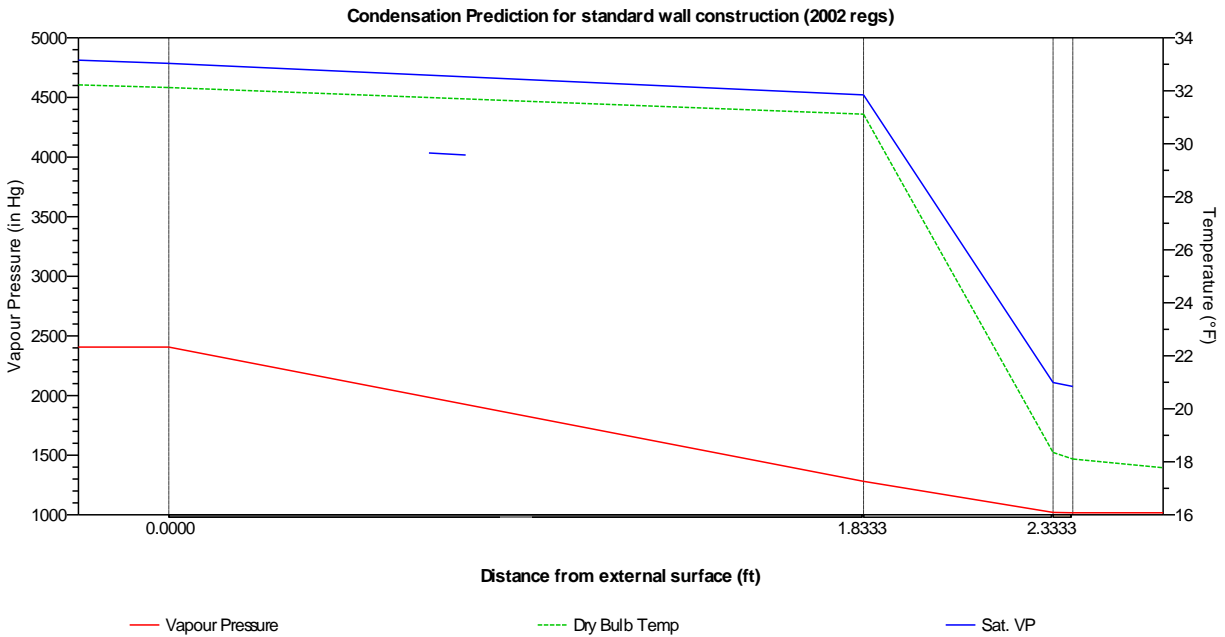


Figure 36. New concrete wall system condensation chart for the summer

Conclusion

The R-value for this region is supposed to be R-30 and after performing these simulations, it shows that the new construction is above the R-30 level. Overall the system is going to be very good to begin with because the 4" insulated metal panels already has an R-value of 26. The R-value for the new wall system makes quite a difference because of how much higher it is. Since fiber cement siding is not a metal, it is not as conductive which means that the R-value increases with this material. The new concrete wall also is acceptable with an R-value of 31.68. As far as condensation goes, all designs would not have a problem with vapor pressure. Therefore, the redesign meets the standards for the R-value and condensation requirements.

Production and Cost

Continuing analysis 3, production and cost effects were mentioned in the breadths that were integrated into this analysis. The original production and cost are shown in **Table 4**.

| Original Production and Cost | | | | | | |
|------------------------------|----------------|-----------------|---------------------------|-----------|-------------|------------|
| Material | Square Footage | Duration (Days) | Production Rate (\$F/Day) | Cost/Sqft | Cost/Day | Total Cost |
| Corrugated | 19,105 | 21 | 940 | \$15.00 | \$14,100.00 | \$296,100 |
| Composite | 2,412 | 15 | 161 | \$40.00 | \$6,440.00 | \$96,600 |
| Fiber Cement Siding | 9,138 | 10 | 979 | \$13.09 | \$12,815.11 | \$128,151 |
| Louvers | 1,833 | 5 | 367 | \$41.50 | \$15,230.50 | \$76,153 |
| Brick | 7,514 | 19 | 395 | \$23.00 | \$9,095.89 | \$172,822 |
| Total | 40,002 | 70 | 2,842 | | \$57,681.50 | \$769,826 |

Table 4. Original Production and Cost

The numbers in the table were determined by take-offs and by finding the item on the schedule to get the duration of each activity. The production rate was then found by taking the square footage found by the take-offs and dividing by the duration. The cost per square foot was gathered from contacting the vendors of each material. The louvers were the only material that was gathered from RS Means. From all this information, the cost per day and total cost was able to be determined. The total of these façade materials cost \$769,826.

The three changes made were to change all of the main façade materials to fiber cement siding. The same square footages and production rates were kept. To determine the durations this time, the square footage had to be divided by the production rate. The new durations are shown in **Table 5**.

| Fiber Cement Siding | | | | | | |
|---------------------|----------------|-----------------|---------------------------|-----------|-------------|------------|
| Material | Square Footage | Duration (Days) | Production Rate (\$F/Day) | Cost/Sqft | Cost/Day | Total Cost |
| Composite | 2,412 | 2 | 979 | \$13.09 | \$12,815.11 | \$31,573 |
| Corrugated | 19,105 | 20 | 979 | \$13.09 | \$12,815.11 | \$250,084 |
| Louvers | 1,833 | 2 | 979 | \$13.09 | \$12,815.11 | \$23,994 |
| Fiber Cement Siding | 9,138 | 10 | 979 | \$13.09 | \$12,815.11 | \$128,151 |
| Total | 32,488 | 34 | 3,916 | | \$51,260.44 | \$433,803 |

Table 5. Fiber cement siding changes

The original production days for the composite metal panels was 15 days, as shown previously. By changing it to fiber cement siding, the production becomes only two days with 2,412 square feet of façade to cover. The original production days for the corrugated metal panels was 21 days. By switching this material to fiber cement siding results in production days being at 20 days. This makes sense since the square foot per day is 39 days difference and since the square footage for corrugated metal panels is a lot higher than fiber cement siding. The production days for the louvers was five days, however with using the fiber cement siding, three days of work are saved. This is similar to replacing the composite metal panels.

The new cost for everything would just be the cost of the fiber cement siding, \$13.09 per square foot. This brings the total cost to \$433,802. The original cost for all these materials was \$769,826. This is quite a difference in which the owner could be interested in saving money on.

The production of brick and concrete was calculated in a similar manner. However, the concrete had to be converted into cubic yards. This was done by taking the same square footage of the brick and multiplying it by the assumed thickness of the new concrete, 1'10". The assumption of the thickness comes from the thickness of the retaining and basement walls in which all of these walls are 1'10" thick. This thickness will help absorb vibrations from the ground since it is a lab facility. The thickness could also help with overturning and sliding of the basement walls. Since the basement walls are all the same thickness, it is economical as you can use the same formwork. The concrete takes 14 days to complete as opposed to the 19 days the brick took. The unit cost is more expensive at \$100.00, however the total cost is cheaper because the concrete's units are covering a larger area than the square footage of the brick. The new construction of the entire wall was not accounted for when configuring the production and cost for this analysis. It is assumed, however that the cost and production will decrease because of fewer and easier managed materials.

Conclusion

As you can see from **Table 6** below, the new façade materials save about \$293,630 and 23 days by just changing those few materials. This time does not include the time saved from having fewer subcontractors and fewer coordination issues.

| New Production and Cost | | | | | | | |
|-------------------------|----------|-------|-----------------|----------------------------|-----------|-------------|------------|
| Material | Quantity | Units | Duration (Days) | Production Rate (Unit/Day) | Cost/Unit | Cost/Day | Total Cost |
| Fiber Cement Siding | 32,488 | SF | 33 | 979 | \$13.09 | \$12,815.11 | \$425,268 |
| Concrete | 509 | CY | 14 | 37 | \$100.00 | \$3,700.00 | \$50,928 |
| Total | | | 47 | 1,016 | | \$16,515.11 | \$476,196 |

Table 6. New production and cost

When speaking with the architect, he approved of the change from brick to concrete. This would help tie in the concrete weir walls which would in turn tie back into the site. He also approved the changes of corrugated metal panels to fiber cement siding but only in less visible places. The fiber cement siding is easier and faster to manage and construct, which makes it a better option for a building material. I would recommend changing the corrugated metal panels, composite metal panels, and louvers to fiber cement siding and changing the brick to poured concrete. Ultimately, the choice lies in what the owner and project stakeholders approve.

Figure 37 shows the new façade part of the schedule. This new façade only takes 41 days as opposed to the old façade that had a duration of 70. Since the activities overlap, the duration is shorter than what was calculated.



Figure 37. New façade section of the schedule

Analysis 4 – Building Information Modeling Implementation

Problem Identification

On the Environmental Studies Lab: Expansion, there was not a lot of Building Information Modeling (BIM) implementation. There were a few problems that could have been prevented with the use of BIM. There was a big issue with coordination between subcontractors. There were issues with coordination between subcontractors, as well as numerous clashes between the MEP systems, primarily the duct work and fire protection. BIM could have also been implemented at the end of the project for facilities management. Since this is a lab, there is a lot of complex equipment and processes that need to be maintained properly.

Research Goals

Implementing BIM would have solved problems before they even occurred. For example, 3D coordination would have solved the clashes before the construction even started, eliminating schedule delays and costly RFIs. Along with 3D coordination, other aspects of construction or design could have been made easier. Virtual mockups implemented would have ensured the construction will be completed properly. The BIM type phase planning would have helped with scheduling and constructability issues. BIM with facilities management can make for an easy turnover. By using all of these BIM tools, the schedule would be reduced and it would make things easier on the end user and the owner after the building is turned over.

Solution Method

- Consult with AE Personnel concerning facilities management
- Research BIM programs that would be applicable to the Environmental Studies Lab: Expansion
 - Contact the owner and the project team to see if they have used any of these programs
- Interview owner to understand their needs and experience with BIM or any asset management
- Advise what BIM is best for the Environmental Studies Lab: Expansion

Background Research

BIM has many uses; it can be used for phase planning, design review, construction system design, 3D coordination, and facilities management. BIM is implemented onto a project in order to simplify the planning, design, construction, and operations phases of a building. When BIM is on a project, coordination between all parties becomes easier and the chemistry between these parties helps the project move smoothly. This analysis will elaborate on a BIM use in each one of the phases of this project.

The main focus on this analysis will be on facility management. Since this is a research lab with complex lab equipment and MEP equipment, the facilities manager may need to be educated on some of the equipment. This was a critical industry issue at the PACE roundtable. BIM could easily assist the maintenance personal in locating and understanding how to proceed with the equipment that has an issue. This process could be very helpful in the long run to prevent costly measures to fix an issue.

BIM Uses

The Environmental Studies Lab: Expansion did not use much Building Information Modeling (BIM). However, a 3D model was created and Navisworks was used. The Navisworks model was not used for clash detection though. **Figure 38** shows more options of where BIM could have been used.

| X | PLAN | X | DESIGN | X | CONSTRUCT | X | OPERATE |
|---|------------------------------|---|----------------------------------|---|------------------------------|---|---------------------------------|
| | PROGRAMMING | | DESIGN AUTHORIZING | | SITE UTILIZATION PLANNING | | BUILDING MAINTENANCE SCHEDULING |
| | SITE ANALYSIS | X | DESIGN REVIEWS | X | CONSTRUCTION SYSTEM DESIGN | | BUILDING SYSTEM ANALYSIS |
| | | X | 3D COORDINATION | X | 3D COORDINATION | X | ASSET MANAGEMENT |
| | | | STRUCTURAL ANALYSIS | | DIGITAL FABRICATION | | SPACE MANAGEMENT / TRACKING |
| | | | LIGHTING ANALYSIS | | 3D CONTROL AND PLANNING | | DISASTER PLANNING |
| | | | ENERGY ANALYSIS | | RECORD MODELING | | RECORD MODELING |
| | | | MECHANICAL ANALYSIS | | | | |
| | | | OTHER ENG. ANALYSIS | | | | |
| | | | SUSTAINABILITY (LEED) EVALUATION | | | | |
| | | | CODE VALIDATION | | | | |
| X | PHASE PLANNING (4D MODELING) | X | PHASE PLANNING (4D MODELING) | X | PHASE PLANNING (4D MODELING) | | PHASE PLANNING (4D MODELING) |
| | COST ESTIMATION | | COST ESTIMATION | | COST ESTIMATION | | COST ESTIMATION |
| | EXISTING CONDITIONS MODELING | | EXISTING CONDITIONS MODELING | | EXISTING CONDITIONS MODELING | | EXISTING CONDITIONS MODELING |

Figure 38. BIM uses

Phase Planning

Phase Planning, or 4D modeling, is a 3D model that incorporates the project schedule. This particular type of BIM is especially beneficial for additions or expansions. For most expansion projects, the existing building is still occupied, as it is in the Environmental Studies Lab. Phase planning is very important when part of the building is still occupied. It helps the owner and the project team better understand the construction sequence and the primary locations for the building occupants. This type of construction sequencing is helpful with safety as well. By visually seeing the 3D model be constructed with the schedule, it gives a good sense of the project milestones and where the project is supposed to be at. Not only does it show milestones, it also shows the critical path, which is helpful in showing if the project is on track or not.

Phase Planning can reduce the schedule in a few ways as well. It is easier to see and plan lay down areas if this method of BIM is used. This eliminates issues with workspace congestion before construction even begins. This will in turn increase productivity when construction does begin. The phase planning also allows the project team to foresee any scheduling, sequencing, and phasing issue that may occur.

In order to have a successful phase planning BIM, the project team needs to have the knowledge and experience to create and understand this type of BIM. The project team would need to understand how to navigate a 3D model and how the software works. There are many different types of software that can be used to create a 3D and 4D model. Autodesk Revit and Autodesk Navisworks are a couple programs that are for making a 3D model. By transferring the model into a 4D program such as Synchro, **Figure 39**, the schedule can be linked in with the corresponding components. This shows when each component is to be constructed. The project team should also be aware of the schedule sequence and process. This is to make sure one item can be constructed before something else needs to go in.

Phase Planning is a continuous process that is performed in all the stages until the building is turned over. This is in order to keep the project team and owner up to date on where construction should be at.

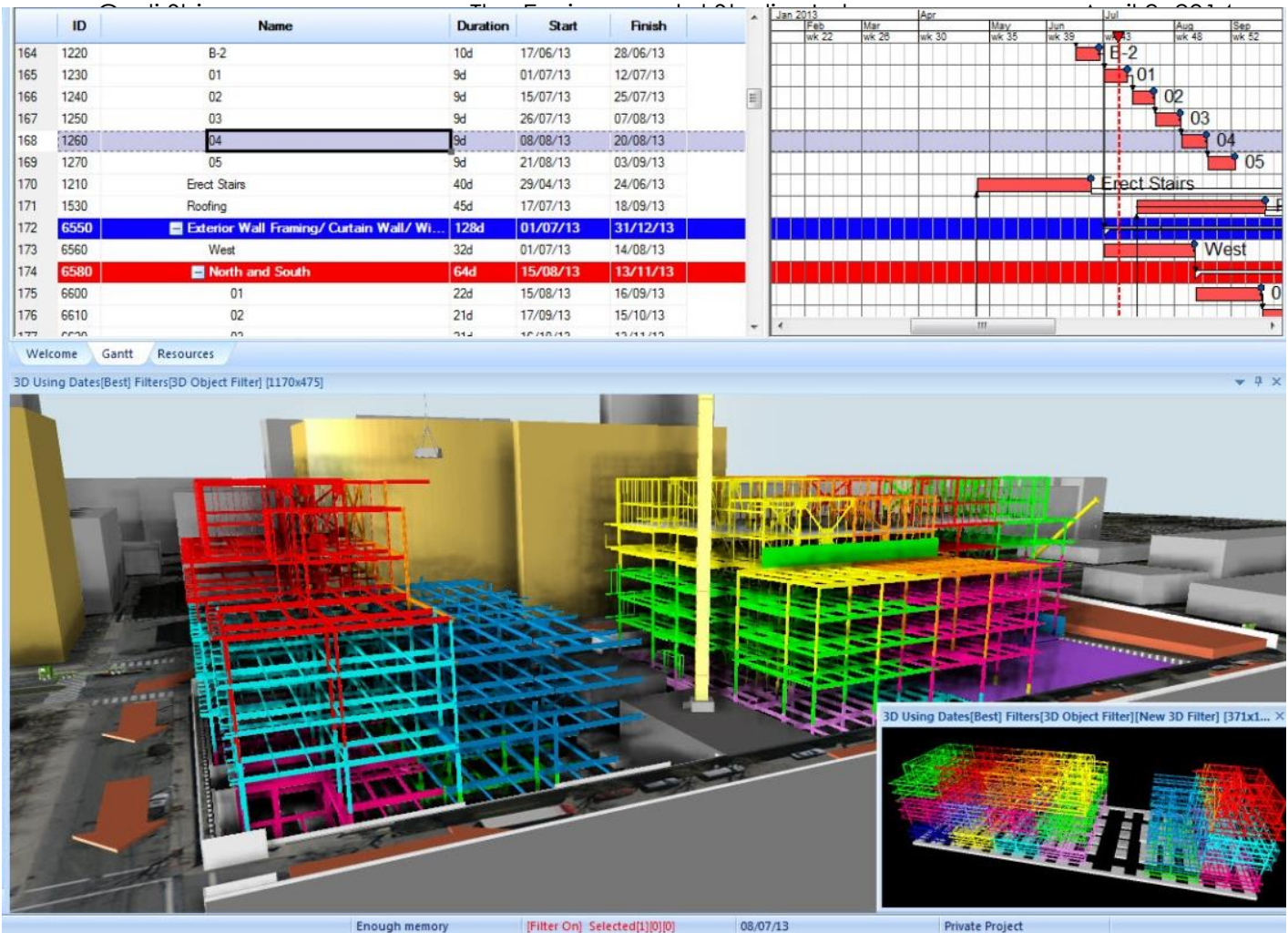


Figure 39. Example of Synchro. Image courtesy of synchroitd.com

Design Review

Design review is mainly for the stakeholders and the owner. In design review, it is a beneficial to the project to have your stakeholders clearly defined. There is a framework designed by Carol Sanford in her book, "The Responsible Business," called "The Stakeholder Pentad" that helps to define the stakeholders. This pentad, shown in **Figure 40**, represents all of the stakeholders including:

- 1) Users
- 2) Co-Creators
- 3) Earth/Environment
- 4) Community
- 5) Investors

When defining the stakeholders based on "The Stakeholder Pentad," the amount of responsibility needs to be assigned to each category. The users hold the most stake in the Environmental Studies Lab: Expansion because they are going to be the ones using the building. With design review BIM, the user could look at what the design is to be and make sure everything is accessible and comfortable for them. There were some late change orders on this project moving some electrical outlets because they were

not as accessible in the locations they were at. This shows that this type of BIM would have been helpful in this sense. The co-creators would be the whole project team including the architect, engineers, general contractor, and MEP subcontractors. By having the design review BIM, the co-creators will be able to review the documents to ensure that

construction would run smoothly with minimal interruptions. The earth/environment stakeholder is considering how the building will impact the earth and environment. In this case, the building was designed at LEED Gold but achieved LEED Platinum. If design review was implemented at the beginning of the project, someone might have been able to realize how close they were to achieving LEED Platinum. The fourth stakeholder, the community, is difficult to define. The community could be the people benefiting from the research being performed in the building. The better the equipment, the better the research can be. With design review, the new equipment could be reviewed for confirmation that it is the newest and best equipment that is needed in the Environmental Studies Lab: Expansion. The last stakeholder is the investor which in this case is the owner. The owner needs to be satisfied for what is being constructed and where their money is going. Design review is where the owner can determine what their intentions are with this building and to make sure that the design is meeting those intentions.

Each of the stakeholders mentioned will be able to provide their feedback to improve the design and to improve the construction process. This process can also be where value engineering plays an important role. Design review can allow for less expensive design alternatives which can quickly be reviewed with mock ups. This particular type of BIM can increase coordination and communication immensely since everybody is giving their opinion on what should be happening with design. However, for design review to be effective, all the systems must be able to integrate with one another. As with phase planning, it is important for the project team to be knowledgeable about the modeling software. With everybody knowing their roles and responsibilities with this type of BIM, it makes for an efficient design review process.

Construction System Design

A construction system design is another name for a virtual mockup. For this type of BIM, a 3D software is used to design and analyze complex building systems. The

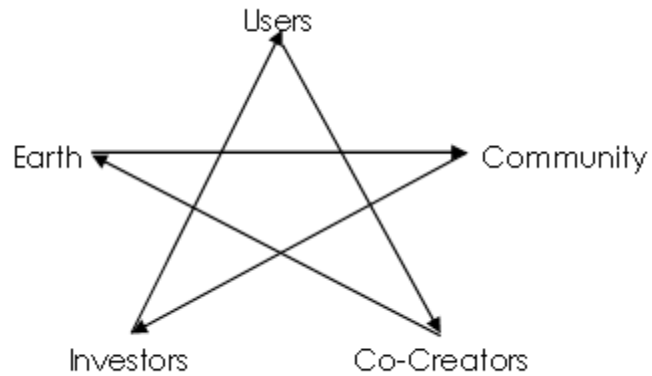


Figure 40. The Stakeholder Pentad

Environmental Studies Lab: Expansion has a very intricate exterior skin that would have worked very well with this type of BIM. This system consisted of 4" insulated metal panels, 6" cold form metal framing and then metal studs. The 6" cold form metal framing is sitting between steel tubing. The issue with the drawings was that the air vapor barrier (AVB) did not provide a true AVB. There were multiple request for information (RFI) written concerning this issue. The first RFI concerned where the AVB should be placed. It was decided that it should be located on the inside face of the 4" insulated panel

and continue over the steel tube. After that issue was resolved, the architect, the general contractor, and the subcontractors that are involved met to coordinate the proper method of developing the AVB. The second RFI was confirmation of what had been discussed during that meeting. It was decided that there was going to be a blue skin, which is a water proof membrane, to act as an AVB. This system is shown in **Figure 41**.

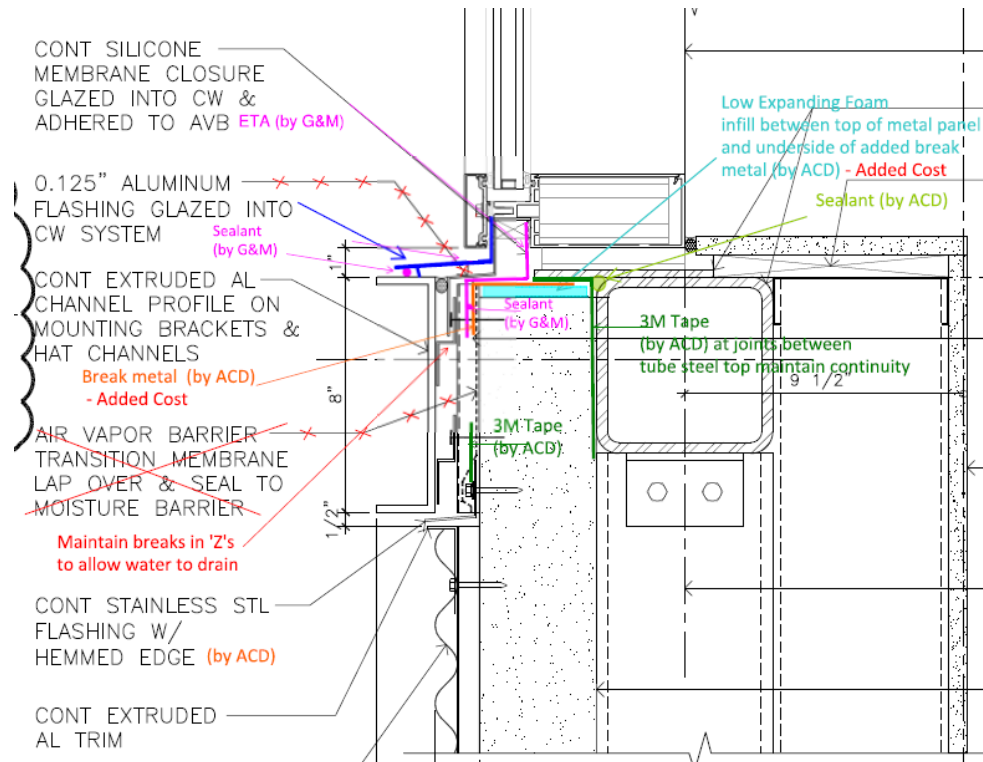


Figure 41. Air Vapor Barrier RFI

By using construction system design, this issue could have been found and resolved before it was constructed. Seeing it as a mockup would have saved time by eliminating these meetings and RFI's. Virtual mockups can also increase the constructability of these complex systems as well as the productivity of the workers.

3D Coordination

3D coordination is a very important model to have on a project. 3D coordination can save time and money especially when used for clash detection. Clash detection can determine conflicts and/or collisions with different building systems. The coordination for the MEP overhead rough-in in the Environmental Studies Lab: Expansion was difficult

for each system. Everything clashed with the ductwork. The electrical drawings did not show how to run the conduit in certain areas which ended up interfering with the duct locations. The biggest issue with the overhead rough-in was the sprinklers and the duct clashing. Unfortunately this problem was not caught before both systems were installed and it had to be fixed out in the field. It was decided that the sprinkler pipe had to be moved since there was more room to move that pipe rather than move large ductwork. This whole issue may have been avoided if the designers ran a clash detection. There was a meeting to look for clashes in the drawings but nothing was ever coordinated and tested for a clash.

A 3D coordination model used in a program such as Navisworks would have easily helped prevent these issues from happening. By visually seeing this construction and where everything actually should go, this increases productivity and reduces construction time. Each clash also requires a change order in order for the subcontractor to get paid for fixing the mistake. Ultimately, 3D coordination would have saved the project time and money on these fixes.

Another use of BIM is for Facilities Management.

Facilities Management

Facilities management is something that is used after the building is turned over and operating. The owner typically has a facilities manager that fixes and maintains any problems or equipment in a building. Different owners have different ways of approaching issues in a building. If an owner were to use BIM for facilities management, they would have a few different options of BIM to choose from. Space/Real Estate Management is where the space is defined. Project Management helps with future renovations that may occur. The last type of facilities management is Asset Management which is designed for equipment.

Asset management is ideal for the Environmental Studies Lab: Expansion because of what it does. According to the Penn State BIM website, asset management is “a process in which an organized management system is bi directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets.” This means that the link to the equipment will alert the facility manager as to what the problem is and where it is exactly. Asset management helps with short term and long term planning. By having this equipment organized into a BIM, it is easy to keep track of when each piece of equipment needs to be inspected. By having this information, it makes planning easier. The asset management also makes it easier for the technician because it generates the work orders on a schedule so they know where and when to be somewhere. It is programmed into each asset management model the operations and maintenance manuals and the specifications of each equipment. The technician needs to be well-informed on the asset management system and the operation of the

building. Asset management can also be cost effective. The system can be used to determine cost implications if a piece of equipment needs upgraded or changed.

There are two different ways to look at Asset Management: quantitatively and qualitatively. Quantitative measures of asset management would be making money and schedule savings. It can be assumed that a technician works 40 hours a week and 50 weeks of the year. This comes out to be 2000 hours per year. These hours should not have to be wasted looking for and identifying the problem then fixing it. Time can also be wasted getting the correct material to fix the equipment. If the technician does not know what the problem is, they could spend time going back and forth to get the right equipment to fix the problem. The qualitative measures would be safety and satisfaction. Safety is always an important factor in all phases of a building. By using the BIM for facilities management, the technicians can know what they are getting themselves into and how to prepare for it. The satisfactory factor is when the design is easier to manage. The technicians appreciate this because it makes their job easier. It is ideal to bring the technicians in during design so they are familiar with what each piece of equipment is and what it does. During design, the technicians can provide input of location or accessibility to ensure every piece can be properly maintained. The technician should be trained after the submittals are approved. It is smart to train them after then because at this point the equipment will not change. By the time the project is 50% into construction, the training should begin because these submittals should be approved and the equipment possibly onsite and/or installed.

Just like in other types of BIM, facilities management has stakeholders. Facilities management can follow The Stakeholder Pentad as well, however the BIM application with facilities management is mainly for the technician. The program needs to be simple for them to maneuver around. In a 3D model program such as Autodesk Revit, there should be view points and more items to click on so the technician does not have to orbit around the model. This is an opportunity to eliminate the potential of the technician getting lost or confused in the building. These view points should be linked to an asset management program. The scientists and the owner are the ultimate beneficiaries of this process. The simpler and easier the process is to find a solution and fix the problem, the sooner that piece of equipment will be able to be utilized to its maximum potential.

There are several programs that are designed for asset management. One program that is used by both Penn State's Office of Physical Plant (OPP) and Hensel Phelps is called IBM Maximo. IBM Maximo is a computerized maintenance management system that analyzes data. This program is a maintenance system as well as an asset tracking data base. It is linked to the specifications and operations and maintenance manuals so it can keep track of when it is time to inspect that piece of equipment and how to maintain it. IBM Maximo is tied to a 3D modeling program such as Autodesk Revit in

order to link the equipment and model together to visually see where it is at in the building. Before the building is complete, the data should be entered into IBM Maximo and Revit. The analyst will put the entries in for each piece of equipment. This is a faster process than entering everything by hand like how it would be done if it was not for BIM. The analyst can then enter a preventative maintenance plan for each piece of equipment to be inspected every six months or more. In turn, the equipment lasts longer. By entering the data analysis and creating the preventative maintenance plan, it is estimated by OPP that one week can be saved.

According to Dr. Craig Dubler, Penn State's OPP assumes that they can save 45 minutes per day by using BIM and facilities management. OPP has a maintenance system that works for them. If there is a problem with one of the rooms at Penn State, someone will call into the control center at OPP to get it taken care of. For example, in a lot of the rooms, the problem is it is either too hot or too cold in that room. When a professor calls into the control center, a work ticket is printed out to a technician. This system is called Facility Information Management. It looks into the particular system and the supply lines in that area. So in this case, the thermostat would be looked at and then what it connects to. This would be the Variable Air Volume (VAV) boxes and then the Air Handling Units (AHU). The first step for the technician once he receives the work order ticket, would be to look at the BIM and see what the system is tied into. If there is no BIM, the technician would need to flip through drawings to find the equipment and what it hooks up to. This could be a long process, however OPP assumes that BIM will save roughly 15 minutes. The next step to fixing this problem is to evaluate the space. The equipment that needs fixed may be in the ceiling so a ladder will be needed. If the technician were to get to the space, realize he needs a certain tool to even access the equipment, he has to go all the way back and get the equipment. It is quicker to just collect all the information in the office so time is not wasted going back and forth. OPP assumes that BIM will save 15 to 20 minutes by not having to go back and forth. After evaluation, the problem turns out to be the AHU. The technician needs to determine if he is qualified to correct the problem. The info about the system and the equipment can be found in the Maximo program. The appropriate measures can be then taken to solve the problem. If AHU needs replaced, it is easy to update the model, since the dimensions are already there. The equipment will be updated in the model and the records quickly changed. With this example, it shows that time can be saved with BIM and facilities management. According to the Penn State BIM Savings Breakdown, that corresponds with a PowerPoint, the 45 minutes saved is justified as well as an estimated amount of money saved from using this software.

The Current Facilities Management

After speaking with the owner's representative, it was understood why BIM was not used on this project. This particular owner is in the process of understanding BIM better in order to start implementing it into their projects. The owner has a system that they use

for facilities management that does not involve BIM. Since the owner possesses many different types of facilities, they need multiple maintenance crews to uphold all of these buildings. It is estimated that there is 16 to 20 maintenance people that work for this owner. Each of them is assigned to a specific building or specialty with a maintenance foreman. These maintenance foremen have certain access rights required for each facility. There is also a group of administrators that maintain this facilities management system for what is called the Facilities Center. The Facilities Center is a data base that has room and building numbers with a list of equipment in the building. The Facilities Center contains equipment history and, to a degree, financial interface software.

In the Environmental Studies Lab: Expansion, if a piece of equipment such as Air Handling Unit 3 stops working, the controls system alerts the Facilities Center and it prints a work order ticket. The maintenance administrators assign the proper technicians to the job. The technician would then go out and fix the problem. Each technician is trained on a new piece of equipment after it is installed. This training is done onsite. If the Environmental Studies Lab: Expansion does not have any problems with the equipment, then there still is scheduled preventative maintenance quarterly. Some equipment may need monthly preventative maintenance attention.

Conclusion

Anything with phase planning would be applicable for the Environmental Studies Lab: Expansion. The 4D model will help with schedule, sequencing, and identifying constructability issues. This method will increase productivity and in turn reduce the schedule. Design review BIM will assist in reducing the schedule because the building will be right for all parties involved in any stage of the building including the end users. With everybody's feedback about the design, there should be less change orders and a faster turn over because of fewer changes. The construction system design would have been directly beneficial with the complex exterior wall system. This system's problem took a while to solve which is why this type of BIM would have been helpful. 3D coordination would have saved both time and money. The clash detection would have been beneficial because during construction they would not have had to fix so many clashes. The MEP systems clashed often during construction, but with BIM these clashes, RFI's, and change orders could be reduced drastically.

Figure 42 shows the use of BIM for Analysis 3. Even a program such as Google SketchUp can be used as a BIM. It was used to show the proposed changes in façade.

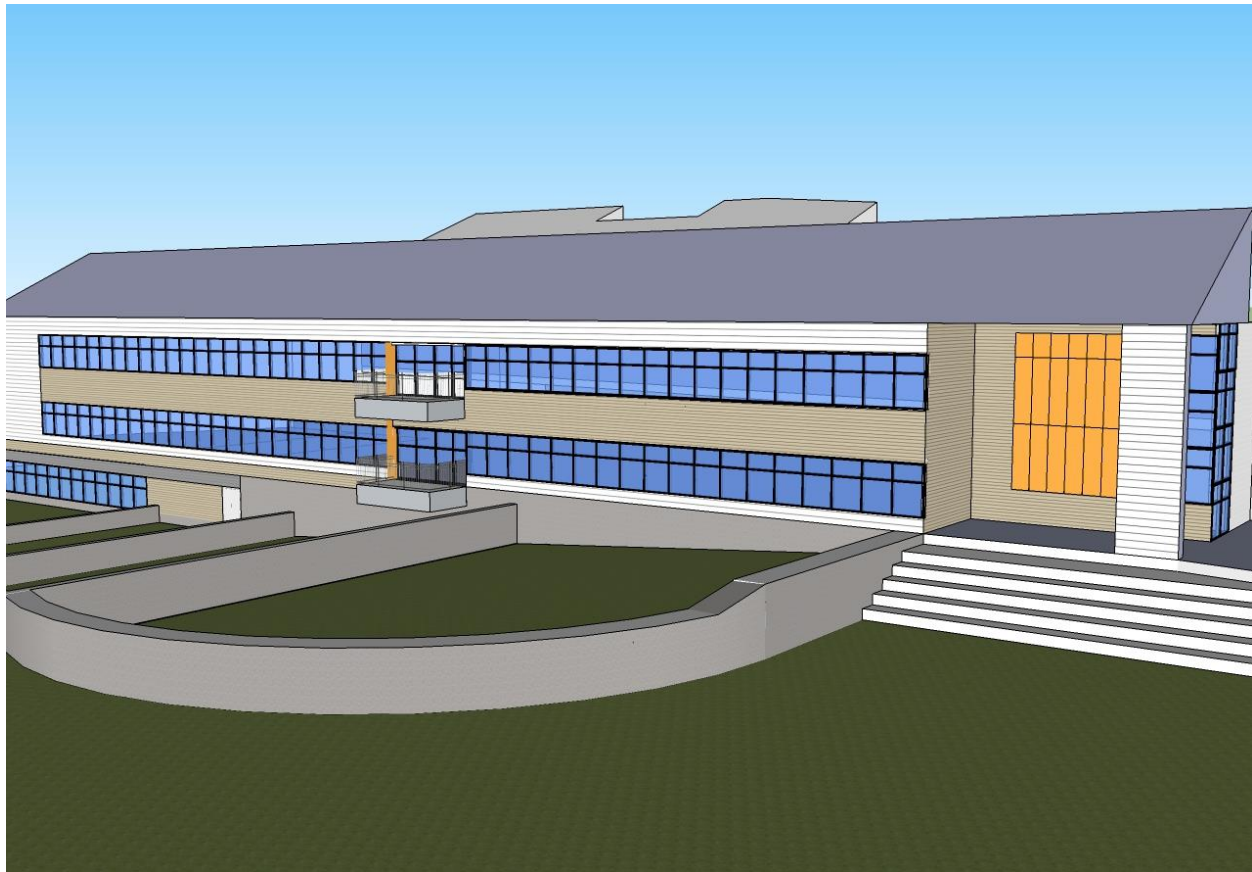


Figure 42. Model using BIM

If the owner were to implement BIM with a facilities management program, it would help out not only on the Environmental Studies Lab: Expansion, but their other facilities as well. As mentioned before, asset management would be the proper facilities management to use for the Environmental Studies Lab: Expansion. The complex mechanical equipment and lab equipment prove that asset management would be helpful. The BIM with facilities management for the Environmental Studies Lab: Expansion would be very similar to what OPP uses. Autodesk Revit and IBM Maximo would both be ideal programs to use in order to make and maintain the facilities management program. There is potential to reduce the time it takes to fix an asset by using BIM with facilities management as opposed to the current facilities management program. It makes sense that the time reduced for OPP would be the same for the Environmental Studies Lab: Expansion since the process would be the same. Therefore, 45 minutes would be saved per day or per visit. All of the technicians will need to be trained to use the BIM, however this will be a onetime occurrence for each person. If the BIM coordinator takes the time to simplify the asset management model, then the training should not be hard or long.

This analysis not only shows how the Environmental Studies Lab: Expansion could implement BIM, but it also helps the owner understand what types of BIM are available. The owner is currently exploring BIM to learn more about it in order to start using it. On this particular project, the BIM types that are most applicable are phase planning, design review, construction system design, and 3D coordination. BIM with facilities management would help this project as well as other facilities for the owner. Although it is difficult to quantify the amount of time these BIM types save the project team, it is certain that BIM eliminates time in all stages of a building: design, construction, and operation.

Conclusion & Recommendations

In analysis 1, there were a few reasonable assumptions made about what part of the schedule can be combined to incorporate the general contractor in earlier. The general contractor could come in at 35% of design development which will give enough time for the owner to input their ideas into the design before the design builder took over. By getting the contractor in earlier, the subcontractors could become involved earlier as well. This coordination would reduce the schedule tremendously. Judging by the assumptions made, 315 days could be saved and construction could begin August 3, 2010 rather than October 31, 2011. This savings proves that the delivery method design build is a better option.

Analysis 2 demonstrated a SIPS of the overhead mechanical ductwork in the large labs. Since there are 18 labs that have repetitive work, this seemed like a good place for a SIPS. After creating a few different SIPS options, the most efficient schedule was decided on. The third SIPS saved the schedule 21 days, which is about a month of work. To determine if this method would be cost efficient as well, the labor rates were considered. If the hourly rate was \$39.93 per sheet metal worker, then the original SIPS cost would have been \$829,703. SIPS 3 totaled \$896,924, which turned out to be the closest to the original cost and the lowest cost out of the three options. Using this SIPS for overhead mechanical rough-in would be recommended.

The façade study in analysis 3 also produced savings in both cost and schedule. By changing the composite metal panels, corrugated metal panels, and non-operable louvers to fiber cement siding, saved 18 days. Changing the brick to cast in place concrete saves five days. This savings does not account for the reduction of material in the wall itself. The architectural breadth shows the changes being made and the justifications of them. The aesthetics of these changes will be apparent, however not noticeable far away, which is how most of these materials will be perceived. A mechanical breadth verifies that the R-value will improve and that condensation will not get into the wall unless the relative humidity outside is at 100%. After performing both of these breadths, both the cost and production was calculated. The cost was a savings of \$293,630 and the total duration was reduced by 23 days. The proposed changes are recommended even though the aesthetics are changed a bit.

The 4th analysis was on implementing BIM into the project. BIM is not something that the owner is familiar with so it was not performed on this project. There were a few BIM uses that would have made planning, design, construction, and operation go smoother. 4D modeling, design review, construction system design, and coordination would have helped with all of these stages. Each of these BIM tools would have reduced the schedule in some way, especially if some of these were implemented before construction. This would mean that the delivery method would need to be design build for collaboration and coordination to be effective. A SIPS from analysis 2 works well

with a 4D model to show exactly where crews should be and when. The façade study can incorporate these methods of BIM best with the design review and 3D coordination. The final part of this analysis was BIM focusing on facilities management. The software used to for asset management will help save time for the facilities manager. OPP estimates about 45 minutes per day savings, which adds up in the long run.

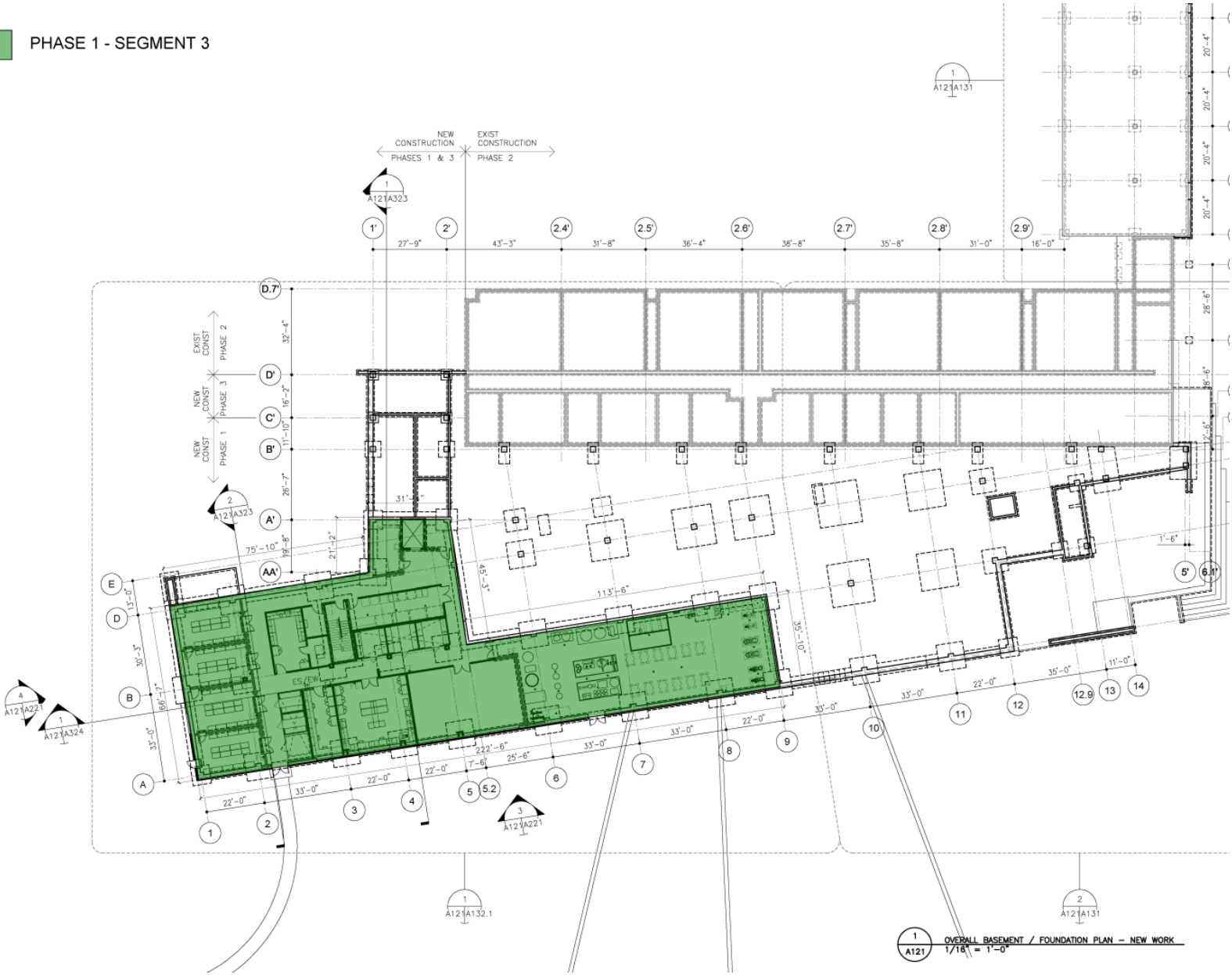
By creating a new schedule out of these analyses, there is a great schedule reduction. The façade changes and SIPS save a total of 44 days, which is two months. With the alternative delivery method of design build, 315 days can be saved. The total BIM savings were not able to be determined quantitatively, however it is assumed that it will save time. These analyses bring the total scheduled savings to 359 days. This number can vary based on when construction actually starts. With these new durations, the construction for the Environmental Studies Lab: Expansion has the possibility of being turned over by November 15, 2011.

Appendix I shows a new schedule which includes all analyses.

Appendix A: Sequencing and Original Project Schedule



PHASE 1 - SEGMENT 3

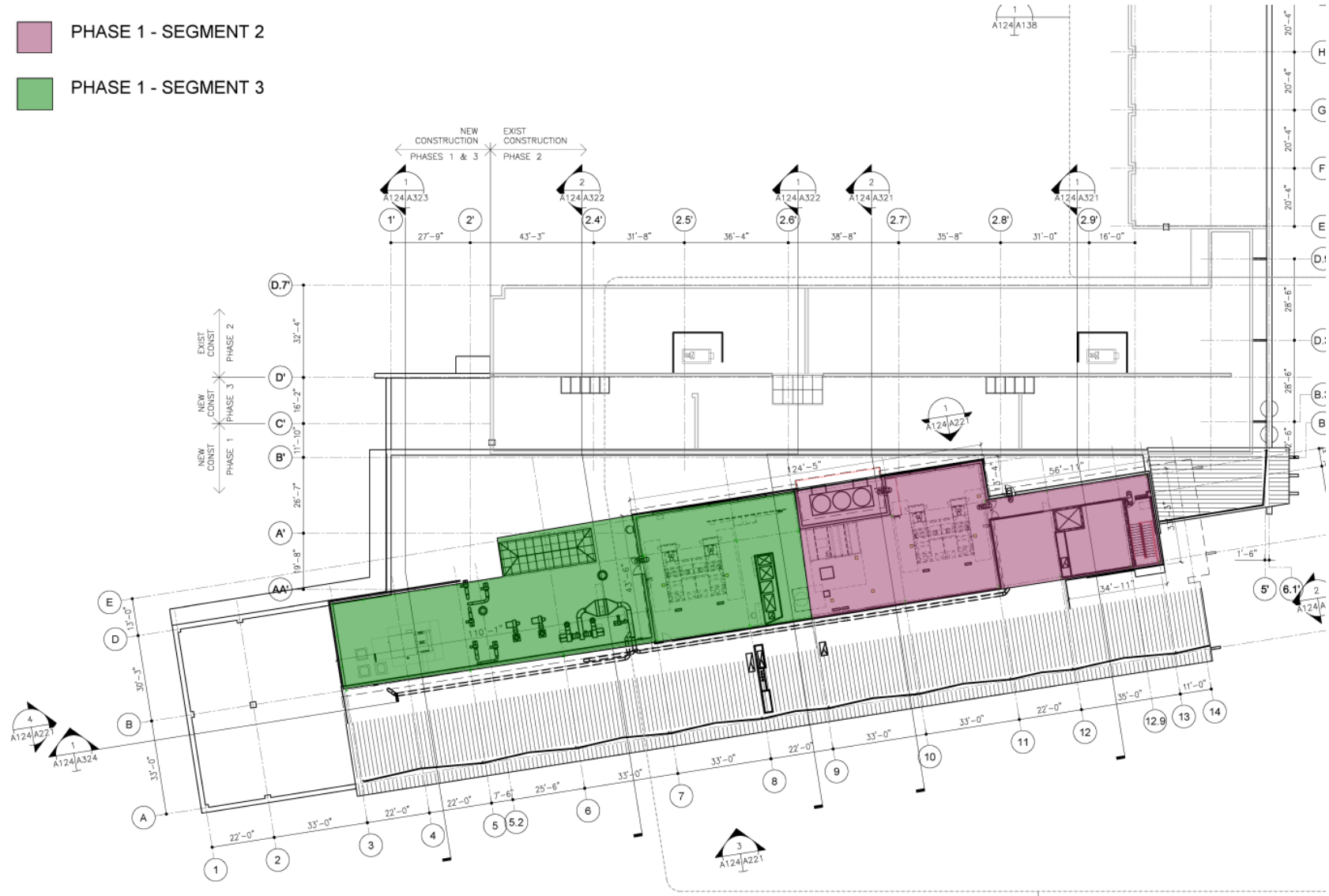


- PHASE 1 - SEGMENT 2
- PHASE 1 - SEGMENT 3
- PHASE 2 - SEGMENT 1
- PHASE 2 - SEGMENT 2
- PHASE 2 - SEGMENT 3



1
A122 OVERALL FIRST FLOOR PLAN - NEW WORK
1/16" = 1'-0"

- PHASE 1 - SEGMENT 2
- PHASE 1 - SEGMENT 3



1
A124
OVERALL PENTHOUSE PLAN - NEW WORK
1/16" = 1'-0"

| # | Activity Name | Original Duration | Start | Finish | 2011 | | | | | | | | | | | | 2012 | | | | | 2013 | | | | | | | |
|----|---------------------------------------|-------------------|-----------|-----------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|--|
| | | | | | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | |
| 1 | Detailed Schedule | 483 | 01-Jun-11 | 22-Apr-13 | ▶ 22-Apr | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Notice to Proceed | 0 | 01-Jun-11 | | ▶ Notice to Proceed, 01-Jun-11 | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Earthwork | 255 | 03-Nov-11 | 01-Nov-12 | ▶ 01-Nov-12, Earthwork | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Excavate spot and continuous footings | 5 | 03-Nov-11 | 09-Nov-11 | ■ Excavate spot and continuous footings | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Excavate for EQ/signage wall | 5 | 18-Jun-12 | 22-Jun-12 | ■ Excavate for EQ/signage wall | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Excavate weir wall and runnel #1 | 5 | 06-Aug-12 | 10-Aug-12 | ■ Excavate weir wall and runnel #1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Excavate weir wall and runnel #2 | 3 | 12-Sep-12 | 14-Sep-12 | ■ Excavate weir wall and runnel #2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Excavate weir wall and runnel #3 | 3 | 05-Oct-12 | 09-Oct-12 | ■ Excavate weir wall and runnel #3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | Excavate weir wall #4 | 3 | 30-Oct-12 | 01-Nov-12 | ■ Excavate weir wall #4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Concrete | 260 | 07-Nov-11 | 12-Nov-12 | ▶ 12-Nov-12, Concrete | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | Site | 80 | 23-Jul-12 | 12-Nov-12 | ▶ 12-Nov-12, Site | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | FRP EQ/Signage wall | 10 | 23-Jul-12 | 03-Aug-12 | ■ FRP EQ/Signage wall | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | FRP weir wall and runnel #1 | 15 | 21-Aug-12 | 11-Sep-12 | ■ FRP weir wall and runnel #1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | FRP weir wall and runnel #2 | 14 | 17-Sep-12 | 04-Oct-12 | ■ FRP weir wall and runnel #2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | FRP weir wall and runnel #3 | 14 | 10-Oct-12 | 29-Oct-12 | ■ FRP weir wall and runnel #3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | FRP weir wall #4 | 7 | 02-Nov-12 | 12-Nov-12 | ■ FRP weir wall #4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | Basement | 44 | 07-Nov-11 | 10-Jan-12 | ▶ 10-Jan-12, Basement | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | FRP spot and continuous footing | 10 | 07-Nov-11 | 18-Nov-11 | ■ FRP spot and continuous footing | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | FRP retaining wall | 20 | 14-Nov-11 | 12-Dec-11 | ■ FRP retaining wall | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | FRP SOG S3 | 5 | 04-Jan-12 | 10-Jan-12 | ■ FRP SOG S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | Level 1 | 34 | 16-Feb-12 | 03-Apr-12 | ▶ 03-Apr-12, Level 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | FRP SOG S3 | 4 | 16-Feb-12 | 21-Feb-12 | ■ FRP SOG S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 23 | FRP SOG S2 | 5 | 12-Mar-12 | 16-Mar-12 | ■ FRP SOG S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | FRP SOMD S3 | 5 | 21-Mar-12 | 27-Mar-12 | ■ FRP SOMD S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | FRP SOMD S2 | 5 | 28-Mar-12 | 03-Apr-12 | ■ FRP SOMD S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 26 | Level 2 | 9 | 03-Apr-12 | 13-Apr-12 | ▶ 13-Apr-12, Level 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 27 | FRP SOMD S3 | 5 | 03-Apr-12 | 09-Apr-12 | ■ FRP SOMD S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 28 | FRP SOMD S2 | 4 | 10-Apr-12 | 13-Apr-12 | ■ FRP SOMD S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 29 | Penthouse | 6 | 08-May-12 | 15-May-12 | ▶ 15-May-12, Penthouse | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | FRP SOMD S3 | 3 | 08-May-12 | 10-May-12 | ■ FRP SOMD S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | FRP SOMD S2 | 3 | 11-May-12 | 15-May-12 | ■ FRP SOMD S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | Structural Steel | 44 | 22-Feb-12 | 23-Apr-12 | ▶ 23-Apr-12, Structural Steel | | | | | | | | | | | | | | | | | | | | | | | | |
| 33 | Basement | 4 | 22-Feb-12 | 27-Feb-12 | ▶ 27-Feb-12, Basement | | | | | | | | | | | | | | | | | | | | | | | | |
| 34 | Erect columns and beams S3 | 4 | 22-Feb-12 | 27-Feb-12 | ■ Erect columns and beams S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 35 | Level 1 | 19 | 28-Feb-12 | 23-Mar-12 | ▶ 23-Mar-12, Level 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 36 | Deck and detail S3 | 5 | 28-Feb-12 | 05-Mar-12 | ■ Deck and detail S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 37 | Erect columns and beams S2 | 5 | 14-Mar-12 | 20-Mar-12 | ■ Erect columns and beams S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 38 | Erect columns and beams S3 | 6 | 16-Mar-12 | 23-Mar-12 | ■ Erect columns and beams S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 39 | Level 2 | 16 | 14-Mar-12 | 04-Apr-12 | ▶ 04-Apr-12, Level 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 40 | Deck and detail S3 | 5 | 14-Mar-12 | 20-Mar-12 | ■ Deck and detail S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 41 | Erect columns and beams S3 | 6 | 21-Mar-12 | 28-Mar-12 | ■ Erect columns and beams S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 42 | Deck and detail S2 | 5 | 21-Mar-12 | 27-Mar-12 | ■ Deck and detail S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 | Erect columns and beams S2 | 5 | 29-Mar-12 | 04-Apr-12 | ■ Erect columns and beams S2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 44 | Penthouse | 18 | 29-Mar-12 | 23-Apr-12 | ▶ 23-Apr-12, Penthouse | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 | Deck and detail S3 | 13 | 29-Mar-12 | 16-Apr-12 | ■ Deck and detail S3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | Erect columns and beams S3 | 4 | 05-Apr-12 | 10-Apr-12 | ■ Erect columns and beams S3 | | | | | | | | | | | | | | | | | | | | | | | | |

■ Actual Level of Effort
 ■ Remaining Work
 ◆ Milestone
■ Actual Work
 ■ Critical Remaining Work
 ▶ summary

| # | Activity Name | Original Duration | Start | Finish | 2011 | | | | | | | | | | | | 2012 | | | | | | | | | | | | 2013 | | | | |
|----|--|-------------------|-----------|-----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|--|--|--|--|
| | | | | | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | Deck and detail S2 | 13 | 05-Apr-12 | 23-Apr-12 | | | | | | | | | | | | | Deck and detail S2 | | | | | | | | | | | | | | | | |
| 48 | Erect columns and beams S2 | 3 | 11-Apr-12 | 13-Apr-12 | | | | | | | | | | | | | Erect columns and beams S2 | | | | | | | | | | | | | | | | |
| 49 | Misc. Metals | 70 | 04-Apr-12 | 12-Jul-12 | | | | | | | | | | | | | 12-Jul-12, Misc. Metals | | | | | | | | | | | | | | | | |
| 50 | Basement | 35 | 04-Apr-12 | 22-May-12 | | | | | | | | | | | | | 22-May-12, Basement | | | | | | | | | | | | | | | | |
| 51 | Install metal framing S3 | 15 | 04-Apr-12 | 24-Apr-12 | | | | | | | | | | | | | Install metal framing S3 | | | | | | | | | | | | | | | | |
| 52 | Install metal panels S3 | 10 | 09-May-12 | 22-May-12 | | | | | | | | | | | | | Install metal panels S3 | | | | | | | | | | | | | | | | |
| 53 | Level 1 | 43 | 16-Apr-12 | 14-Jun-12 | | | | | | | | | | | | | 14-Jun-12, Level 1 | | | | | | | | | | | | | | | | |
| 54 | Install metal framing S3 | 15 | 16-Apr-12 | 04-May-12 | | | | | | | | | | | | | Install metal framing S3 | | | | | | | | | | | | | | | | |
| 55 | Install metal framing S2 | 15 | 25-Apr-12 | 15-May-12 | | | | | | | | | | | | | Install metal framing S2 | | | | | | | | | | | | | | | | |
| 56 | Install metal panels S2 | 10 | 07-May-12 | 18-May-12 | | | | | | | | | | | | | Install metal panels S2 | | | | | | | | | | | | | | | | |
| 57 | Install metal panels S3 | 16 | 23-May-12 | 14-Jun-12 | | | | | | | | | | | | | Install metal panels S3 | | | | | | | | | | | | | | | | |
| 58 | Level 2 | 45 | 25-Apr-12 | 27-Jun-12 | | | | | | | | | | | | | 27-Jun-12, Level 2 | | | | | | | | | | | | | | | | |
| 59 | Install metal framing S3 | 30 | 25-Apr-12 | 06-Jun-12 | | | | | | | | | | | | | Install metal framing S3 | | | | | | | | | | | | | | | | |
| 60 | Install metal framing S2 | 30 | 16-May-12 | 27-Jun-12 | | | | | | | | | | | | | Install metal framing S2 | | | | | | | | | | | | | | | | |
| 61 | Install metal panels S2 | 15 | 21-May-12 | 11-Jun-12 | | | | | | | | | | | | | Install metal panels S2 | | | | | | | | | | | | | | | | |
| 62 | Install metal panels S3 | 15 | 23-May-12 | 13-Jun-12 | | | | | | | | | | | | | Install metal panels S3 | | | | | | | | | | | | | | | | |
| 63 | Penthouse | 40 | 16-May-12 | 12-Jul-12 | | | | | | | | | | | | | 12-Jul-12, Penthouse | | | | | | | | | | | | | | | | |
| 64 | Install metal framing S3 | 25 | 16-May-12 | 20-Jun-12 | | | | | | | | | | | | | Install metal framing S3 | | | | | | | | | | | | | | | | |
| 65 | Install metal panels S2 | 10 | 05-Jun-12 | 18-Jun-12 | | | | | | | | | | | | | Install metal panels S2 | | | | | | | | | | | | | | | | |
| 66 | Install metal framing S2 | 25 | 07-Jun-12 | 12-Jul-12 | | | | | | | | | | | | | Install metal framing S2 | | | | | | | | | | | | | | | | |
| 67 | Install metal panels S3 | 10 | 07-Jun-12 | 20-Jun-12 | | | | | | | | | | | | | Install metal panels S3 | | | | | | | | | | | | | | | | |
| 68 | HVAC | 275 | 31-Oct-11 | 27-Nov-12 | | | | | | | | | | | | | 27-Nov-12, HVAC | | | | | | | | | | | | | | | | |
| 69 | Site | 126 | 31-Oct-11 | 26-Apr-12 | | | | | | | | | | | | | 26-Apr-12, Site | | | | | | | | | | | | | | | | |
| 70 | Drill geothermal wells | 50 | 31-Oct-11 | 11-Jan-12 | | | | | | | | | | | | | Drill geothermal wells | | | | | | | | | | | | | | | | |
| 71 | Install vaults 1, 2, and 3 | 5 | 13-Jan-12 | 19-Jan-12 | | | | | | | | | | | | | Install vaults 1, 2, and 3 | | | | | | | | | | | | | | | | |
| 72 | Install supply/return piping (250 wells) | 70 | 20-Jan-12 | 26-Apr-12 | | | | | | | | | | | | | Install supply/return piping (250 wells) | | | | | | | | | | | | | | | | |
| 73 | Basement | 187 | 20-Dec-11 | 12-Sep-12 | | | | | | | | | | | | | 12-Sep-12, Basement | | | | | | | | | | | | | | | | |
| 74 | Install water-to-water heat pumps | 4 | 20-Dec-11 | 23-Dec-11 | | | | | | | | | | | | | Install water-to-water heat pumps | | | | | | | | | | | | | | | | |
| 75 | Install AHU 4 | 9 | 24-May-12 | 06-Jun-12 | | | | | | | | | | | | | Install AHU 4 | | | | | | | | | | | | | | | | |
| 76 | Install ductwork | 15 | 18-Jun-12 | 09-Jul-12 | | | | | | | | | | | | | Install ductwork | | | | | | | | | | | | | | | | |
| 77 | Install VAV boxes | 10 | 25-Jun-12 | 09-Jul-12 | | | | | | | | | | | | | Install VAV boxes | | | | | | | | | | | | | | | | |
| 78 | Insulate ductwork | 20 | 14-Aug-12 | 11-Sep-12 | | | | | | | | | | | | | Insulate ductwork | | | | | | | | | | | | | | | | |
| 79 | Install grilles and diffusers | 5 | 06-Sep-12 | 12-Sep-12 | | | | | | | | | | | | | Install grilles and diffusers | | | | | | | | | | | | | | | | |
| 80 | Level 1 | 96 | 10-Jul-12 | 21-Nov-12 | | | | | | | | | | | | | 21-Nov-12, Level 1 | | | | | | | | | | | | | | | | |
| 81 | Install ductwork S3 | 20 | 10-Jul-12 | 06-Aug-12 | | | | | | | | | | | | | Install ductwork S3 | | | | | | | | | | | | | | | | |
| 82 | Install VAV boxes S3 | 15 | 17-Jul-12 | 06-Aug-12 | | | | | | | | | | | | | Install VAV boxes S3 | | | | | | | | | | | | | | | | |
| 83 | Install mechanical equipment S3 | 20 | 07-Aug-12 | 04-Sep-12 | | | | | | | | | | | | | Install mechanical equipment S3 | | | | | | | | | | | | | | | | |
| 84 | Install ductwork S2 | 15 | 07-Aug-12 | 27-Aug-12 | | | | | | | | | | | | | Install ductwork S2 | | | | | | | | | | | | | | | | |
| 85 | Insulate ductwork S3 | 30 | 14-Aug-12 | 25-Sep-12 | | | | | | | | | | | | | Insulate ductwork S3 | | | | | | | | | | | | | | | | |
| 86 | Insulate ductwork | 15 | 14-Aug-12 | 04-Sep-12 | | | | | | | | | | | | | Insulate ductwork | | | | | | | | | | | | | | | | |
| 87 | Install VAV boxes S2 | 15 | 28-Aug-12 | 18-Sep-12 | | | | | | | | | | | | | Install VAV boxes S2 | | | | | | | | | | | | | | | | |
| 88 | Install mechanical equipment S2 | 12 | 19-Sep-12 | 04-Oct-12 | | | | | | | | | | | | | Install mechanical equipment S2 | | | | | | | | | | | | | | | | |
| 89 | Install grilles and diffusers S3 | 18 | 28-Sep-12 | 23-Oct-12 | | | | | | | | | | | | | Install grilles and diffusers S3 | | | | | | | | | | | | | | | | |
| 90 | Install grilles and diffusers S2 | 21 | 24-Oct-12 | 21-Nov-12 | | | | | | | | | | | | | Install grilles and diffusers S2 | | | | | | | | | | | | | | | | |
| 91 | Level 2 | 104 | 02-Jul-12 | 27-Nov-12 | | | | | | | | | | | | | 27-Nov-12, Level 2 | | | | | | | | | | | | | | | | |
| 92 | Install mechanical equipment S2 | 9 | 02-Jul-12 | 13-Jul-12 | | | | | | | | | | | | | Install mechanical equipment S2 | | | | | | | | | | | | | | | | |

█ Actual Level of Effort
 █ Remaining Work
 █ Critical Remaining Work
 ◆ Milestone
 ▾ summary

| # | Activity Name | Original Duration | Start | Finish | 2011 | | | | | | | | | | | | 2012 | | | | | 2013 | | | | |
|-----|---------------------------------------|-------------------|-----------|-----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|------|-----|-----|-----|-----|------|-----|-----|-----|-----|
| | | | | | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
| 186 | OH rough-in storm piping S3 | 8 | 01-Jun-12 | 12-Jun-12 | | | | | | | | | | | | OH rough-in storm piping S3 | | | | | | | | | | |
| 187 | OH rough-in industrial waste pipe S2 | 4 | 01-Jun-12 | 06-Jun-12 | | | | | | | | | | | | OH rough-in industrial waste pipe S2 | | | | | | | | | | |
| 188 | IW rough-in industrial waste pipe S3 | 5 | 02-Aug-12 | 08-Aug-12 | | | | | | | | | | | | IW rough-in industrial waste pipe S3 | | | | | | | | | | |
| 189 | IW rough-in storm piping S3 | 2 | 02-Aug-12 | 03-Aug-12 | | | | | | | | | | | | IW rough-in storm piping S3 | | | | | | | | | | |
| 190 | IW rough-in domestic water supply t | 16 | 02-Aug-12 | 23-Aug-12 | | | | | | | | | | | | IW rough-in domestic water supply H/C S3 | | | | | | | | | | |
| 191 | IW rough-in industrial water supply t | 16 | 02-Aug-12 | 23-Aug-12 | | | | | | | | | | | | IW rough-in industrial water supply H/C S3 | | | | | | | | | | |
| 192 | OH rough-in industrial water supply t | 32 | 07-Aug-12 | 20-Sep-12 | | | | | | | | | | | | OH rough-in industrial water supply H/C S3 | | | | | | | | | | |
| 193 | OH rough-in domestic water supply l | 30 | 09-Aug-12 | 20-Sep-12 | | | | | | | | | | | | OH rough-in domestic water supply H/C S3 | | | | | | | | | | |
| 194 | IW rough-in industrial waste pipe S2 | 2 | 14-Aug-12 | 15-Aug-12 | | | | | | | | | | | | IW rough-in industrial waste pipe S2 | | | | | | | | | | |
| 195 | IW rough-in domestic water supply t | 4 | 14-Aug-12 | 17-Aug-12 | | | | | | | | | | | | IW rough-in domestic water supply H/C S2 | | | | | | | | | | |
| 196 | IW rough-in industrial water supply t | 3 | 14-Aug-12 | 16-Aug-12 | | | | | | | | | | | | IW rough-in industrial water supply H/C S2 | | | | | | | | | | |
| 197 | OH rough-in domestic water supply l | 8 | 15-Oct-12 | 24-Oct-12 | | | | | | | | | | | | OH rough-in domestic water supply H/C S2 | | | | | | | | | | |
| 198 | OH rough-in industrial water supply t | 7 | 15-Oct-12 | 23-Oct-12 | | | | | | | | | | | | OH rough-in industrial water supply H/C S2 | | | | | | | | | | |
| 199 | Penthouse | 87 | 12-Jun-12 | 12-Oct-12 | | | | | | | | | | | | 12-Oct-12, Penthouse | | | | | | | | | | |
| 200 | Install and connect roof drain | 6 | 12-Jun-12 | 19-Jun-12 | | | | | | | | | | | | Install and connect roof drain | | | | | | | | | | |
| 201 | OH rough-in storm pipe S2 | 2 | 20-Jun-12 | 21-Jun-12 | | | | | | | | | | | | OH rough-in storm pipe S2 | | | | | | | | | | |
| 202 | OH rough-in storm pipe S3 | 3 | 21-Jun-12 | 25-Jun-12 | | | | | | | | | | | | OH rough-in storm pipe S3 | | | | | | | | | | |
| 203 | IW rough-in storm pipe S3 | 2 | 03-Oct-12 | 04-Oct-12 | | | | | | | | | | | | IW rough-in storm pipe S3 | | | | | | | | | | |
| 204 | OH rough-in industrial water supply t | 3 | 10-Oct-12 | 12-Oct-12 | | | | | | | | | | | | OH rough-in industrial water supply H/C S2 | | | | | | | | | | |
| 205 | Curtain wall | 63 | 21-May-12 | 17-Aug-12 | | | | | | | | | | | | 17-Aug-12, Curtain wall | | | | | | | | | | |
| 206 | Basement | 7 | 23-May-12 | 01-Jun-12 | | | | | | | | | | | | 01-Jun-12, Basement | | | | | | | | | | |
| 207 | Install curtain wall system S3 | 7 | 23-May-12 | 01-Jun-12 | | | | | | | | | | | | Install curtain wall system S3 | | | | | | | | | | |
| 208 | Level 1 | 33 | 21-May-12 | 06-Jul-12 | | | | | | | | | | | | 06-Jul-12, Level 1 | | | | | | | | | | |
| 209 | Install curtain wall system S2 | 15 | 21-May-12 | 11-Jun-12 | | | | | | | | | | | | Install curtain wall system S2 | | | | | | | | | | |
| 210 | Install curtain wall system S3 | 15 | 15-Jun-12 | 06-Jul-12 | | | | | | | | | | | | Install curtain wall system S3 | | | | | | | | | | |
| 211 | Level 2 | 48 | 12-Jun-12 | 17-Aug-12 | | | | | | | | | | | | 17-Aug-12, Level 2 | | | | | | | | | | |
| 212 | Install curtain wall system S2 | 27 | 12-Jun-12 | 19-Jul-12 | | | | | | | | | | | | Install curtain wall system S2 | | | | | | | | | | |
| 213 | Install curtain wall system S3 | 30 | 09-Jul-12 | 17-Aug-12 | | | | | | | | | | | | Install curtain wall system S3 | | | | | | | | | | |
| 214 | Penthouse | 17 | 20-Jul-12 | 13-Aug-12 | | | | | | | | | | | | 13-Aug-12, Penthouse | | | | | | | | | | |
| 215 | Install curtain wall system S3 | 15 | 20-Jul-12 | 09-Aug-12 | | | | | | | | | | | | Install curtain wall system S3 | | | | | | | | | | |
| 216 | Install curtain wall system S2 | 10 | 31-Jul-12 | 13-Aug-12 | | | | | | | | | | | | Install curtain wall system S2 | | | | | | | | | | |
| 217 | Specialist Trades/Services | 300 | 21-Dec-11 | 22-Feb-13 | | | | | | | | | | | | 22-Feb-13, Specialist Trades/Services | | | | | | | | | | |
| 218 | Site | 208 | 21-Dec-11 | 12-Oct-12 | | | | | | | | | | | | 12-Oct-12, Site | | | | | | | | | | |
| 219 | Install cistern vault | 9 | 21-Dec-11 | 04-Jan-12 | | | | | | | | | | | | Install cistern vault | | | | | | | | | | |
| 220 | Install cistern | 10 | 17-Sep-12 | 28-Sep-12 | | | | | | | | | | | | Install cistern | | | | | | | | | | |
| 221 | Connect piping to cistern | 10 | 01-Oct-12 | 12-Oct-12 | | | | | | | | | | | | Connect piping to cistern | | | | | | | | | | |
| 222 | Basement | 63 | 08-Oct-12 | 07-Jan-13 | | | | | | | | | | | | 07-Jan-13, Basement | | | | | | | | | | |
| 223 | Hang drywall S3 | 4 | 08-Oct-12 | 11-Oct-12 | | | | | | | | | | | | Hang drywall S3 | | | | | | | | | | |
| 224 | Paint walls and ceiling | 30 | 26-Oct-12 | 07-Dec-12 | | | | | | | | | | | | Paint walls and ceiling | | | | | | | | | | |
| 225 | Finish floor | 15 | 14-Dec-12 | 07-Jan-13 | | | | | | | | | | | | Finish floor | | | | | | | | | | |
| 226 | Level 1 | 169 | 21-May-12 | 18-Jan-13 | | | | | | | | | | | | 18-Jan-13, Level 1 | | | | | | | | | | |
| 227 | Install fiber cement siding S2 | 7 | 21-May-12 | 30-May-12 | | | | | | | | | | | | Install fiber cement siding S2 | | | | | | | | | | |
| 228 | Install fiber cement siding S3 | 10 | 15-Jun-12 | 28-Jun-12 | | | | | | | | | | | | Install fiber cement siding S3 | | | | | | | | | | |
| 229 | Hang drywall S3 | 24 | 12-Sep-12 | 15-Oct-12 | | | | | | | | | | | | Hang drywall S3 | | | | | | | | | | |
| 230 | Paint walls S3 | 20 | 04-Oct-12 | 31-Oct-12 | | | | | | | | | | | | Paint walls S3 | | | | | | | | | | |
| 231 | Hang drywall S2 | 20 | 16-Oct-12 | 12-Nov-12 | | | | | | | | | | | | Hang drywall S2 | | | | | | | | | | |

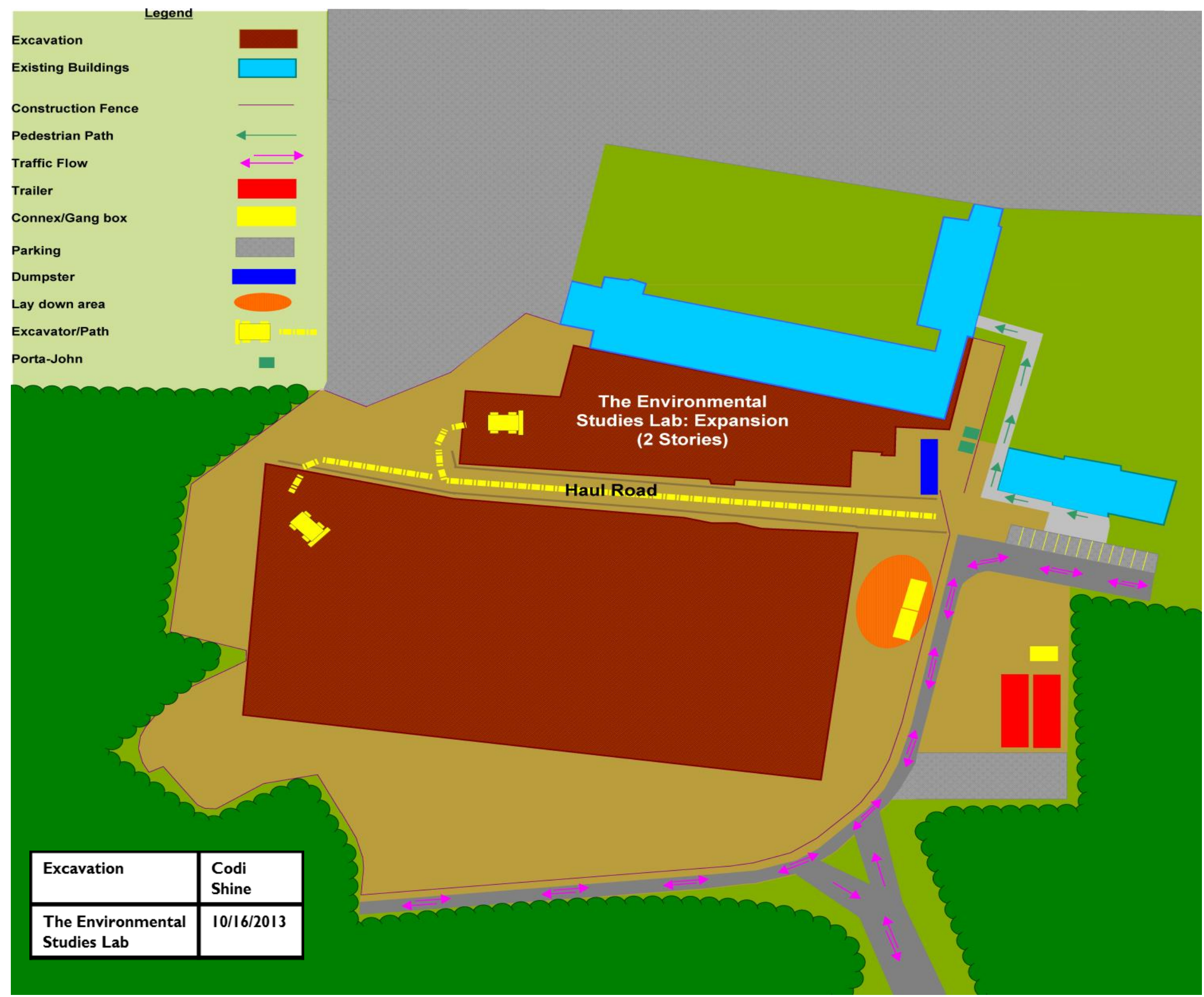
█ Actual Level of Effort
 █ Remaining Work
 █ Critical Remaining Work
 ◆ Milestone
 ▼ summary

Appendix B: Site Layouts



Legend

| | |
|--------------------|--|
| Excavation | |
| Existing Buildings | |
| Construction Fence | |
| Pedestrian Path | |
| Traffic Flow | |
| Trailer | |
| Connex/Gang box | |
| Parking | |
| Dumpster | |
| Lay down area | |
| Excavator/Path | |
| Porta-John | |

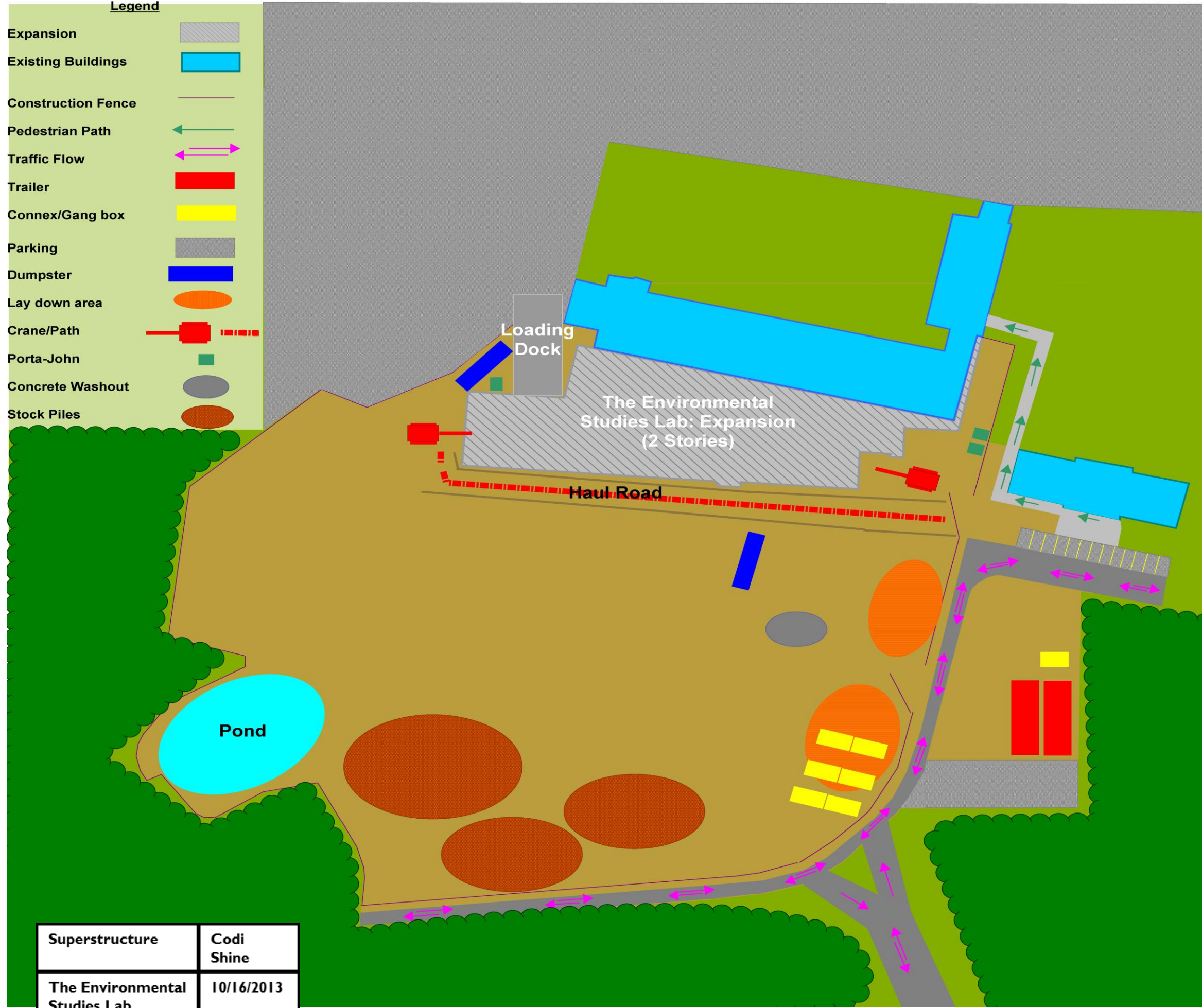


| | |
|-------------------------------|------------|
| Excavation | Codi Shine |
| The Environmental Studies Lab | 10/16/2013 |



Legend






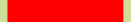







| | |
|--------------------|--|
| Expansion | |
| Existing Buildings | |
| Construction Fence | |
| Pedestrian Path | |
| Traffic Flow | |
| Trailer | |
| Connex/Gang box | |
| Parking | |
| Dumpster | |
| Lay down area | |
| Crane/Path | |
| Porta-John | |
| Concrete Washout | |
| Stock Piles | |

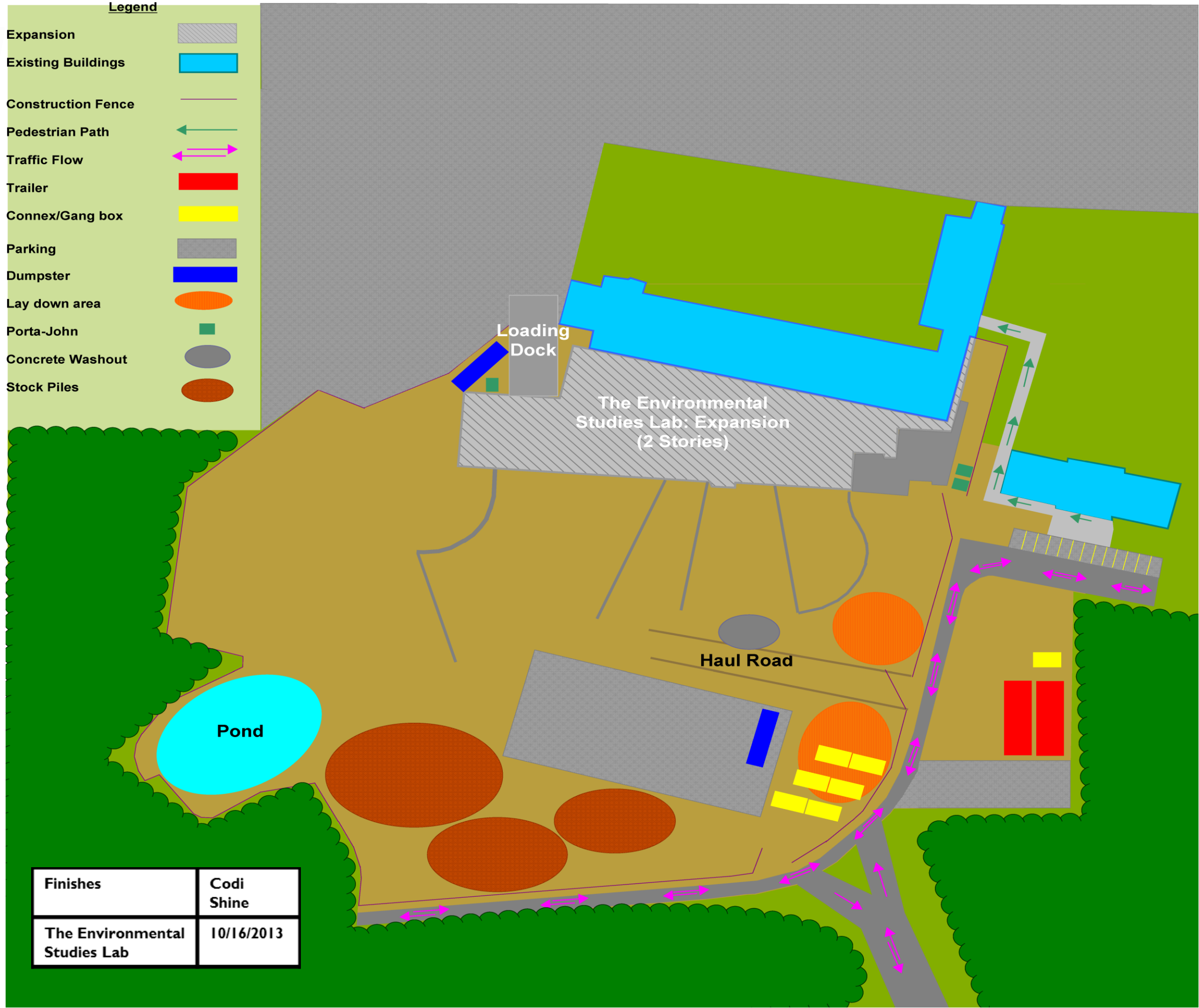


| | |
|-------------------------------|------------|
| Superstructure | Codi Shine |
| The Environmental Studies Lab | 10/16/2013 |



Legend

- Expansion 
- Existing Buildings 
- Construction Fence 
- Pedestrian Path 
- Traffic Flow 
- Trailer 
- Connex/Gang box 
- Parking 
- Dumpster 
- Lay down area 
- Porta-John 
- Concrete Washout 
- Stock Piles 



| | |
|-------------------------------|------------|
| Finishes | Codi Shine |
| The Environmental Studies Lab | 10/16/2013 |

Appendix C: Questionnaire

PROJECT PERFORMANCE QUESTIONNAIRE



Purpose: The University of Colorado at Boulder and Pennsylvania State University are conducting a survey to investigate the role of project delivery methods, contracting terms, procurement, team behavior and technology in project success. Please help us by completing the survey for at least one project you have completed in the last 5 years in the United States. The questionnaire should take between 20-30 minutes to complete. If needed, any follow-up interviews with the respondent will take approximately 15-20 minutes to conduct.

Confidentiality: The project information you provide will be kept in strict confidentiality, within a password protected database. Only the primary investigators and their research assistants will see and have access to your information. In the event of a publication or presentation based on the results of this study, no personal or company identifiable information will be shared.

Participation: Your decision to participate in this research is voluntary and you may withdraw at any time. There is no direct compensation; however, participants may request a copy of the final reports. If you have any questions, complaints or concerns regarding this research, you may contact Dr. Robert Leicht at (814) 863-2080.

Completed questionnaires may be returned by mail or email to:

Dr. Robert Leicht, Dept. of Architectural Engineering, Penn State University
104 Engineering Unit A, University Park, PA 16802
rleicht@enr.psu.edu

SECTION 1: PROJECT CHARACTERISTICS

Project name: Environmental Studies Lab Phase 1
Project location: Last Coast, USA
Your name: _____
Your company name: Hensel Phelps
Phone #: _____ Email: _____

Specify your role on the project:

- Owner Construction Manager (CM)/General Contractor (GC)
 Architect/Designer Design-Builder Other: _____

Owner type: Public Private

Specify the project type (e.g. Office, Hospital) or describe the intended use of the project: Lab

Relative to your experience with similar project types, rate the level of complexity for this project (1=Low, 6=High):

Low 1 2 3 4 5 6 High

Building gross square footage: 72,000 ft²

No. of floors above grade: 3 No. of floors below grade: 1

Percentage (by cost or area): Renovation _____ % New construction 100 %

Select the closest foundation type:

- Slab on grade with spread footings Caissons, piles or slurry walls
 Mat foundation Other: _____

SECTION 2: PROJECT ORGANIZATION

Select the project delivery system best matching the delivery of your project:

- Design-Bid-Build Design-Build (DB)
 Construction Manager at Risk (CM/GC) Integrated Project Delivery

Denote when each project participant was contracted for the project (timing as based on percent of overall design completion):

| | Pre-Design | Concept Design (0-15%) | SD (15-30%) | DD (30-60%) | CD (60-90%) | Bidding (Full CD) |
|------------------------|----------------------------------|------------------------|-----------------------|-----------------------|-----------------------|----------------------------------|
| Architect/Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| GC, CM/GC or DB | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| MEP Contractors | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| Structural Contractors | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |

Were specialty contractors involved before being contracted? Yes No

Relative to your expectations, evaluate the administrative burden you experienced (1=Low, 6=High):

Low 1 2 3 4 5 6 High

SECTION 3: PROJECT COST

What were the following project costs?

Provide separate Construction Costs if known; otherwise, enter Total Project Costs only, indicating whether the cost data provided is estimated (E) or actual (A). Please deduct all property costs, owner costs, costs of installed process or manufacturing equipment, furnishings, fittings and equipment, or items not a cost of the base building.

| | Construction Costs | Total Project Costs |
|----------------|--|--|
| Contract award | <u>35,000,000</u> <input checked="" type="radio"/> E <input type="radio"/> A | <u>37,000,000</u> <input checked="" type="radio"/> E <input type="radio"/> A |
| Final cost | <u>41,000,000</u> <input checked="" type="radio"/> E <input type="radio"/> A | <u>43,000,000</u> <input checked="" type="radio"/> E <input type="radio"/> A |

Estimate the cost of site work (work performed outside the building footprint) included in the project costs listed above: \$ 3,000,000

Are there any unresolved costs or change orders? Yes No

Has the project ever been in litigation?

Yes, resolved Yes, unresolved No

If applicable, are the costs of litigation and/or claims included in the project costs listed above? N/A Yes No

SECTION 4: PROJECT SCHEDULE

Please provide the following schedule information:

| | Planned (mm/dd/yy) | Actual (mm/dd/yy) |
|--|--------------------|-------------------|
| Design start date (Notice to proceed) | | |
| Construction start date (Notice to proceed) | <u>6/1/11</u> | <u>6-1-11</u> |
| Construction end date (Substantial completion) | <u>4/22/13</u> | <u>10/7/13</u> |

SECTION 5: PROJECT QUALITY

If you are the owner, please complete this section. If not, please provide the owner's name or point of contact: _____
phone number or email address: _____

Relative to your expectations, evaluate the facility turnover and operation (1=Low, 6=High):

Difficulty of facility start-up 1 2 3 4 5 6 High
Number and magnitude of call backs 1 2 3 4 5 6 High
Operation and maintenance costs 1 2 3 4 5 6 High

Relative to your expectations, evaluate the quality of the facility and systems (1=Low, 6=High):

Envelope, roof, structure, foundation 1 2 3 4 5 6 High
Interior finishes 1 2 3 4 5 6 High
Environmental systems (lights, HVAC) 1 2 3 4 5 6 High
Exterior aesthetic (style, proportions) 1 2 3 4 5 6 High
Interior environment (mood, feel, image) 1 2 3 4 5 6 High

Rate your overall satisfaction with the design and construction process (1=Not satisfied, 6=Exceeded expectations):

Not satisfied 1 2 3 4 5 6 Exceeded

SECTION 6: PROJECT SAFETY

If you are the builder, please complete this section. If not, please provide the builder's name or point of contact: _____

phone number or email address: _____

Number of recordable injuries: 14 Number of lost time injuries: 2

Work-hours for all onsite construction activities (indicate (E) for estimated or (A) for actual): 1,200,000 E A

SECTION 7: SUSTAINABILITY

Specify any green or sustainable rating system used on this project: LEED

What level of certification was planned and awarded?

Planned: Gold Number of points/credits: _____

Awarded: Platinum Number of points/credits: _____

SECTION 8: TEAM PROCUREMENT & CONTRACTS

Indicate how proposals were solicited from each project participant:

| | Open Bid | Pre-Qualified Bid | 1-Stage RFP | 2-Stage RFP | Sole Source |
|------------------------|-----------------------|----------------------------------|----------------------------------|-----------------------|----------------------------------|
| Architect/Designer | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| GC, CM/GC or DB | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| MEP Contractors | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Structural Contractors | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> |

Which of the following factors were considered in the selection of each project participant (check all that apply)?

| | Price (Fee) | Price (Work) | Tech. Proposal | Design Concept | Similar Experience | Project Performance | Interview |
|------------------------|--------------------------|-------------------------------------|--------------------------|-------------------------------------|--------------------------|--------------------------|--------------------------|
| Architect/Designer | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| GC, CM/GC or DB | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| MEP Contractors | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Structural Contractors | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Select the commercial terms used for the following project participants:

| | Lump Sum | GMP | Unit Price | Cost Plus |
|------------------------|----------------------------------|-----------------------|-----------------------|--|
| Architect/Designer | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| GC, CM/GC or DB | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| MEP Contractors | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |
| Structural Contractors | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> Fixed Fee / <input type="radio"/> % Fee |

Were performance-based incentives used in any contracts? Yes No

Was the operation and maintenance of the facility included in the contract scope of any team member or members? Yes No

Did the project team use a formal partnering agreement? Yes No
If Yes, please explain:

SECTION 9: TEAM CHARACTERISTICS & BEHAVIOR

Indicate the owner's type of relationship with the project team:

Architect/Designer First Time Repeat
GC, CM/GC or DB First Time Repeat

Evaluate each of the following attributes of your project team:

Team's prior experience as a unit (1=Low, 6=High):
Low 1 2 3 4 5 6 High

Team chemistry (1=Poor, 6=Excellent):
Poor 1 2 3 4 5 6 Excellent

Relative to your expectations, denote the frequency of staff turnover within the project team (1=Low, 6=High):
Low 1 2 3 4 5 6 High

When was end-user feedback provided to the project (check all that apply)?

Inception Conceptual DD Construction
 Programming SD CD Operation

Specify when each project participant was co-located or sharing a workspace with other team members (check all that apply):

| | Owner | Architect/Designer | CM/GC | MEP Contractors | Structural Contractors |
|--------------------|--------------------------|--------------------------|--------------------------|-------------------------------------|-------------------------------------|
| Design Phase | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Construction Phase | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |

Evaluate the communication among the project team:

Formality of communication (1=Informal, 6=Formal):

Informal 1 2 3 4 5 6 Formal

Timeliness of communication (1=Never on time, 6=Always on time):

Never 1 2 3 4 5 6 Always

How often did the project team compromise on project issues (1=Never, 6=Frequently)?

Never 1 2 3 4 5 6 Frequently

Did the project team manage a shared, internal contingency usable by both design and construction team members? Yes No

Who participated in setting goals for the project (check all that apply)?

Owner Architect/Designer GC, CM/GC or DB
 MEP Contractors Structural Contractors Other: _____

To what extent were all project team members committed to the same project goals (1=Very Weakly, 6=Very Strongly):

Weakly 1 2 3 4 5 6 Strongly

SECTION 10: PROCESS AND TECHNOLOGY

Number of design charrettes held by the project team: 3

Who was involved with the design charrettes (check all that apply)?

Owner GC, CM/GC or DB Structural Contractors
 Architect/Designer MEP Contractors Other: EXTENSIVE SLIM

How was Building Information Modeling (BIM) used (check all that apply)?

BIM was not used MEP Coordination/Clash Detection
 Architectural Design 4D Scheduling
 Engineered Systems Design Facility Management

Who was involved in developing a BIM execution plan (check all that apply)?

No BIM execution plan was developed for this project
 Owner GC, CM/GC or DB Structural Contractors
 Architect/Designer MEP Contractors Other: _____

To what extent was electronic file and information sharing used by the project team (1=Primarily paper-based, 6=All electronic)?

Paper-based 1 2 3 4 5 6 Electronic

List any lean tools or approaches consistently used by the project team:

Evaluate the level of offsite fabrication and modularization used on the project (1=Entirely built onsite, 6=Entirely built offsite):

Onsite 1 2 3 4 5 6 Offsite

Did any prefabricated or modularized system on the project involve multiple trades? Yes No

SECTION 11: LESSONS LEARNED

Rate the overall success of this project (1=Poor, 6=Excellent):

Poor 1 2 3 4 5 6 Excellent

How could this project have been delivered more successfully?

DESIGN COMPLETION & DESIGN COORDINATION
COULD HAVE BEEN BETTER

Describe any unique features of this project that may have influenced its cost, schedule, quality or sustainability:

EXTERIOR SKIN OF THE BUILDING
GEO THERMAL WELLS

Appendix D: Analysis 1 Calculations

| Building Name | Building Type | Delivery Method | Square Foot | NTP | Project End | Project Duration |
|-----------------------|-------------------------------|-----------------|-------------|----------|-------------|------------------|
| Environmental Studies | Lab | DBB | 72,000 | 06/01/11 | 10/17/13 | 622 |
| | Naval Base | DB | 99,460 | 04/30/09 | 05/12/11 | 531 |
| | Health Care | IPD | 4,350,100 | 04/14/08 | 09/12/12 | 1153 |
| | Municipal building | DB | 520,000 | 12/23/10 | 08/17/12 | 432 |
| | Transportation | DB | 71,336 | 06/02/11 | 04/22/13 | 493 |
| | Office/Training/ Warehouse | DB | 41,155 | 03/14/12 | 04/24/13 | 291 |
| | Transportation | DB | 2,656,300 | 10/17/06 | 06/30/10 | 967 |
| | Office | DB | 250,000 | 08/01/07 | 08/01/09 | 525 |
| | | DB | 449,000 | 06/03/11 | On Schedule | NA |
| | Museum | DB | 47,000 | 12/07/09 | 11/10/12 | 766 |
| | Hanger-Commercial | DB | 60,000 | 11/03/11 | 08/01/13 | 456 |

| Start Actual Date | Finish Plan date | Finish Actual date | Construction Duration | Initial Construction Cost | Final Construction Cost | Cost/Sq Ft | Intensity | Construction Speed | Delivery Duration |
|-------------------|------------------|--------------------|-----------------------|---------------------------|-------------------------|------------|--------------|--------------------|-------------------|
| 6/15/11 | 04/22/13 | 10/07/13 | 604 | 33,981,000 | 35,358,000 | \$491 | \$1,756,192 | 3576 | 3473 |
| 10/22/09 | 05/15/11 | 05/12/11 | 406 | 53,787,000 | 54,518,970 | \$548 | \$4,028,495 | 7349 | 5619 |
| 5/28/09 | 08/31/12 | 02/09/12 | 706 | 352,852,000 | 272,892,000 | \$63 | \$11,595,977 | 184848 | 113186 |
| 2/28/11 | 06/29/12 | 07/22/12 | 366 | 49,177,044 | 53,396,376 | \$103 | \$4,376,752 | 42623 | 36111 |
| 8/10/11 | 08/01/13 | 04/22/13 | 444 | 25,900,000 | 32,832,966 | \$460 | \$2,218,444 | 4820 | 4341 |
| 5/21/12 | 05/31/13 | 04/24/13 | 243 | 8,256,000 | 10,309,714 | \$251 | \$1,272,804 | 5081 | 4243 |
| 7/1/07 | 06/30/10 | 06/30/10 | 784 | 512,771,000 | 669,456,000 | \$252 | \$25,616,939 | 101644 | 82408 |
| 8/1/07 | 06/01/09 | 06/01/09 | 479 | 92,860,000 | 92,727,765 | \$371 | \$5,807,584 | 15658 | 14286 |
| 1/3/12 | 12/16/15 | On Schedule | NA | 141,231,044 | TBD | NA | NA | NA | NA |
| 8/7/10 | 08/23/11 | 11/09/12 | 591 | 11,400,000 | 12,562,509 | \$267 | \$637,691 | 2386 | 1841 |
| 3/13/12 | 06/24/13 | 06/24/13 | 335 | 19,498,000 | 19,744,063 | \$329 | \$1,768,125 | 5373 | 3947 |

Project Outcome Metrics

| Metric | Equation |
|--------------------------------|---|
| Unit cost (\$/SF) | Actual project cost / Gross square-footage |
| Cost growth (%) | $[(\text{Actual project cost} - \text{Initial project cost}) / \text{Initial project cost}] \times 100$ |
| Intensity (\$/SF/Month) | Unit cost / (Actual project duration in days / 30) |
| Schedule growth (%) | $[(\text{Actual project duration in days} - \text{Initial project duration in days}) / \text{Initial project duration in days}] \times 100$ |
| Delivery speed (SF/Month) | Gross square-footage / (Actual project duration in days / 30) |
| Construction speed (SF/Month) | Gross square-footage / (Actual construction duration in days / 30) |
| Turnover quality (Sum ratings) | Start-up difficulty + Call back frequency + O&M costs |
| System quality (Sum ratings) | Structure & envelope expectations met + Interior expectations met + Environmental system expectations met |
| Design quality (Sum ratings) | Aesthetic expectations met + Functional expectations met |
| Sustainability | LEED certification level |

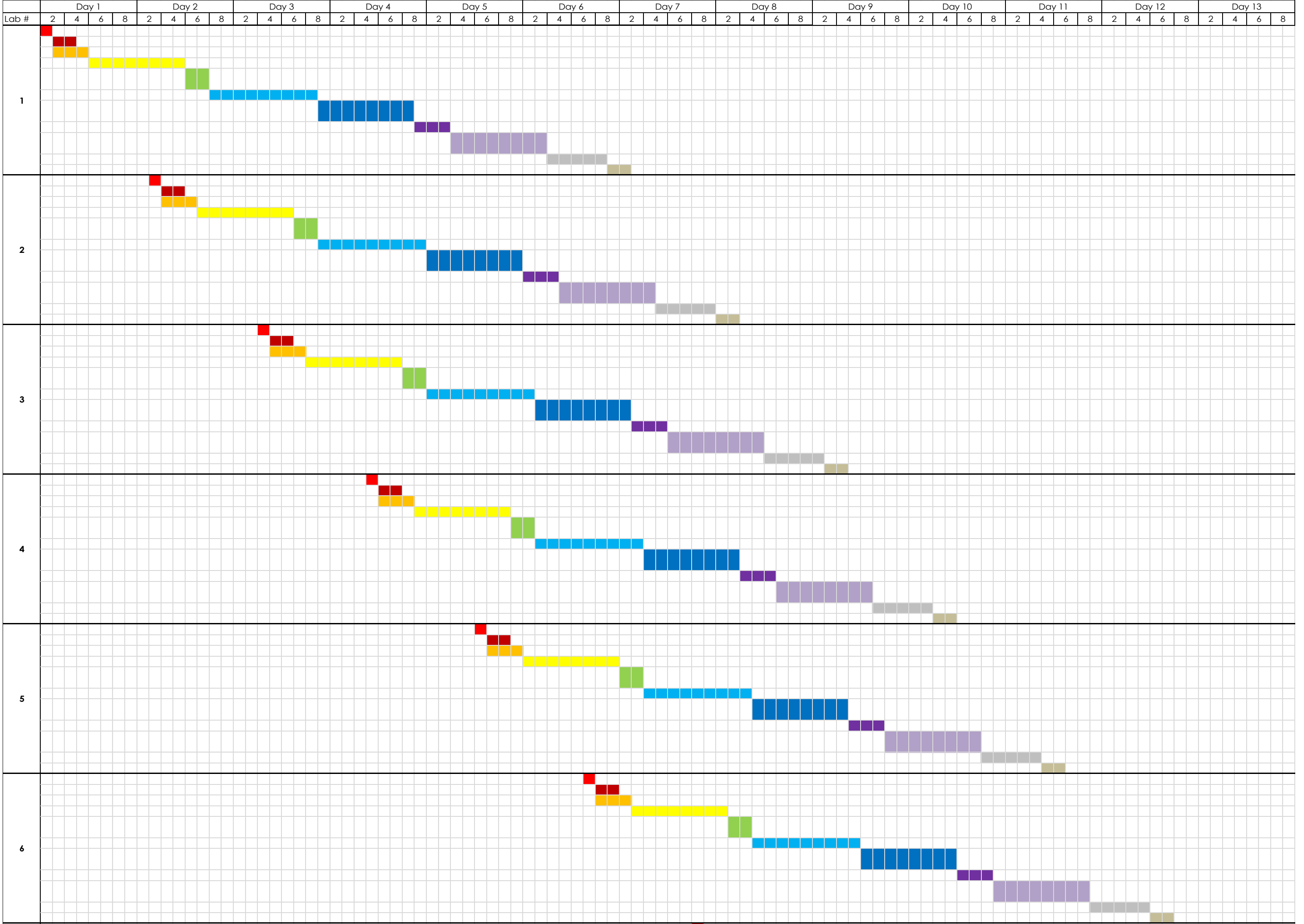
Information courtesy of Mark Konchar's Thesis Dissertation.

Appendix E: Calculations of the workers and activities

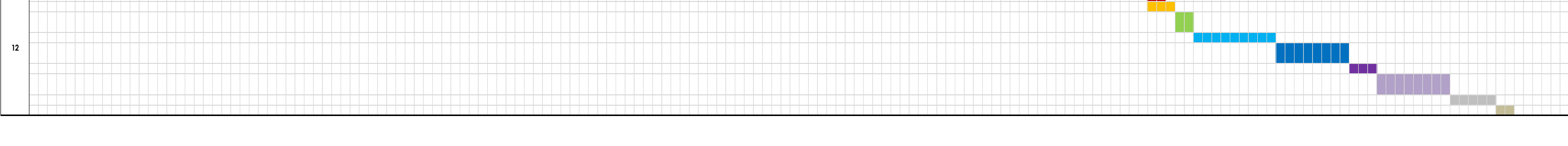
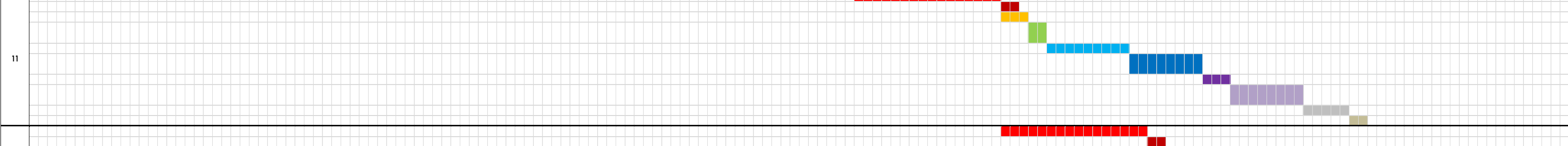
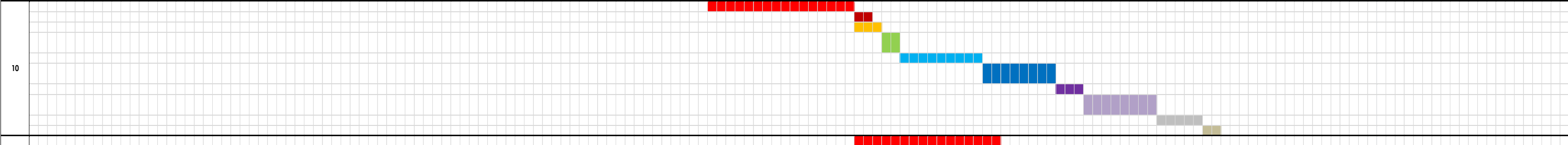
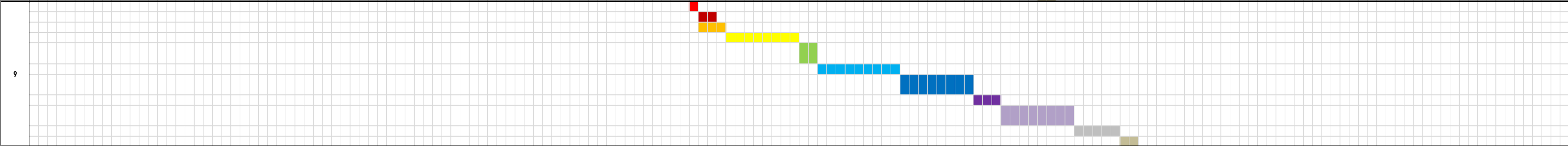
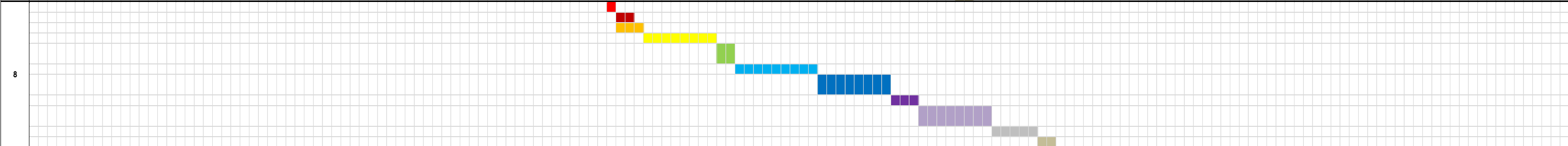
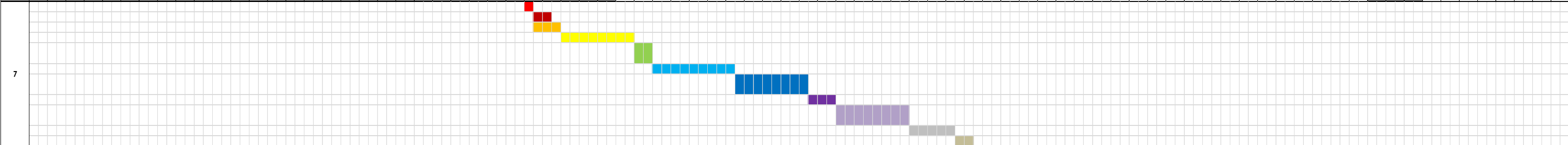
| First Floor | | | | | | | | | |
|-------------------------------------|------------|--------------|-------------|-----------|--------------|-------------------------|--------------------|--------------------|--------------------|
| Activity | Days/Floor | Crew Members | Hours/floor | Hours/lab | Hours/Worker | SIPS 1 & 2 Crew Members | Adjusted Hours/lab | SIPS 3Crew Members | Adjusted Hours/lab |
| Layout | 1 | 1 | 8 | 0.89 | 0.89 | 1 | 0.89 | 1 | 0.89 |
| Install Sleeves | 2 | 1 | 16 | 1.78 | 1.78 | 1 | 1.78 | 1 | 1.78 |
| Install Hangers/Anchors | 3 | 2 | 24 | 2.67 | 1.33 | 2 | 2.67 | 2 | 2.67 |
| Unload and Distribute Duct Sections | 2 | 2 | 16 | 1.78 | 0.89 | 2 | 1.78 | 2 | 1.78 |
| Layout/Rough-in | 9 | 1 | 72 | 8.00 | 8.00 | 2 | 4.00 | 2 | 4.00 |
| Hang Trunk Lines | 10 | 3 | 80 | 8.89 | 2.96 | 4 | 6.67 | 4 | 6.67 |
| Install Medium Pressure Branch | 9 | 3 | 72 | 8.00 | 2.67 | 4 | 6.00 | 5 | 4.80 |
| Install SACs, EACs | 3.5 | 2 | 28 | 3.11 | 1.56 | 2 | 3.11 | 2 | 3.11 |
| Install Low Pressure Branch | 9 | 3 | 72 | 8.00 | 2.67 | 4 | 6.00 | 5 | 4.80 |
| Hard Duct Taps (Exhaust) | 6 | 3 | 48 | 5.33 | 1.78 | 3 | 5.33 | 3 | 5.33 |
| Install RGD | 2 | 1 | 16 | 1.78 | 1.78 | 1 | 1.78 | 1 | 1.78 |
| | | | | | | | | | |
| Total | | 22.00 | 452 | 50.22 | | 26 | 40.00 | 34 | 37.60 |

| Second Floor | | | | | | | | | |
|-------------------------------------|------------|--------------|-----------|-----------|--------------|---------------------|--------------------|--------------------|--------------------|
| Activity | Days/Floor | Crew Members | Hours/day | Hours/lab | Hours/Worker | SIPS 1 Crew Members | Adjusted Hours/lab | SIPS 3Crew Members | Adjusted Hours/lab |
| Layout/Rough-in | 18 | 1 | 144 | 16.00 | 16.00 | 3 | 5.33 | 3 | 5.33 |
| Install Sleeves | 2 | 1 | 16 | 1.78 | 1.78 | 1 | 1.78 | 1 | 1.78 |
| Install Hangers/Anchors | 3 | 2 | 24 | 2.67 | 1.33 | 2 | 2.67 | 2 | 2.67 |
| Unload and Distribute Duct Sections | 2 | 2 | 16 | 1.78 | 0.89 | 2 | 1.78 | 2 | 1.78 |
| Hang Trunk Lines | 10 | 3 | 80 | 8.89 | 2.96 | 4 | 6.67 | 4 | 6.67 |
| Install Medium Pressure Branch | 9 | 3 | 72 | 8.00 | 2.67 | 4 | 6.00 | 5 | 4.80 |
| Install SACs, EACs | 3.5 | 2 | 28 | 3.11 | 1.56 | 2 | 3.11 | 2 | 3.11 |
| Install Low Pressure Branch | 9 | 3 | 72 | 8.00 | 2.67 | 4 | 6.00 | 5 | 4.80 |
| Hard Duct Taps (Exhaust) | 6 | 3 | 48 | 5.33 | 1.78 | 3 | 5.33 | 3 | 5.33 |
| Install RGD | 2 | 1 | 16 | 1.78 | 1.78 | 1 | 1.78 | 1 | 1.78 |
| | | | | | | | | | |
| Total | | 21.00 | 516 | 57.33 | | 26 | 40.44 | 32 | 38.04 |

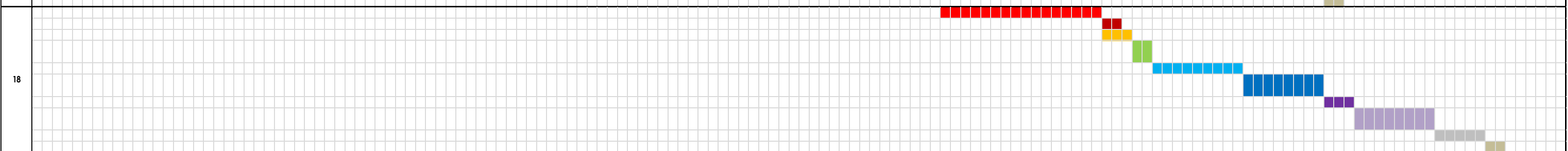
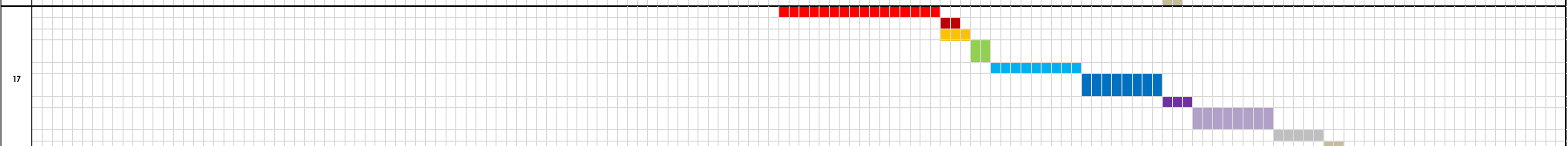
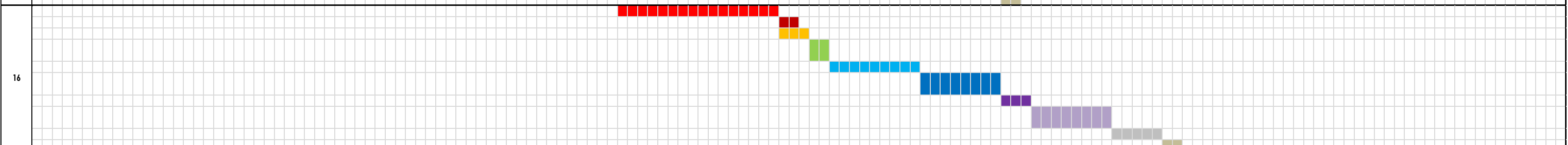
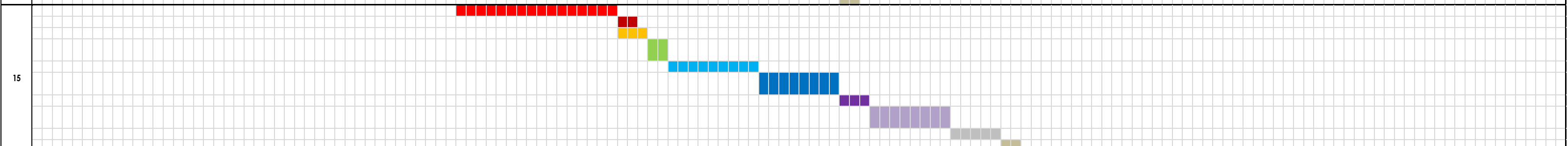
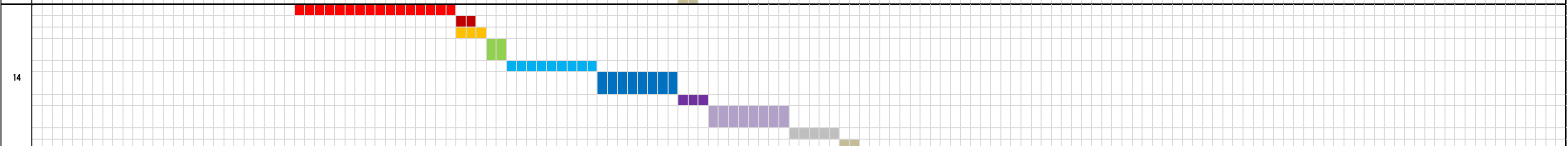
Appendix F: Complete SIPS of the Original Durations



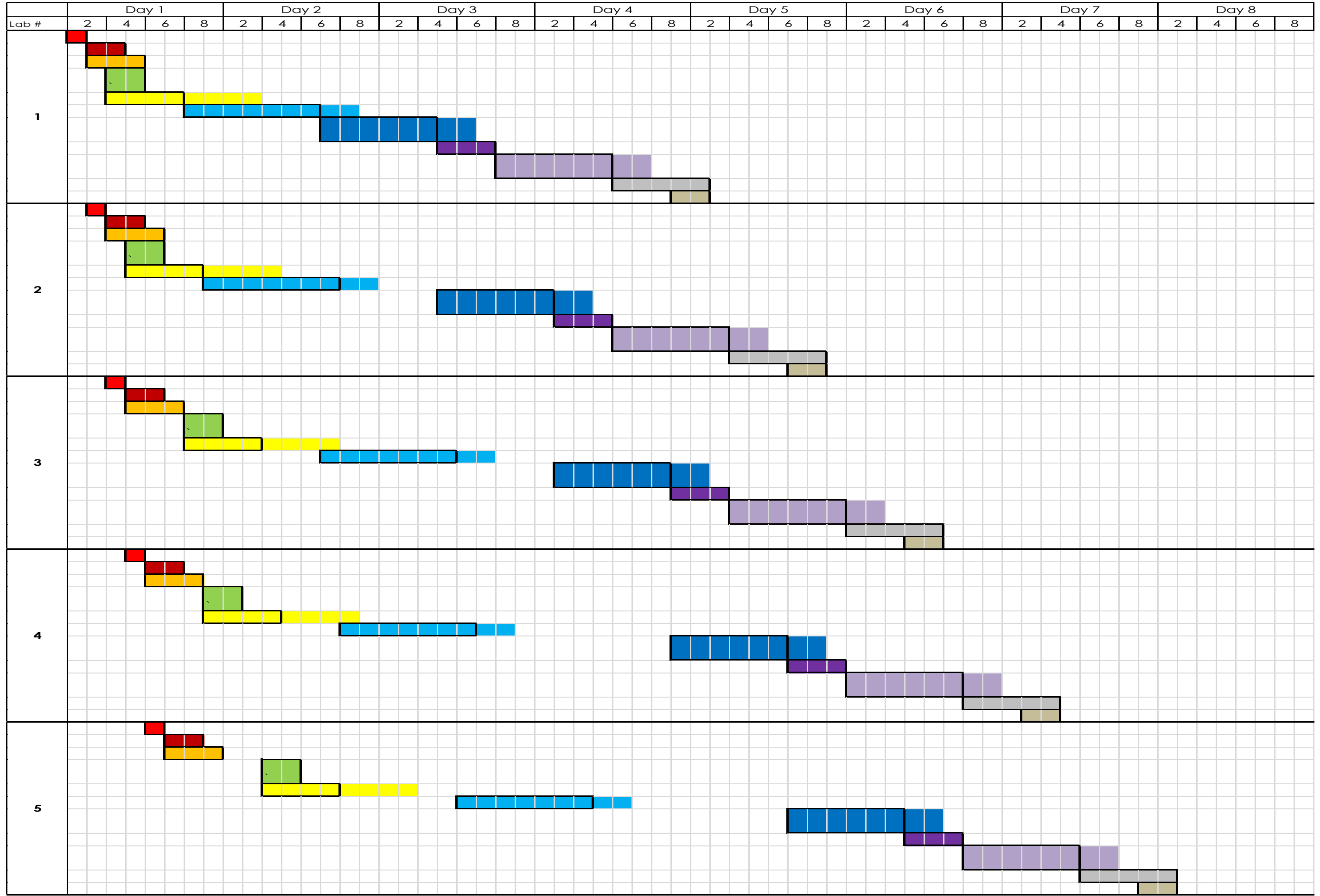
| Lab # | Day 1 | | | | Day 2 | | | | Day 3 | | | | Day 4 | | | | Day 5 | | | | Day 6 | | | | Day 7 | | | | Day 8 | | | | Day 9 | | | | Day 10 | | | | Day 11 | | | | Day 12 | | | | Day 13 | | | | Day 14 | | | | Day 15 | | | | Day 16 | | | | Day 17 | | | | Day 18 | | | | Day 19 | | | | Day 20 | | | | Day 21 | | | |
|-------|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|
|-------|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|-------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|--------|--|--|--|

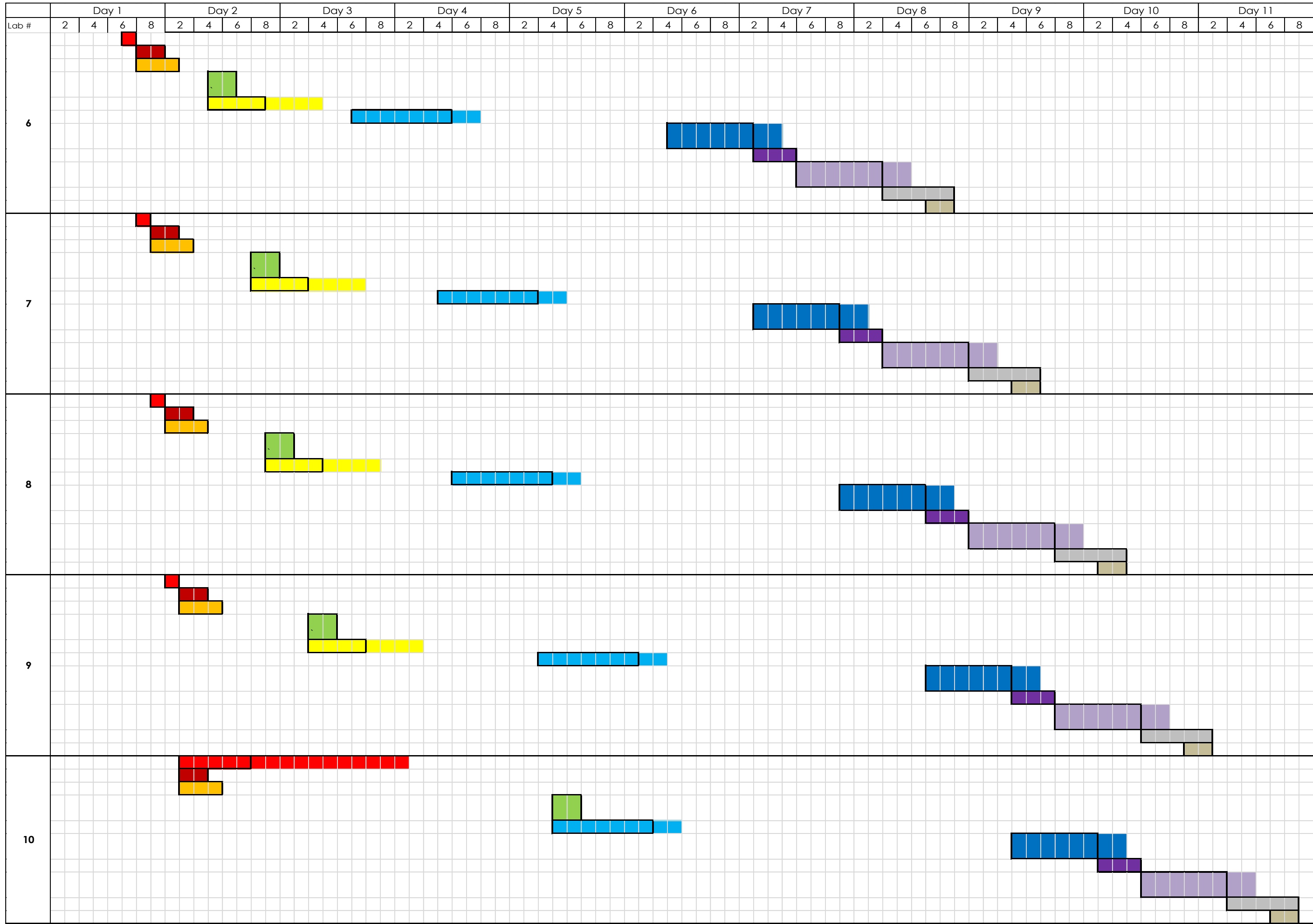


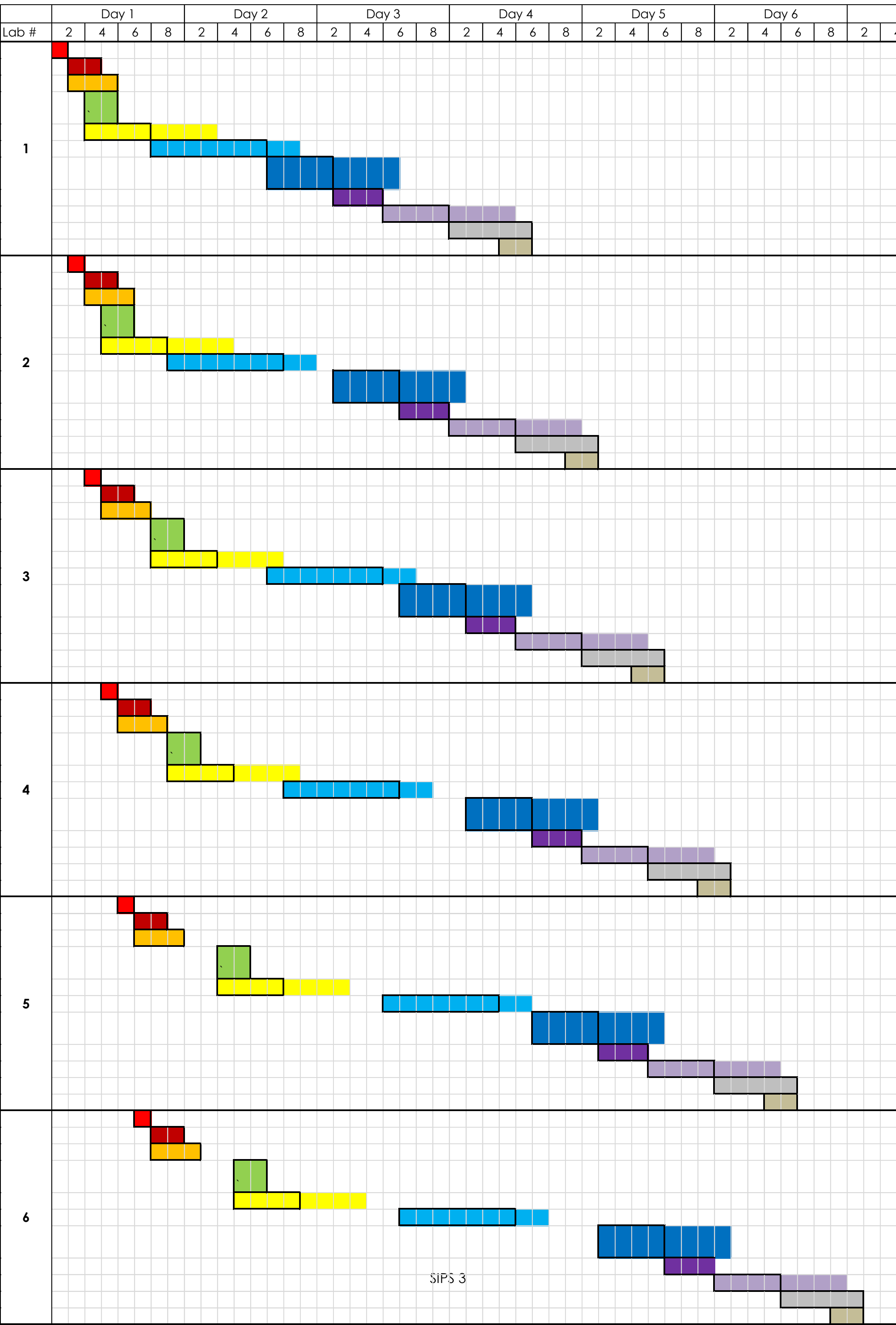
| Lab # | Day 1 | | | | Day 16 | | | | Day 17 | | | | Day 18 | | | | Day 19 | | | | Day 20 | | | | Day 21 | | | | Day 22 | | | | Day 23 | | | | Day 24 | | | | Day 25 | | | | Day 26 | | | | Day 27 | | | | Day 28 | | | | Day 29 | | | | Day 30 | | | | Day 31 | | | | Day 32 | | | | Day 33 | | | | | | | | | | |
|-------|-------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|--------|---|---|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 | 8 | 2 | 4 | 6 |



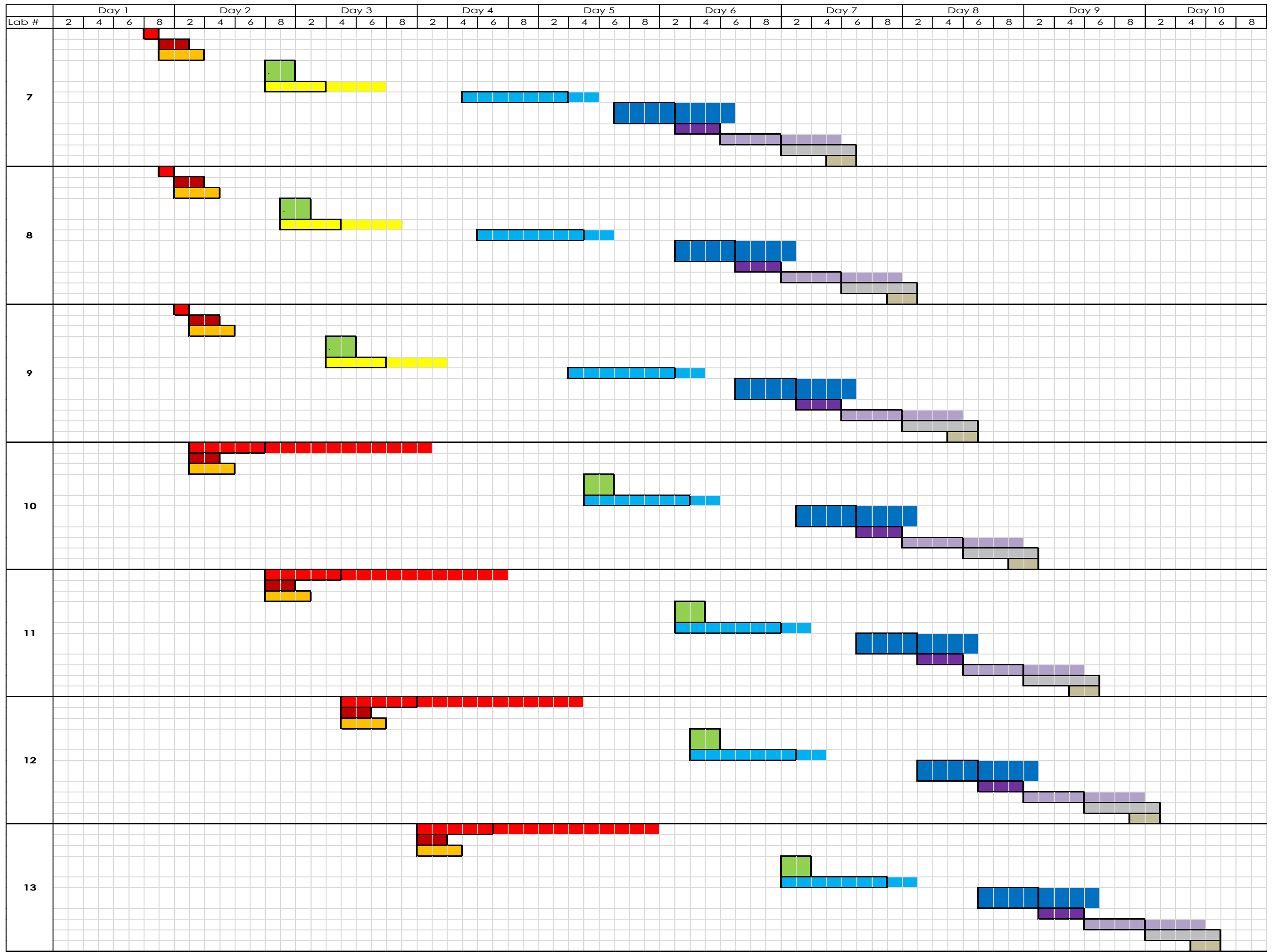
Appendix G: SIPS Options

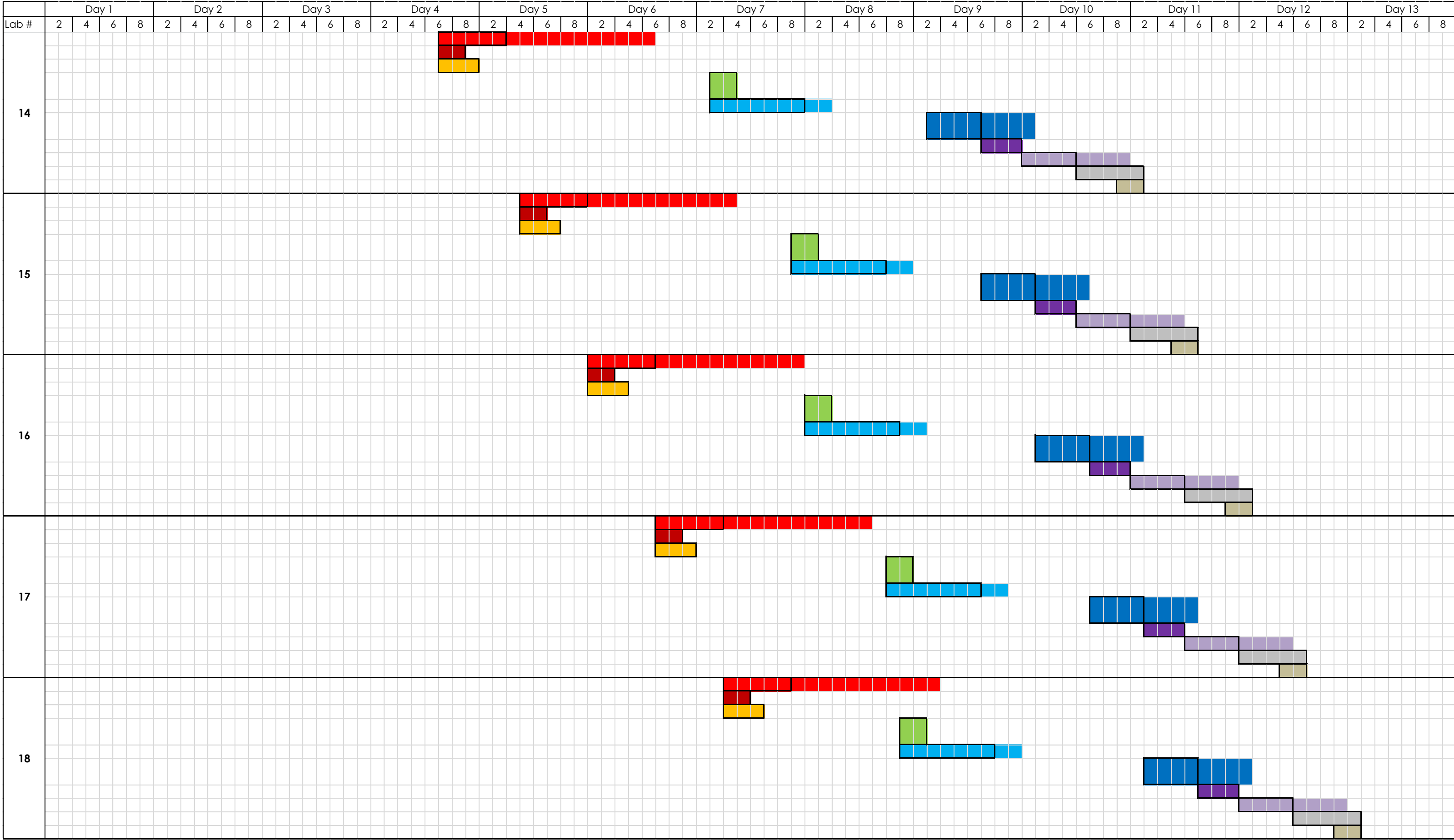






SIPS 3

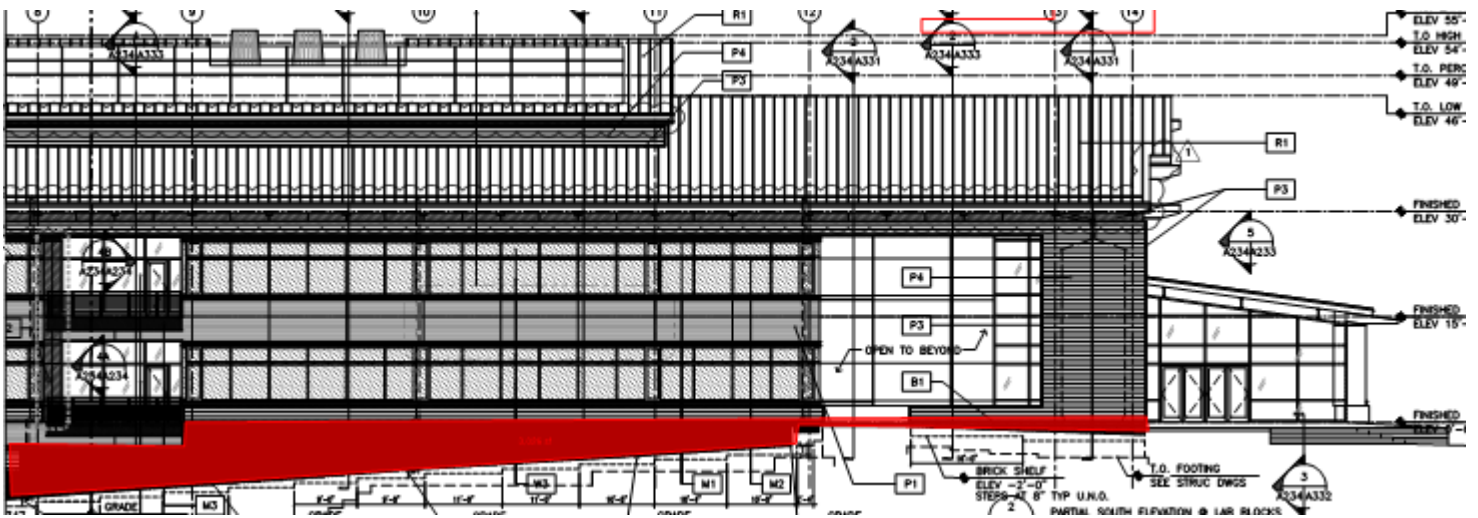
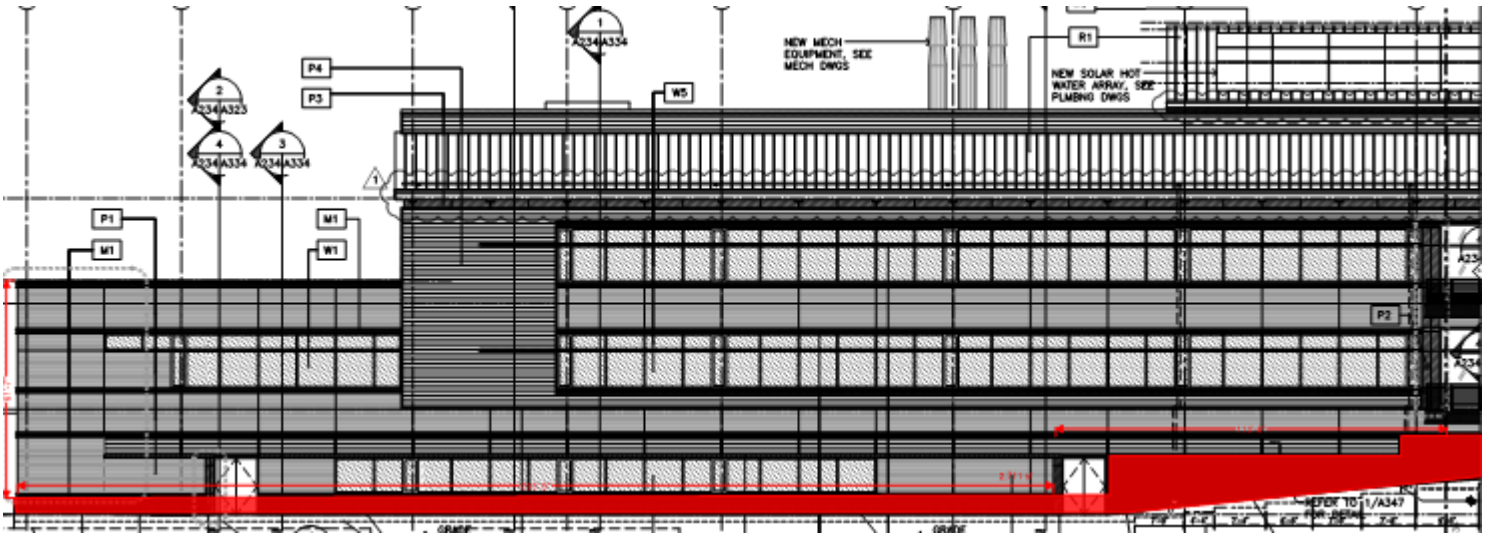




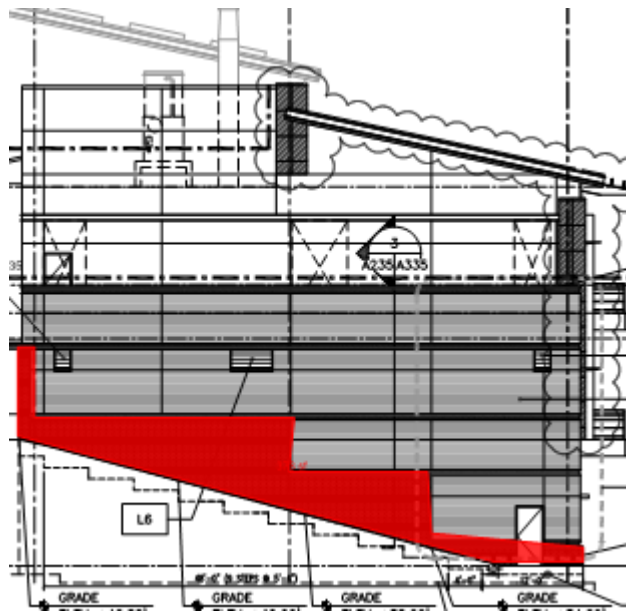
Appendix H: Façade Changes

Changes to Brick:

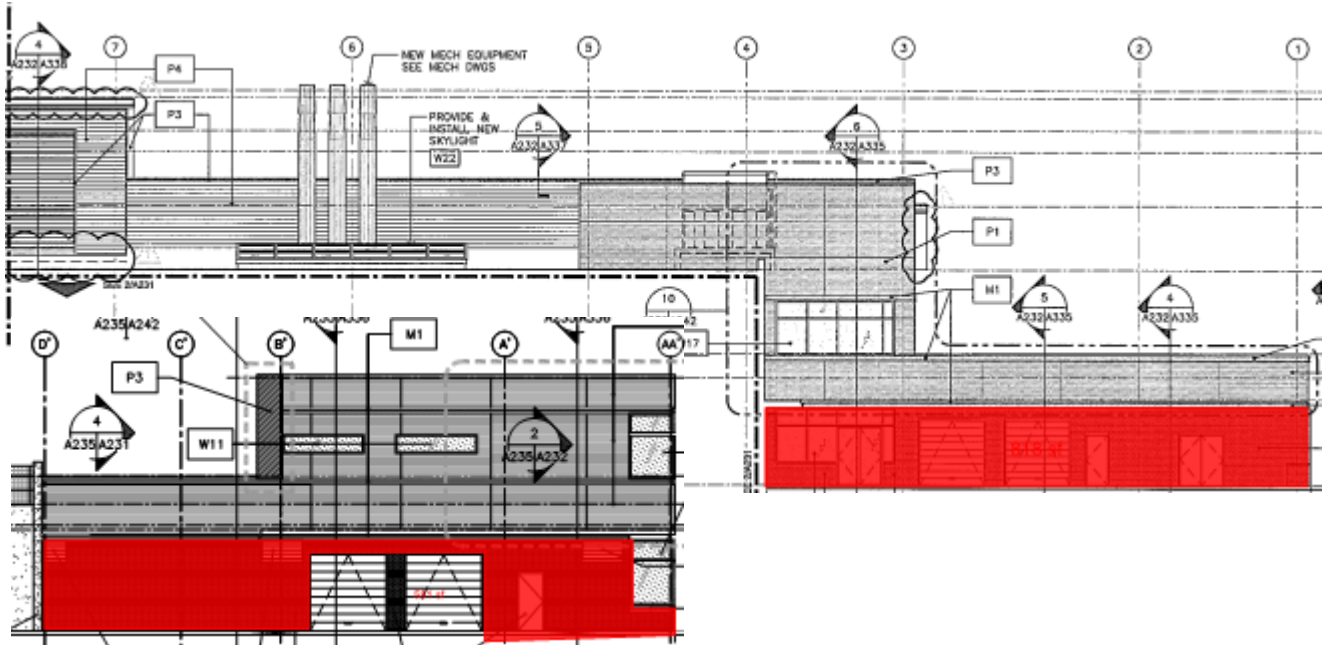
South



West

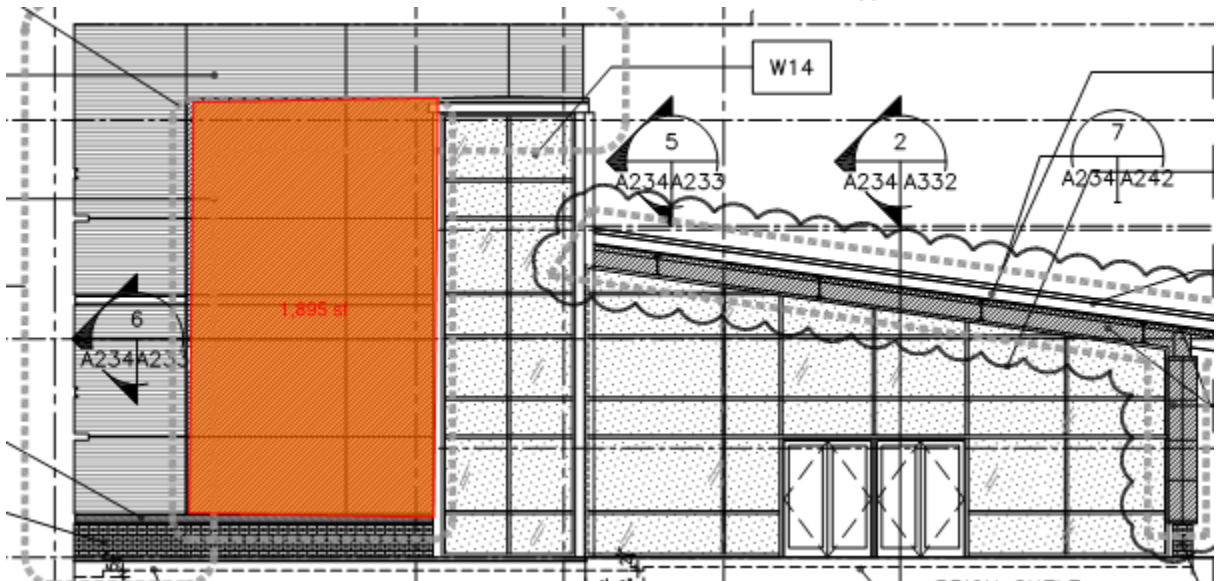
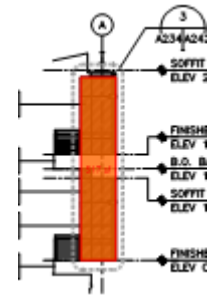


North



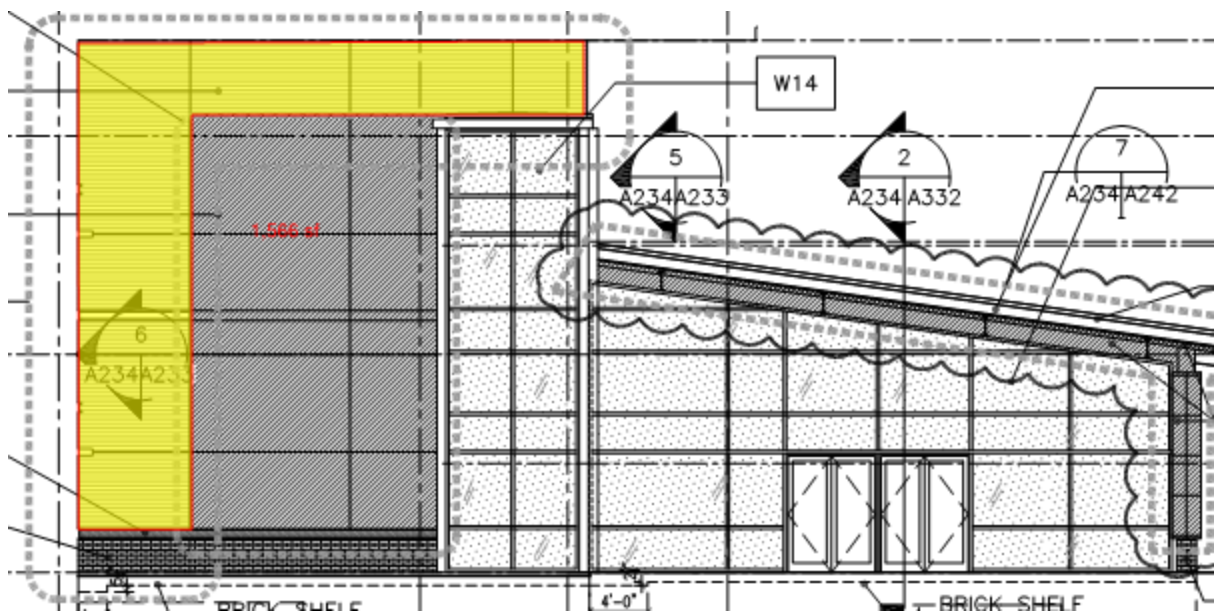
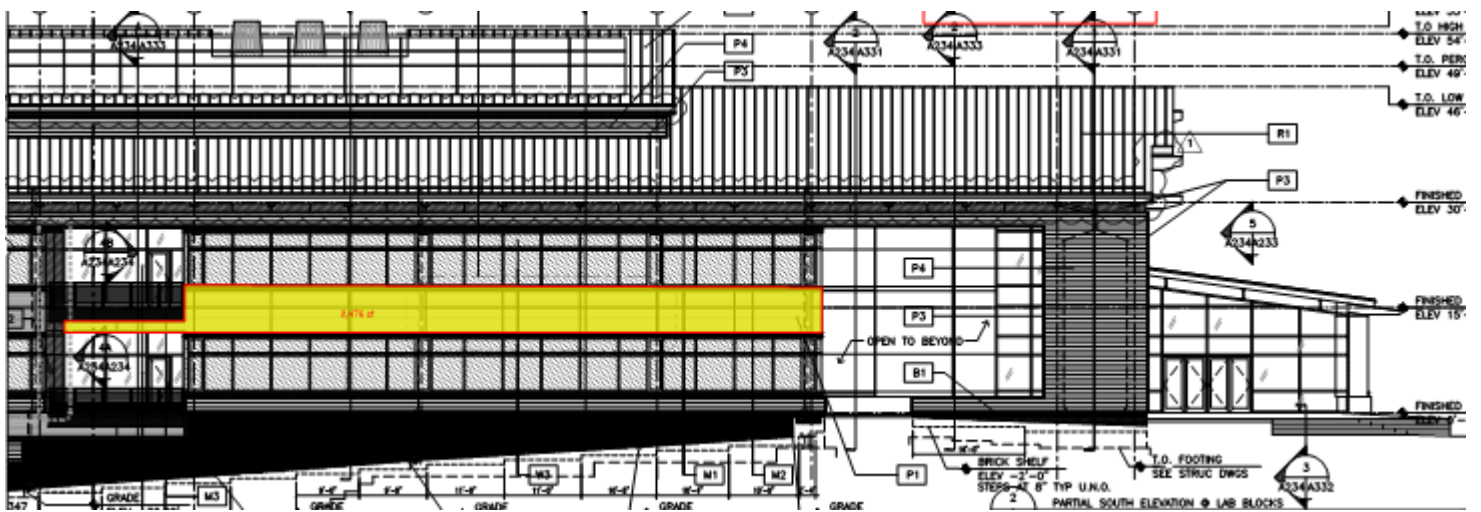
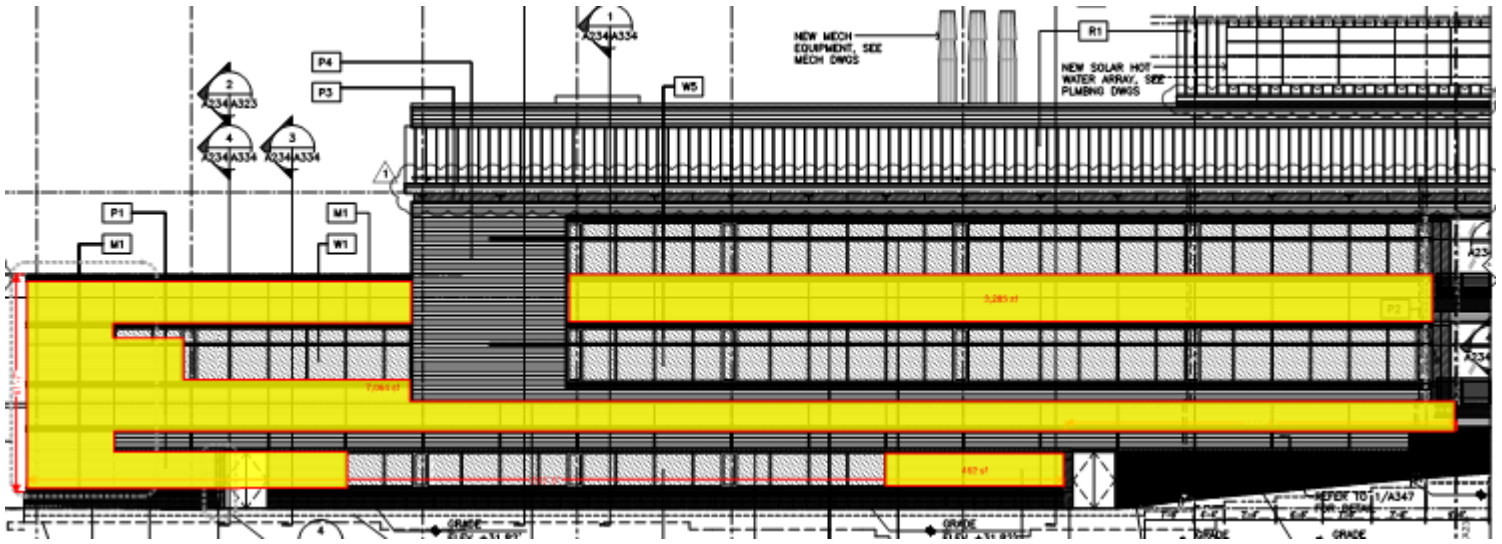
Changes to Composite Metal Panels

South

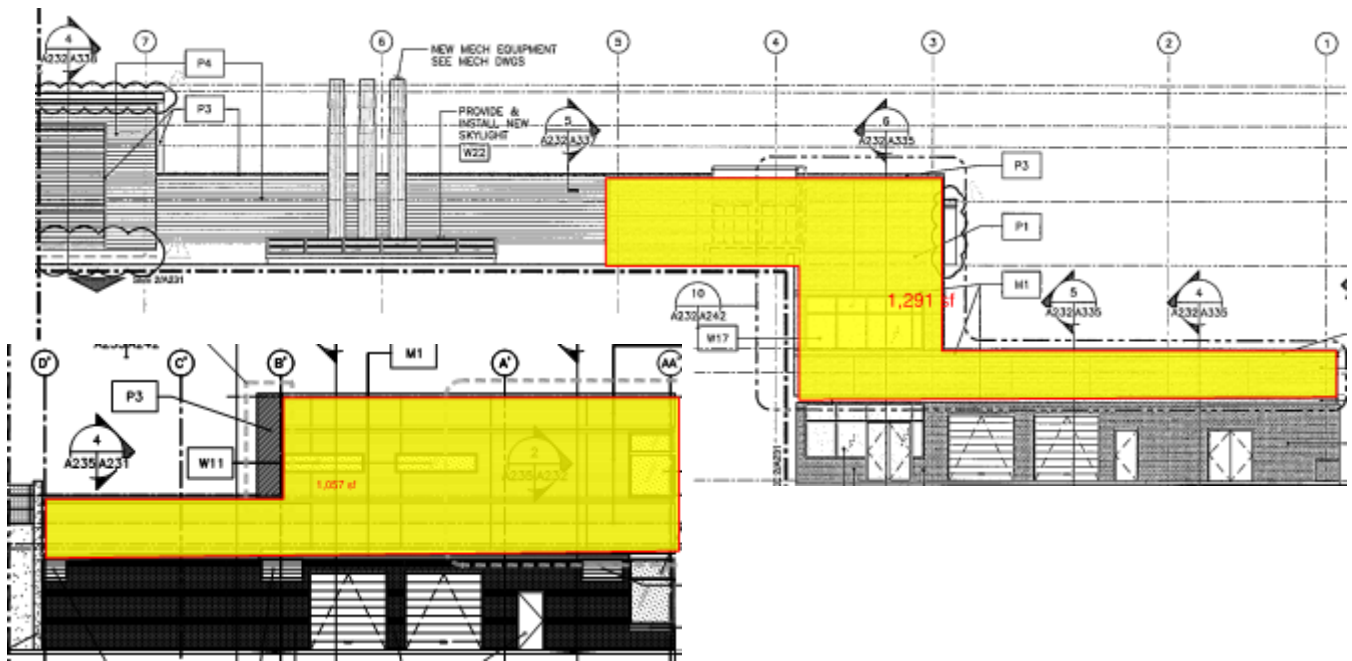


Changes to Corrugated Metal Panels

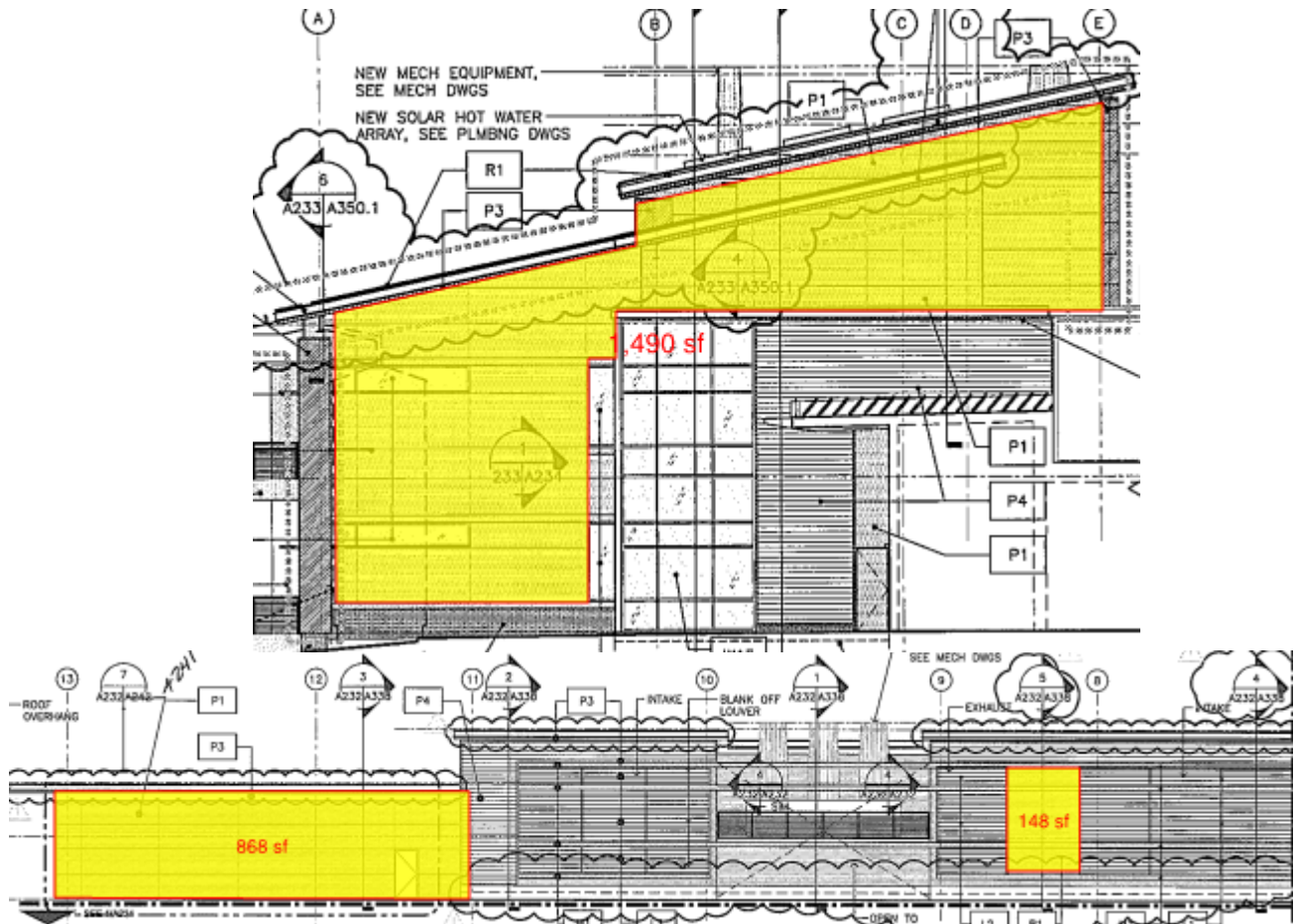
South



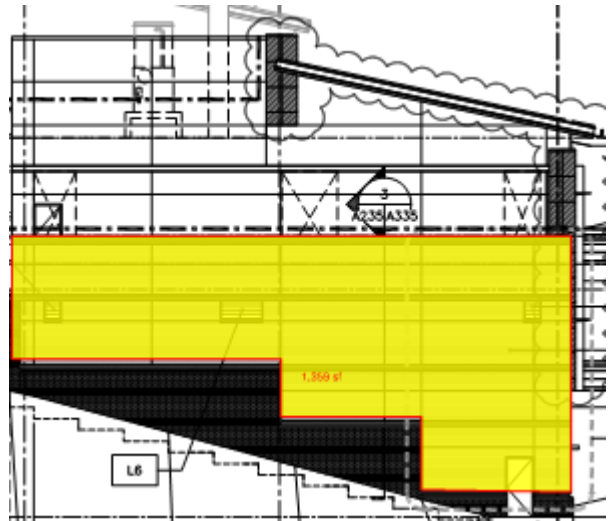
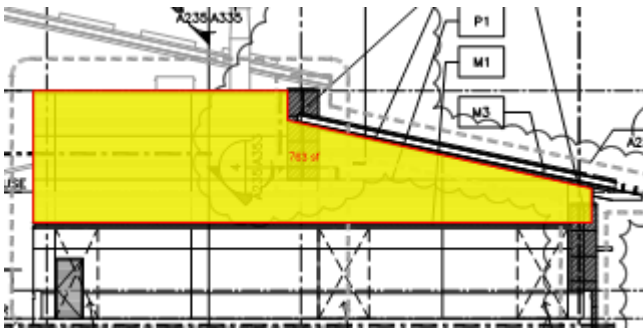
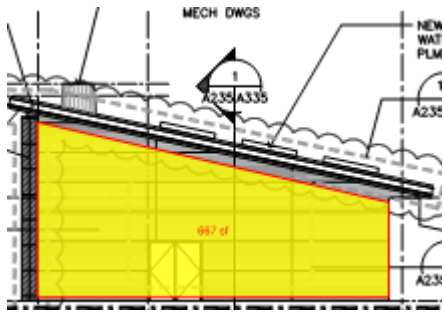
North



East



West



Appendix I: Final Schedule

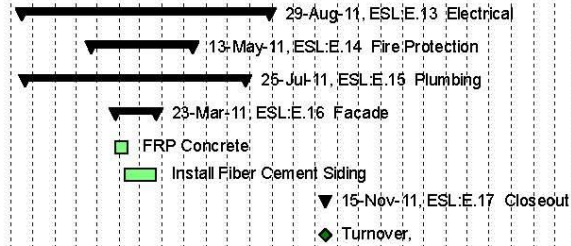
Environmental Studies Lab: Expansion

| Activity Name | Original Duration | Start | Finish | 2009 | | 2010 | | | | 2011 | | | | 2012 | | | | 2013 | | | |
|---|-------------------|-----------|-----------|------------------|----|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|--|
| | | | | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | |
| | | | | Gantt Chart Area | | | | | | | | | | | | | | | | | |
| ESL:E Environmental Studies Lab: E | 1039 | 23-Mar-09 | 10-Apr-13 | | | | | | | | | | | | | | | | | | |
| ESL:E.2 Pre-Design | 75 | 23-Mar-09 | 03-Jul-09 | | | | | | | | | | | | | | | | | | |
| ESL:E.3 Schematic Design | 14 | 29-Jun-09 | 17-Jul-09 | | | | | | | | | | | | | | | | | | |
| Prepare SD drawings | 10 | 29-Jun-09 | 10-Jul-09 | | | | | | | | | | | | | | | | | | |
| Fundamental design report | 11 | 29-Jun-09 | 13-Jul-09 | | | | | | | | | | | | | | | | | | |
| Issue SD package | 0 | 17-Jul-09 | | | | | | | | | | | | | | | | | | | |
| ESL:E.4 Design Development 35% | 24 | 10-Aug-09 | 11-Sep-09 | | | | | | | | | | | | | | | | | | |
| Prepare DD drawings | 20 | 10-Aug-09 | 04-Sep-09 | | | | | | | | | | | | | | | | | | |
| Issue DD package | 0 | 11-Sep-09 | | | | | | | | | | | | | | | | | | | |
| Notice of Award | 0 | 11-Sep-09 | | | | | | | | | | | | | | | | | | | |
| ESL:E.5 Design Development 65% | 49 | 14-Sep-09 | 20-Nov-09 | | | | | | | | | | | | | | | | | | |
| Advance DD documents to Construction Document level | 20 | 14-Sep-09 | 09-Oct-09 | | | | | | | | | | | | | | | | | | |
| Prepare DD drawings | 25 | 12-Oct-09 | 13-Nov-09 | | | | | | | | | | | | | | | | | | |
| Prepare DD specs | 25 | 12-Oct-09 | 13-Nov-09 | | | | | | | | | | | | | | | | | | |
| Issue DD package | 0 | 20-Nov-09 | | | | | | | | | | | | | | | | | | | |
| ESL:E.6 Construction Documents 95% | 835 | 04-Jan-10 | 10-Apr-13 | | | | | | | | | | | | | | | | | | |
| Prepare drawings | 35 | 04-Jan-10 | 19-Feb-10 | | | | | | | | | | | | | | | | | | |
| Prepare specs | 35 | 04-Jan-10 | 19-Feb-10 | | | | | | | | | | | | | | | | | | |
| Notice to Proceed | 0 | 19-Feb-10 | | | | | | | | | | | | | | | | | | | |
| Submittals | 800 | 22-Feb-10 | 10-Apr-13 | | | | | | | | | | | | | | | | | | |
| Issue 95% CD package | 0 | 01-Mar-10 | | | | | | | | | | | | | | | | | | | |
| ESL:E.7 Construction Documents 100% | 115 | 22-Feb-10 | 03-Aug-10 | | | | | | | | | | | | | | | | | | |
| Obtain approved permits | 43 | 22-Feb-10 | 21-Apr-10 | | | | | | | | | | | | | | | | | | |
| Prepare drawings | 5 | 12-Apr-10 | 16-Apr-10 | | | | | | | | | | | | | | | | | | |
| Prepare specs | 5 | 12-Apr-10 | 16-Apr-10 | | | | | | | | | | | | | | | | | | |
| Issue 100% CD package | 0 | 19-Apr-10 | | | | | | | | | | | | | | | | | | | |
| Prepare & Approve Baseline CPM schedule | 75 | 19-Apr-10 | 03-Aug-10 | | | | | | | | | | | | | | | | | | |
| ESL:E.8 Construction | 330 | 03-Aug-10 | 16-Nov-11 | | | | | | | | | | | | | | | | | | |
| ESL:E.9 Earthwork | 255 | 03-Aug-10 | 02-Aug-11 | | | | | | | | | | | | | | | | | | |
| ESL:E.10 Concrete | 260 | 09-Aug-10 | 15-Aug-11 | | | | | | | | | | | | | | | | | | |
| ESL:E.11 Structural Steel | 44 | 17-Nov-10 | 20-Jan-11 | | | | | | | | | | | | | | | | | | |
| ESL:E.12 HVAC | 254 | 29-Jul-10 | 27-Jul-11 | | | | | | | | | | | | | | | | | | |
| Site HVAC | 126 | 29-Jul-10 | 26-Jan-11 | | | | | | | | | | | | | | | | | | |
| Basement HVAC | 187 | 16-Sep-10 | 09-Jun-11 | | | | | | | | | | | | | | | | | | |
| Penthouse HVAC | 124 | 02-Feb-11 | 27-Jul-11 | | | | | | | | | | | | | | | | | | |
| Lab 1 | 4 | 08-Apr-11 | 13-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 2 | 4 | 08-Apr-11 | 13-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 3 | 4 | 08-Apr-11 | 13-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 4 | 5 | 08-Apr-11 | 14-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 5 | 5 | 08-Apr-11 | 14-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 6 | 6 | 08-Apr-11 | 15-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 7 | 6 | 11-Apr-11 | 18-Apr-11 | | | | | | | | | | | | | | | | | | |
| Lab 8 | 6 | 11-Apr-11 | 18-Apr-11 | | | | | | | | | | | | | | | | | | |

█ Actual Level of Effort █ Remaining Work
█ Actual Work █ Critical Remaining Work

Environmental Studies Lab: Expansion

| Activity Name | Original Duration | Start | Finish | 2009 | | | 2010 | | | | 2011 | | | | 2012 | | | | 2013 | | | | |
|-------------------------------|-------------------|-----------|-----------|---------|----|-----------|-----------|----|----|----|------|----|----|----|------|----|----|----|------|----|--|--|--|
| | | | | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | | | |
| | | | | ■ Lab 9 | 6 | 11-Apr-11 | 18-Apr-11 | | | | | | | | | | | | | | | | |
| ■ Lab 10 | 7 | 11-Apr-11 | 19-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 11 | 7 | 12-Apr-11 | 20-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 12 | 6 | 12-Apr-11 | 19-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 13 | 6 | 13-Apr-11 | 20-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 14 | 6 | 13-Apr-11 | 20-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 15 | 6 | 18-Apr-11 | 25-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 16 | 6 | 18-Apr-11 | 25-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 17 | 6 | 18-Apr-11 | 25-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Lab 18 | 6 | 20-Apr-11 | 27-Apr-11 | | | | | | | | | | | | | | | | | | | | |
| ■ ESL:E.13 Electrical | 244 | 15-Sep-10 | 29-Aug-11 | | | | | | | | | | | | | | | | | | | | |
| ■ ESL:E.14 Fire Protection | 100 | 23-Dec-10 | 13-May-11 | | | | | | | | | | | | | | | | | | | | |
| ■ ESL:E.15 Plumbing | 216 | 20-Sep-10 | 25-Jul-11 | | | | | | | | | | | | | | | | | | | | |
| ■ ESL:E.16 Facade | 43 | 24-Jan-11 | 23-Mar-11 | | | | | | | | | | | | | | | | | | | | |
| ■ FRP Concrete | 14 | 24-Jan-11 | 10-Feb-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Install Fiber Cement Siding | 33 | 07-Feb-11 | 23-Mar-11 | | | | | | | | | | | | | | | | | | | | |
| ■ ESL:E.17 Closeout | 0 | 15-Nov-11 | 15-Nov-11 | | | | | | | | | | | | | | | | | | | | |
| ■ Turnover | 0 | | 15-Nov-11 | | | | | | | | | | | | | | | | | | | | |



Actual Level of Effort
 Remaining Work
 Actual Work
 Critical Remaining Work

Appendix J: Resources and References

Analysis 1:

- "The Design-Build Bridging Method"
<http://www.dsvlaw.com/images/publications/dbNewsletterP1.pdf>
- *AGC Project Delivery Systems for Construction* by Michael E. Kenig
- Bryan Franz Thesis
- Dr. Robert Leicht
- Hensel Phelps Employees

Analysis 2:

- Hensel Phelps Employees
- Hourly wage for sheet metal workers:
<https://www.dllr.state.md.us/PrevWage/web/content/PWRequestRates.aspx>

Analysis 3:

- Architect: David Virgil
- Fiber cement siding:
 - http://www.jameshardie.com/homeowner/products_siding_hardiepanelSiding.py?search_zip_code=retail
 - [http://www.jameshardiecommercial.com/apps/products/hardiepanel#sr=kbnftibsejf.dpn&m=r&cp=\(sfgfssbm\)&ct=-tmc&ts=1394677270](http://www.jameshardiecommercial.com/apps/products/hardiepanel#sr=kbnftibsejf.dpn&m=r&cp=(sfgfssbm)&ct=-tmc&ts=1394677270)
 - <http://www.artisanluxury.com/siding-artisan-lap-siding.py>
- Louvers: <http://www.airolite.com/Products.aspx?v=p&pid=29&sid=4&cid=1>
- Brick Veneer: <http://www.nachi.org/solid-brick-vs-veneer.htm>
- Corrugated metal panels:
 - http://www.centriaperformance.com/products/wall/profile_series_metal_panels/exposed_fastener_panels/hor/econolap_3qtr.aspx
 - <http://doc.spdirect.net/files/Exposed%20Fastener%20Series-%20Wall.pdf>
- Composite Metal panels:
http://www.centriaperformance.com/products/wall/mcm_metal_composite_panels/formabond/sub/8.aspx

Analysis 4:

- Dr. Craig Dubler
- <http://bim.psu.edu/>
- Asset Management: http://bim.psu.edu/Uses/Asset_Management.aspx
- Owner's Representative
- Dr. David Riley

Other:

- <http://www.timeanddate.com/date/workdays.html>
- Primavera