·THE NEW DICKINSON SCHOOL OF LAW·

University Park, PA
Steve Ayer
Construction Management Option

Final Thesis Report

Resubmitted: Wednesday, April 9th, 2008

CPEP Website: http://www.engr.psu.edu/ae/thesis/portfolios/2008/ska124/

Faculty Consultant: Dr. Messner

·THE NEW DICKINSON SCHOOL OF LAW·

Steve Ayer ***Construction Management Option***

Project Location:
University Park, PA

Owner:
Penn State University – Dickinson School of Law

Architect:
Polshek Partnership Architects

Structural Engineer:
Robert Silman Associates

MEP Engineer:
Flack and Kurtz

Construction Manager:
Gilbane Building Company

Delivery Method:
Design-Bid-Build with CM

CPEP Website: http://www.engr.psu.edu/ae/thesis/portfolios/2008/ska124/

Architectural Features

- 113,000 Square Feet
- Curving, tilting glass curtain wall
- Brick and stone masonry
- Unique light tan brick that differs from standard University Park campus brick color
- Rare and exotic interior finishes
  - Interior slate wall panels, European Red Elm wall panels, custom Anigre millwork
- Curving and tilting interior walls and ceilings
- Café to sell snacks and sandwiches
- Legal Library
- Extensive landscaping and site beautification

Construction Features

- Groundbreaking: January 2007
- Finish Construction: January 2009
- Main architectural curtain wall poses a coordination challenge
- 3-D CAD Coordination process
  - Contractors submit standard 2-D coordination drawings
  - In addition they also submit 3-D versions of their drawings
  - Computer software detects and tracks clashes
- Seeking LEED certification upon completion of project

M.E.P. Features

- 7 Air handling units fed by campus utilities
  - Air Handlers range in size from 2,500 CFM to 26,000 CFM
- Variable Air Volume control system for temperature control in individual rooms
- Return air system uses mostly plenum space to direct air and allows for minimal return air ductwork
- 1500 kVA 480Y/277V Feed into building
- 40 kW Uninterruptible Power Supply
- Fully sprinklered building
- Commissioning for Mechanical, Electrical, and Plumbing systems

Structural Features

- Large sinkhole ran beneath the building footprint
  - Clay soil was removed from site
  - 1650 Yards of concrete were used to fill void from clay
- Concrete foundation walls sit on grade beams and spread footers
- Columns transfer loads to spread footings
- Steel superstructure with 2.5” and 4.5” composite 4000psi slabs on metal decks
  - Project uses approximately 950 tons of steel
- Numerous braced frames prevent overturning
- No typical bay size because of curved building footprint

TABLE OF CONTENTS:

EXECUTIVE SUMMARY:

This Thesis Assignment analyzes a few different options that could have been done slightly differently on the new Dickinson School of Law located in University Park, PA. The following specific areas were examined for this project:

- **3-D Coordination Case Study**
  - Goal: Determine the general opinions of contractors who have actually used 3-D models for coordination of MEP work. Also determine if there is a trade that had a particularly hard time modeling/coordinating in 3-D.
  - Outcome: The general outlook related to 3-D coordination is a positive one. There are still some negative feelings towards this process, but the overwhelming feeling is positive. Furthermore, there was no trade that had a particular struggle with the 3-D aspect of the MEP coordination process.

- **Architectural Curtain Wall Redesign Options (Including Architectural Breadth)**
  - Goal: When looking at removing the tilt and substituting flat glass panes for curved panes on the main curtain wall (CW-4), generate a list of pros and cons associated with these changes from a construction and also an architectural point of view to assist the owner in making a decision.
  - Outcome: Eliminating the tilt on the curtain wall and mullions saves a significant amount of money ($1.1 Million) and makes the construction process easier. It does take away from the rising aesthetic of the current design, however. Eliminating the curved glass has less monetary impact ($170,000) that eliminating the curtain wall tilt. Although, from a far distance away, this change has virtually no aesthetic impact. From a near distance away from the building (from either the inside of the building or close to the outside of the building), this will detract somewhat from the sleek, organic, curving shape that is currently designed on the curtain wall.

- **Curtain Wall Glazing Alternative (Including Mechanical Breadth)**
  - Goal: Look at the feasibility of using triple pane glazing on the main architectural curtain wall (CW-4) from life cycle and upfront points of view.
  - Outcome: Triple pane glazing will cost about 25% more money upfront than double pane which would mean a $125,000 additional upfront cost. As a result of the extra pane of glass, it would save $3,500 annually in cooling costs indicating approximately a 35 year payback period based on cooling.

- **Alternative Utility Tunnel Construction Process**
  - Goal: Look at the feasibility of boring under Park Avenue to build utility tunnel because it took 6 months to obtain the necessary highway occupancy permits, half of the Park Avenue traffic had to be inconvenienced with a detour during construction, and the utility tunnel construction process had to essentially be performed twice which led to a loss in productivity.
  - Outcome: Boring the tunnel under the road would most likely not be a viable option for the owner under the circumstances. This process costs significantly more, saves no time from permitting, and offers no additional level of quality from digging up the road. However, if situations were slightly different and the process got delayed a few weeks such that it would have to occur during football season or student move-in week, this process could become a much more attractive option for the university so they would not have to close down one of the major arteries for carrying football/move-in traffic to Beaver Stadium and the dormitories.

ACKNOWLEDGEMENTS:

I want to take this opportunity to acknowledge and give thanks to everyone who helped me out in one way or another on this thesis project. Your suggestions, insight, and support has greatly helped me accomplish this thesis assignment.

Professional:

Gilbane Building Company
- Mr. Stephen O’connor
- Mr. Jerry Shaheen
- Ms. Mary Mulligan
- Mr. Dwayne Rush
- Mr. Brian “Fishman” Horn
- Ms. Jessica “Ica” Dubler
- Mr. Darwin Appleby
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- Ms. Kate Mann

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- Mr. Marty Finkle

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- Mr. Emory Lukacs
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Dr. James Freihaut
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My fellow Architectural Engineering students

Family & Friends

Thanks to all of my friends who helped me relax, study, and party.

Mom, Dad, and Jen (And Peter, but he already got a shout out) – Thanks so much. You offered to help me financially with school and I thanked you by picking a major that would bill you for five and a half years of the most expensive public education money can buy. I’ll build you guys a great beach house some day to return the favor. Thanks to all of you for your help and support. I could not have made it through school without you.

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INTRODUCTION:

About the Project and Owner:

The New Dickinson School of Law project in University Park, PA marks the beginning of a new era for both Penn State University and the Dickinson School of Law. Penn State has always prided itself on its solid and diverse scope of education. One of the few educational disciplines that Penn State lacked, until recently, was Law education. Recently, Penn State acquired the Dickinson School of Law based out of Carlisle, PA.[1] This building project will mark the start of a new campus location option for students seeking an education from Dickinson. Students will now be able to decide if they would like to attend law school in Carlisle or Happy Valley.

This flagship building will be located on the northeast side of campus at the Park Avenue

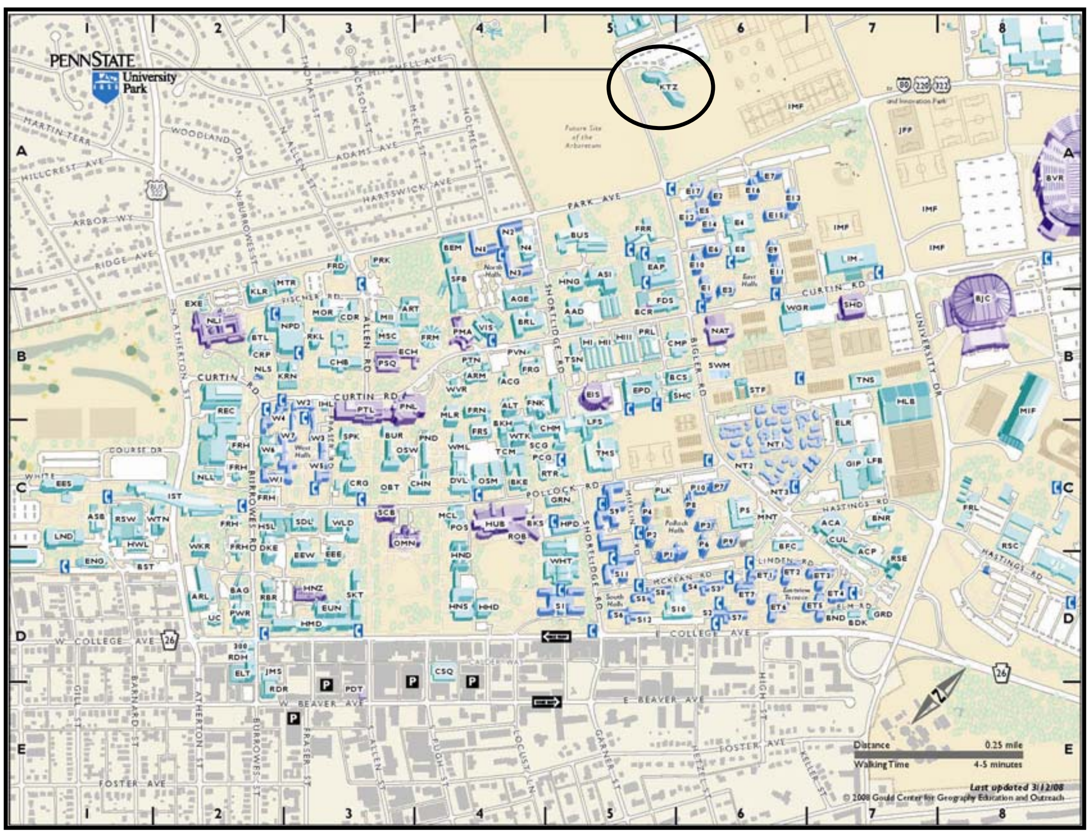

Figure 1: Map showing building location. Photo taken from www.campusmaps.psu.edu

[1] "The Dickinson School of Law." Penn State. 31 Mar. 2008 <http://www.dsl.psu.edu/about/>.

and Bigler Road intersection. Figure 1 shows a map of the University Park campus with the Dickinson Law School project circled.

Penn State's Office of the Physical Plant (OPP) is the owner of this project. Their responsibility is to ensure that this project meets the University design requirements by choosing specific design elements, specific project delivery methods and construction techniques. Because of the way Penn State is organized, OPP has the authority to approve or disapprove a variety of design elements, changes, and additions. In some instances however, it is necessary for OPP to go to the University executives (including the university president, Dr. Graham Spanier) to approve specific changes to the design. For this specific project, it was necessary to get the approval from the university executives to use the light tan brick that is being used on the North side of the building (shown in Figure 2) because it does not conform to the University's standard brick color.

Figure 2: Tan masonry mockup to be approved by university executives.

Penn State has relatively high expectations for this project – especially as it relates to building quality. As always, there are three expectations that an owner can have for a project which are cost, quality, and speed of construction. Typically an owner can set priorities on one or two of these expectations, but the third will likely suffer as a result of the first two. For this project, the owner clearly has a priority on quality, with time as a secondary priority, and cost as a third priority. Based on the design of this project, construction quality has to be top-notch. The coordination efforts necessary to incorporate a complex curtain wall, curved masonry walls, and curved interior walls and ceilings into the project require skilled contractors to perform quality work. To ensure a high-quality finished project, Penn State requires all contractors interested in bidding on the project to be pre-qualified.

The fourth expectation that an owner can have (that should always be a top priority) is safety – for workers and building occupants after project completion. The construction manager (Gilbane Building Company) attempts to ensure project safety during construction by requiring workers to wear hard hats and safety glasses as well as having an annual safety day where workers attend discussions about how to stay safe on the job site. Penn State also expects the building occupants to be safe in the building after project completion. They hope to accomplish this goal with sprinklers to protect the building and its occupants in case of a fire and a security system to keep people and property safe.

Project Theme

Because the university has built many building project on campus, and has plans to build many more, it would be advantageous for any construction manager to please the owner so that they may get repeat business from the university. Since Penn State has unique needs and unique project goals, it is important that the construction manager realize these needs and goals so that they may perform their job with the intent of helping OPP meet those needs. Therefore, specific studies will be examined that attempt to help the owner meet or exceed their goals.

As a Penn State student and an employee with the construction manager on this project, I have a great amount of interest in this project. Because of my status as a Penn State student, I have learned some of the values and concerns that the University may have for its new building projects. As a Gilbane employee working on this project, I learned some of the concerns and goals that the construction manager considers when on a project like this.

Therefore, it is my goal in this thesis project to examine the specific needs of Penn State as an owner. I intend to look at different design and delivery options that may help to reduce costs, improve quality/convenience, and point out alternative design options for consideration of the university. These goals will be accomplished through a few studies that vary in topic, but focus on meeting and exceeding or attempting to meet and exceed the specific expectations of Penn State.

PROJECT BACKGROUND:

Project Delivery System:

This project is being delivered using a Design-Bid-Build (DBB) with a CM system. Gilbane was chosen to provide the construction management at risk services for this project. This delivery method was chosen over a standard owner-managed DBB system because of the complexity of the building project. This project's organization is slightly different than many other projects. Contractors bid on work before a design is complete which is typically not seen on DBB projects, but the contractors are given documents to base bids on and any changes that occur to the design and increase their costs are treated as change orders. Arguably a cost plus fee contract could have been used with the subcontractors to account for design changes that would arise, but instead a cost plus fee arrangement was used for the contract between Penn State and Gilbane. This way, if a design change occurs, the subcontractor gives a quote for the change cost, which the owner can see and decide if the change is still desirable. If it is desirable, the change is authorized and Gilbane is reimbursed for the added cost and they pay the subcontractor for the extra work. To understand all contractual and professional relationships on this project, an organizational chart is shown in Figure 3.

This type of organizational structure utilizes three different contract types listed on the diagram. The contracts on the construction side of the diagram have already been discussed so let's examine the contracts on the design side of the diagram. The design professionals are all paid based on a fee for their professional services. The owner hires the architect who contracts with other design professionals as needed.

In addition to contractual relationships, there are also professional relationships between parties. This type of relationship is shown with a dashed purple line. It is important to note that these types of interactions are between the design professionals and the construction manager only. In other words, if a subcontractor needs to have an RFI (Request For Information) addressed, they go through the construction manager who, in turn, contacts the design professionals. Conversely, if the architect issues an ASI, (Architect's Supplemental Instruction) they contact the construction manager who informs the necessary subcontractors. This allows the construction manager to maintain a log of all communication and documentation that exists on the job. If a question or issue related to a certain RFI would arise later in the project, the construction manager would be able to show all correspondence related to that RFI.

For this project contractors interested in bidding had to be prequalified by Penn State and also by Gilbane via iBidPro which is their online prequalification system. After bidders were successfully prequalified by both parties, winning bidders were selected on the basis of lowest bid. The contractors had to be fully bonded with payment and performance bonds. In addition to the bonding requirements, contractors were also required to have statutory workers' compensation, employers' liability, commercial general liability, automobile liability, and excess umbrella liability insurance.

This organizational structure makes sense for this project because construction started when the building design was just wrapping up the schematic design phase. Therefore a Cost Plus Fee contract would make sense. It allows some leeway for design modifications. Also it is advantageous to bring a CM on board at this early phase of the project because they can make constructability suggestions throughout the design development phase.

Figure 4 illustrates the construction manager's basic staffing plan for this project. The project executive is responsible to generally oversee the project. The project manager runs the project on a day-to-day basis. The manager of engineering is in charge of most of the paperwork associated with the project including, submittals, RFI's, bid packages, change orders, etc. The superintendants supervise the project from onsite and help to ensure quality workmanship, worker safety, and appropriate work sequencing on site. The accountant processes all payments and money issues related to the project.

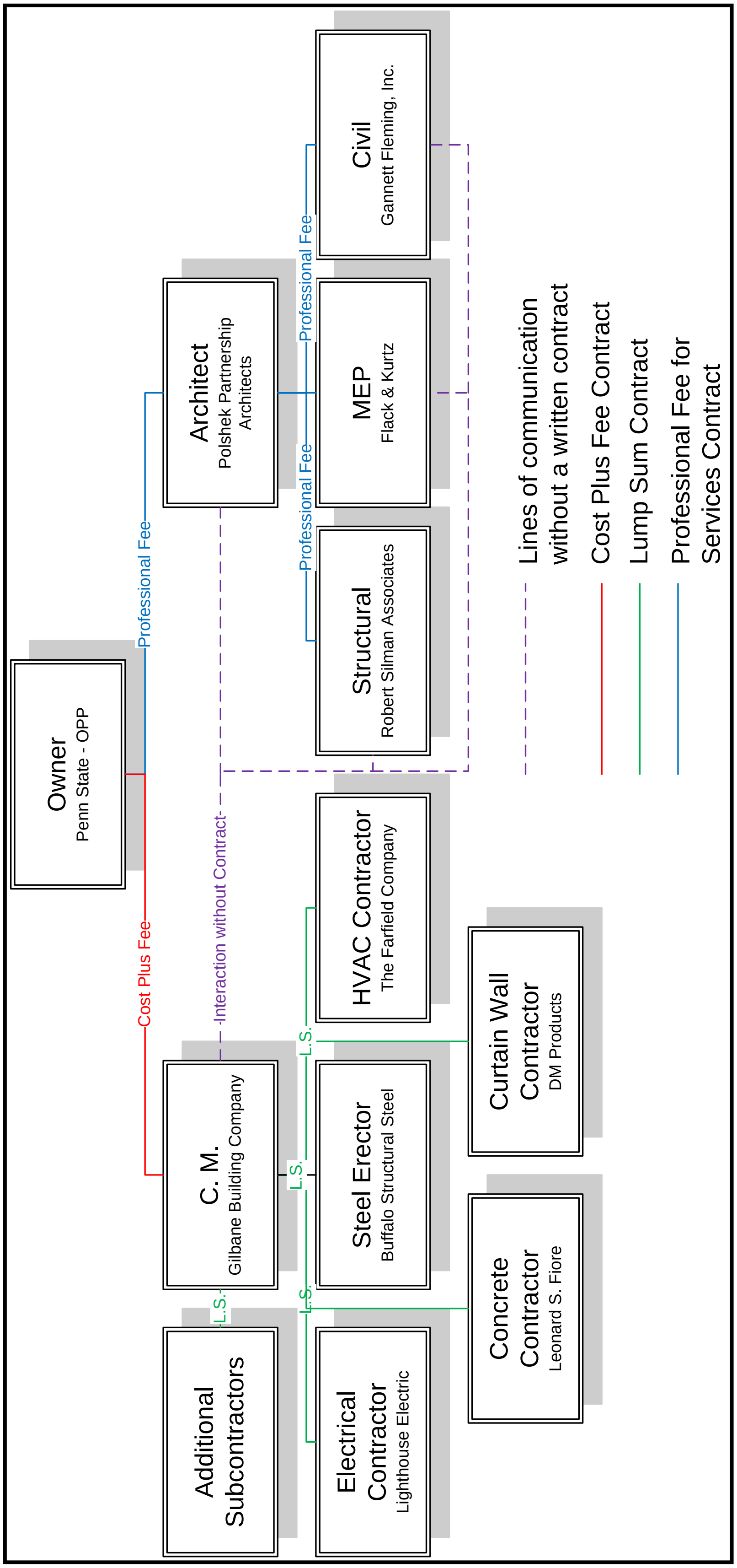

Figure 3: Project level organizational chart

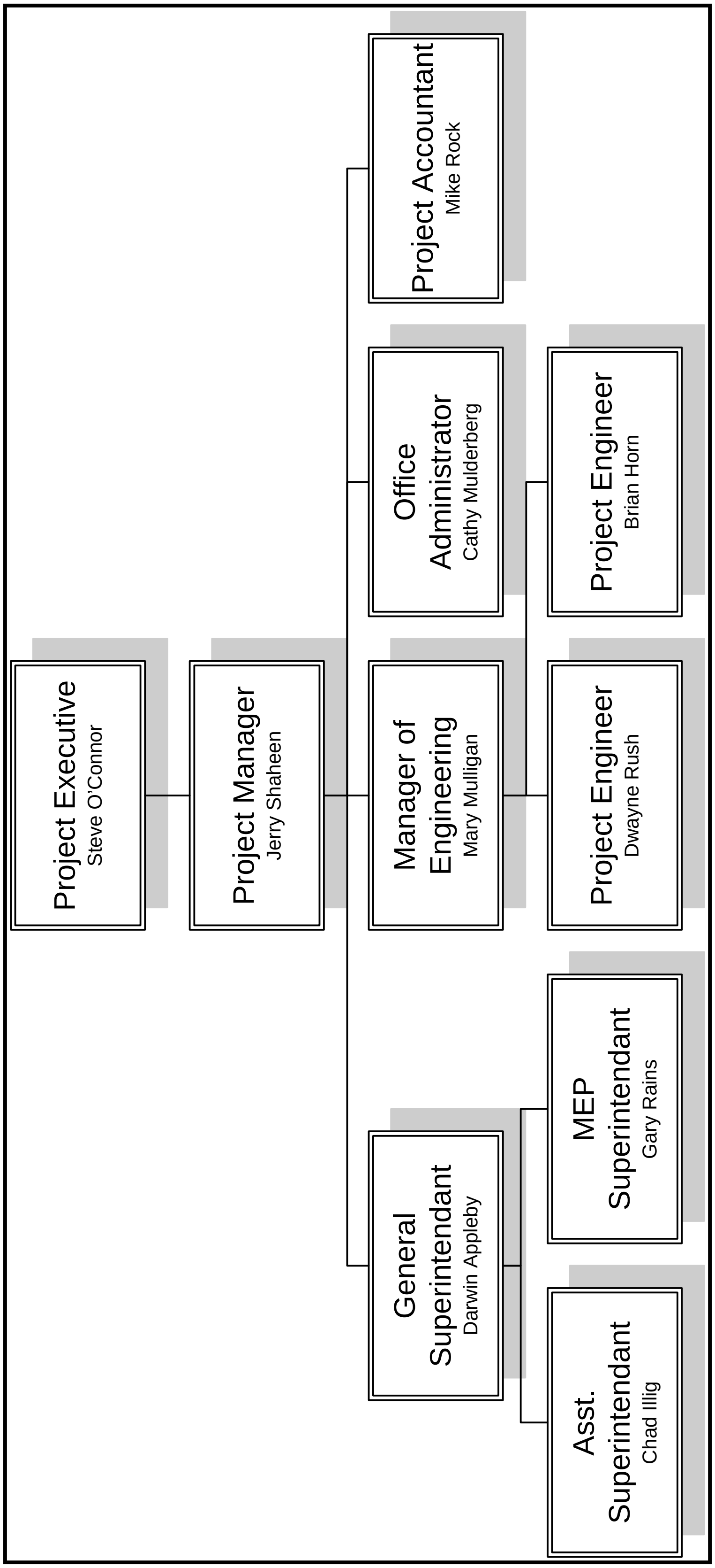

Figure 4 Construction Manager level organizational chart.

Architectural Features:

Arguably the most striking feature of the building's exterior is the prominent architectural curtain wall (CW-4) that covers the South side and part of the North side of the building. This complex curtain wall curves, tilts, and bends. In addition to the curving curtain wall, this building will also utilize stone and brick masonry veneer that will differ from the standard brick used on most new building projects on the University Park campus. Figure 5 shows an image of the framing for the South curtain wall and also the custom brick on the base of the building. In addition to the main curtain wall shown in the photo, the building is also enclosed by 6 other curtain walls. These curtain walls feature heat treated/tempered, double pane, insulated glass with painted aluminum mullions.

Figure 5: Masonry and Curtain Wall Framing on the South Side of the Building.

Because this building utilizes a prominent curtain wall that visually defines the top of the building, a parapet wall is used at the roof level. This effectively hides the roof from view. Therefore, the roof becomes an ideal location to place roof gardens which can help the building thermally and contribute to its LEED points. The roof gardens sit on 4" rigid Styrofoam insulation and constitute most of the high roof area on the building

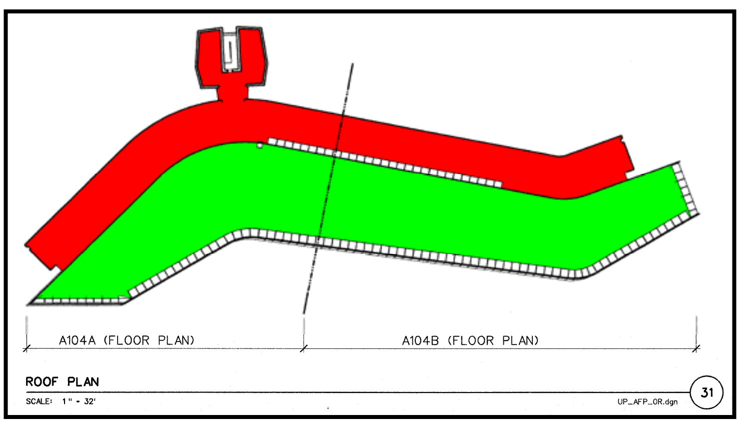

Figure 6: Green roof (Green) and TPO (Red) roofing systems

shown in green in Figure 6. A TPO (Thermoplastic Polyolefin Membrane) roof membrane is adhered to 3" insulation boards on top of the steel deck and makes up the majority of the low roof area shown in red in the diagram. Both of these elements will help to insulate the law school.

While a large part of the building's exterior is covered by curtain walls, there is also a significant amount of brick and stone masonry. The exterior sandstone veneer wraps the lower part of the building below the main curtain wall and the lower half of the back side of the building. The brick used for this project can be seen on the rear of the building above the sandstone veneer. As mentioned earlier, this brick is of special interest because it is not the standard brick used on Penn State projects. As mentioned earlier, it is a light tan that required special approval from the University's President Graham Spanier.

Figure 7: A view of the courtroom construction (top) and the same view of a rendered virtual mockup of the courtroom. (bottom)

The building's interior features a number of other amenities to improve the building (both in aesthetics and function). The functional features include a large auditorium in addition to classrooms, a mock courtroom (shown in Figure 7), a reheat snack bar, and a legal library. The aesthetic highlights of the interior include exotic wood veneers

(European Red Elm and Anigre), slate accents, and curving and tilting interior walls and ceilings.

Construction Features

This project required some demolition work before site excavation could occur. There was an existing parking lot on the site which had approximately 1,200 parking spaces. This substantial parking lot along with the light poles all needed to be demolished.

Figure 8: A view of the large sinkhole that ran underneath the building footprint (top) and a view of the process of filling the sinkhole with concrete.

After the demolition work, excavation began on site. One of the interesting problems that arose once excavation started was related to a large sinkhole that ran under the building's foundation (shown in Figure 8). The existence of this sinkhole was not known before excavators started work. Because the clay soil would not be structurally sound to support the building foundations the workers dug out all of the clay soil and filled the void where the clay was with concrete. This effort required a substantial amount of concrete. (Approximately 1650 yards)

Figure 9: Image showing construction ramp, rebar reinforcing for walls to be poured, and some of the poured walls on the west end of the building.

After the soil problems were dealt with, it was possible for construction to start. The construction started with the foundations which consisted of spread footers and grade beams. The cast-in-place foundation walls were formed, reinforced, and poured and then the lower level slab on grade was placed. All foundation walls were poured except for the west side of the south wall. This wall would be left open while the construction ramp was in place. This opening can be seen on the left side of Figure 9.

Figure 10: Image showing steel erection progress on the East end of the building early in the erection phase.

After the substructure was constructed, the steel superstructure erection commenced. The steel started being erected on the east end of the building (shown in Figure

10) and work westward. As steel columns and beams were erected, steel deck was installed, any concrete embeds were placed, and concrete slabs on metal deck were poured.

Figure 11: Masonry work on the East end of the building around the auditorium.

After the superstructure was erected, the building enclosure was the next step. The curtain walls and masonry walls (shown in Figure 11) were built. After the enclosure had been completed, the interior walls were framed, drywall was hung, and FF&E work began.

Structural Features

The building's substructure is comprised of concrete spread footings and grade beams supporting cast-in-place concrete foundation walls. The superstructure is a steel skeleton with composite slabs on metal deck. While there are many different sizes of W-shapes incorporated in the building plan, the most common sizes are W8x13, W12X19, W10X33, and W10X49. The slabs range in thickness from 2.5" lightweight 4000psi slabs on 2" 18 gauge steel deck with 6x6-W2.0xW2.0 welded wire fabric up to 4.5" normal weight 4000psi concrete on 3" 16 gauge steel deck with 6x6-W2.0xW2.0 welded wire fabric. The steel bays vary greatly in size. By the nature of the building's curving footprint, it is difficult to maintain one typical bay size throughout this project. The largest bay used in this project is 10'-8"x27'6".

Mechanical Features

Figure 12: The campus utilities entering the building.

The building's environment is regulated by 7 air handling units that are fed from the campus utilities (shown in Figure 12). The 7 units range in size from 2,500 CFM to 26,000 CFM. The units also vary greatly in cooling and heating capacities. The smallest has 89,000 Btu/Hr cooling and 109,000 Btu/Hr heating capacities. The largest capacity is 972,000 Btu/Hr cooling and 1,128,000 Btu/Hr heating.

Variable Air Volume (VAV) control units are used to control temperature in each room. These allow for the supply air temperature to remain relatively constant throughout the whole building and will use differing amounts of air flow to change room temperatures. The return air system in this building uses predominantly ceiling plenum space to direct it back to the air handlers. Air is supplied to the rooms and then exhausted via a small return duct that directs the air into the ceiling plenum in the long corridor through the building.

Lighting/Electrical Features

The Law School is fed by a 1500kVA 480Y/277 power supply. That power supply is distributed to a series of distribution panel boards which in turn feed the room panel boards. The building also utilizes a 40,000 Watt uninterruptible power supply (UPS) power system for potential electrical system failure.

There is a wide variety of light fixtures used on this project. There are fluorescent (T5 and T8), incandescent, HID (T4.5 Ceramic Metal Halide), and Light-Emitting Diode (LED) light fixtures used. These fixtures vary in form from track lighting, to recessed lighting, to ceiling mounted, to cove lighting, to accent lighting. One of the more interesting light fixtures used is a curving fixture that uses numerous compact fluorescent lamps. This allows it to be placed in coves (in the Legal Library, for example) that have curved corners and will help eliminate cold spots from the cove lighting.

Other Design Features

This project will utilize fully sprinklered fire protection. The sprinklers are fed by a 6" siamese fire department connection and also an 8" incoming line from Penn State's utilities. The fire department connection is located on the Bigler Road extension to the west of the building.

The building utilizes four hydraulic elevators. Three of these (PE-1, PE-2, PE-4) are passenger elevators with a 2000Lb capacity. The fourth elevator (SE-3) is a service elevator with a 4,500Lb capacity. All elevators will stop at all floors with the exception of PE-4. PE-4 (located on the east side of the building) will stop at every level except the lower level.

The telecommunications in this building consist of fiber optic cables that are fed to room 005G Server Room where the fiber lines are terminated. 24 Category 6 lines are then run to the telecommunications rooms located on the east side of the building and just south of the building's core. (The "core" of the building refers to the northernmost section of the building that contains PE-1.) The Category 6 lines are then distributed from the equipment racks in the telecomm. rooms to each individual room in the building via a 18" basket cable tray that will follow the building's main corridor.

EXISTING CONDITIONS:

Local Conditions:

State College does not seem to have one preferred style of construction. There are precast concrete projects, Cast-In-Place concrete projects and steel projects seen in the area. That being said, it does seem that, in recent years, Penn State has been doing a lot of steel projects similar to this building's style of construction.

Parking for some projects in State College can be a big challenge – especially in the downtown area. The law school has some space for parking, but not enough for all workers. This has created some challenges related to parking on-site. To deal with this problem, workers were asked to park their cars off site and a small school bus was used to bring all workers to site in the mornings and take them back to their vehicles at the end of the day.

A fairly substantial recycling effort has been made to earn some LEED credits on this project. Different dumpsters are on site for general trash, wood, and metals. The wood and metal dumpsters can be recycled which is why the LEED credits are given out for this type of effort on a construction site. The recycling and tipping fees for Centre County are $66.00 per ton for municipal waste and $6.00 per ton for recyclables.

As mentioned in the prior section, the subsurface soil conditions on the site proved to be a challenge for construction. The soil on the site is made up of primarily clay and rock. The issues on site arose from the prevalence of clay. After excavation started, it was discovered that there was a large sinkhole under the project site. This vast amount of clay was unsuitable for supporting the spread footings that would need to support the building mass. To remedy this situation the clay soil had to be excavated out of the sinkhole and the void had to be filled with 1650 CY of concrete to provide a suitable base for the building's foundations to rest on.

Project Schedule

A detailed project schedule can be found in Appendix A of this document. The main feature of the project schedule that is worth noting is related to the Steel Sequencing on the project.

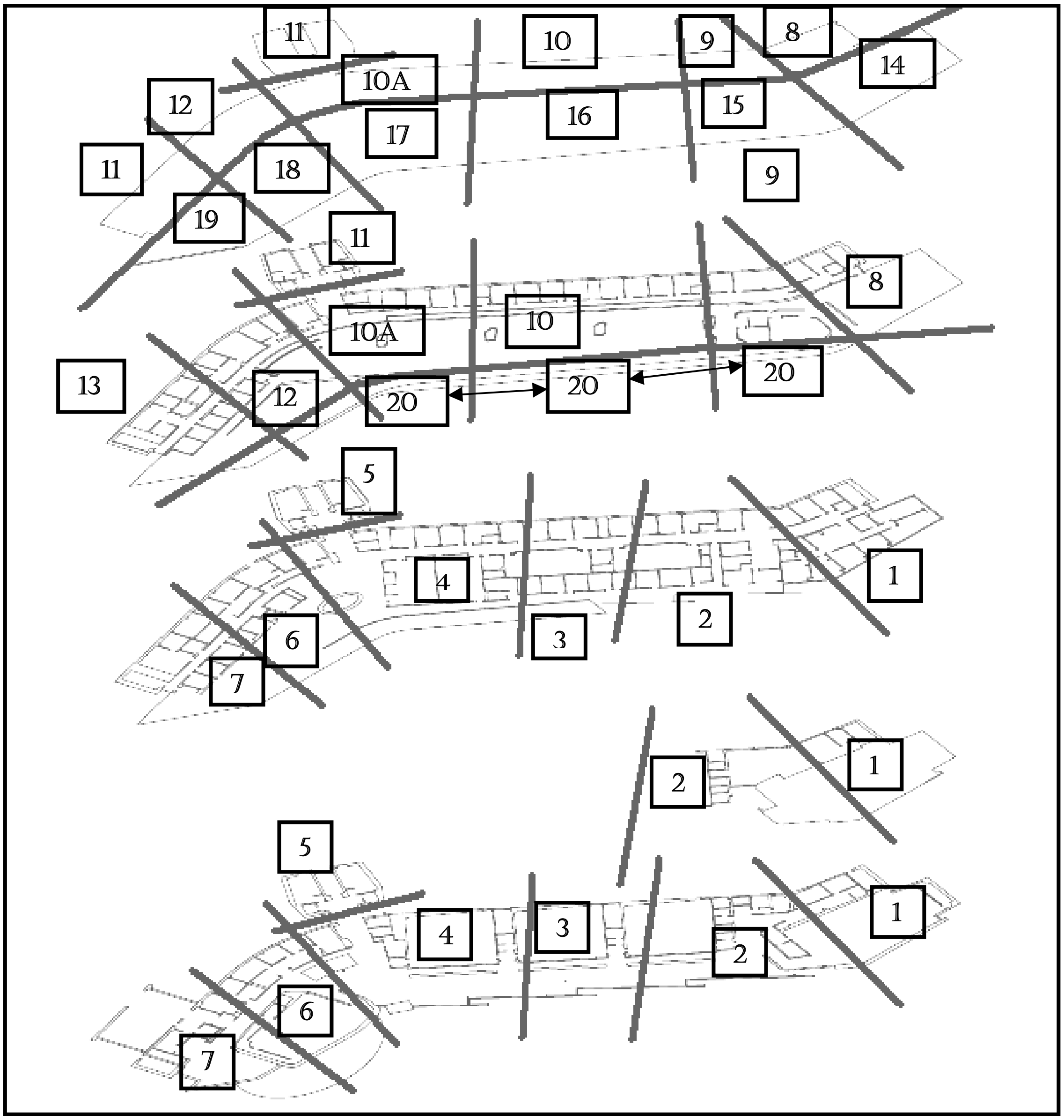

Figure 13: Building key plans indicating steel lift sequencing

Figure 13 shows the steel sequencing scheme used for the project. It can be seen that there are 20 different lift sequences. The steel erection flows from east to west (Right to Left in the diagram.) The first, mezzanine, and second floor framing and column steel members are lifted in the same sequences as shown. The third and low roof level framing steel and columns are lifted in the same sequences as well. Finally after the low roof has been framed, the high roof framing (sequences 14-19) are erected.

The steel for this project had a clear flow from one side of the building to the other. The interior trades were not as strictly scheduled as to where and when they were to complete work. The main method of phasing used for the MEP and other interior trades was by floor. For some trades work was completed from the bottom of the building up. Others began work on the third floor and worked down through the building.

Project Cost:

The following list indicates cost information that is pertinent to this thesis and the overall project.

Description	**Cost (In Millions)**
Total Cost (Including FF&E, Designer's Fees, CM Fees, All Soft Costs)	$60 Million
Total Construction Cost	$39 Million
Curtain Walls (Total)	$11 Million
Curtain Wall 4 Double Pane Glass (Mat'l Only)	$0.5 Million
Curtain Wall 4 Triple Pane Glazing (Mat'l Only)	$0.6 Million
Structural System	$5.8 Million
Mechanical System	$4.8 Million
Electrical System	$3.8 Million
Plumbing System	$0.8 Million
Fire Protection System	$0.6 Million
Utility Tunnel Construction Costs	
Digging (As performed)	$0.5 Million
Boring Tunnel	$0.8 Million
Omitting Tunnel and Boring Utilities	$0.3 Million

INVESTIGATION 1: 3-D MEP COORDINATION CASE STUDY

Background:

All building projects require some degree of coordination between trades to ensure that one trade's work will not interfere with the workflow of a different trade. Traditional coordination methods require each contractor involved in a given coordination process to submit 2-D coordination drawings at a specific scale. These drawings would then be placed on top of each other on a light table and a person with an experienced eye would have to follow each piece of duct, pipe, etc. to see where an intersection would occur between that building element and an element from a different trade's work. The elevations of all intersecting elements would have to be checked and adjusted to allow for adequate clearance for all building elements. Unfortunately, this process can be slow and imprecise.

Recently, there has been a push in the construction industry to use electronic 3-D coordination models as opposed to the 2-D paper copies to facilitate trade coordination. This type of coordination method uses computer technology to locate clashes. By using programs such as Navisworks Jetstream, clashes can be located much faster than even the most experienced coordination professional.[2] Figure 14 shows the basic process of compiling two 3-D models and running a clash detection program to highlight clashing geometry.

While this coordination method clearly has some potential advantages, some of the industry professionals I have spoken to at career fairs and PACE activities, expressed some feelings of uncertainty related to utilizing this type of coordination process on a project. The feeling is that they do not know what degree of initial struggle they will have to overcome to go from drawing their coordination drawings in a standard 2-D format to modeling in 3-D. As a future construction manager in the world, it would seem to reason that it would be advantageous to learn which trades are the ones that will likely struggle

[2] "Jetstream Clash Detective." Navisworks. 3 Mar. 2008 <http://www.navisworks.com/en/jetstream/overview/clashdetective>.

or be most resistant to this type of coordination process and what the feeling about 3-D coordination is from contractors who have actually been involved with the process in their work experience.

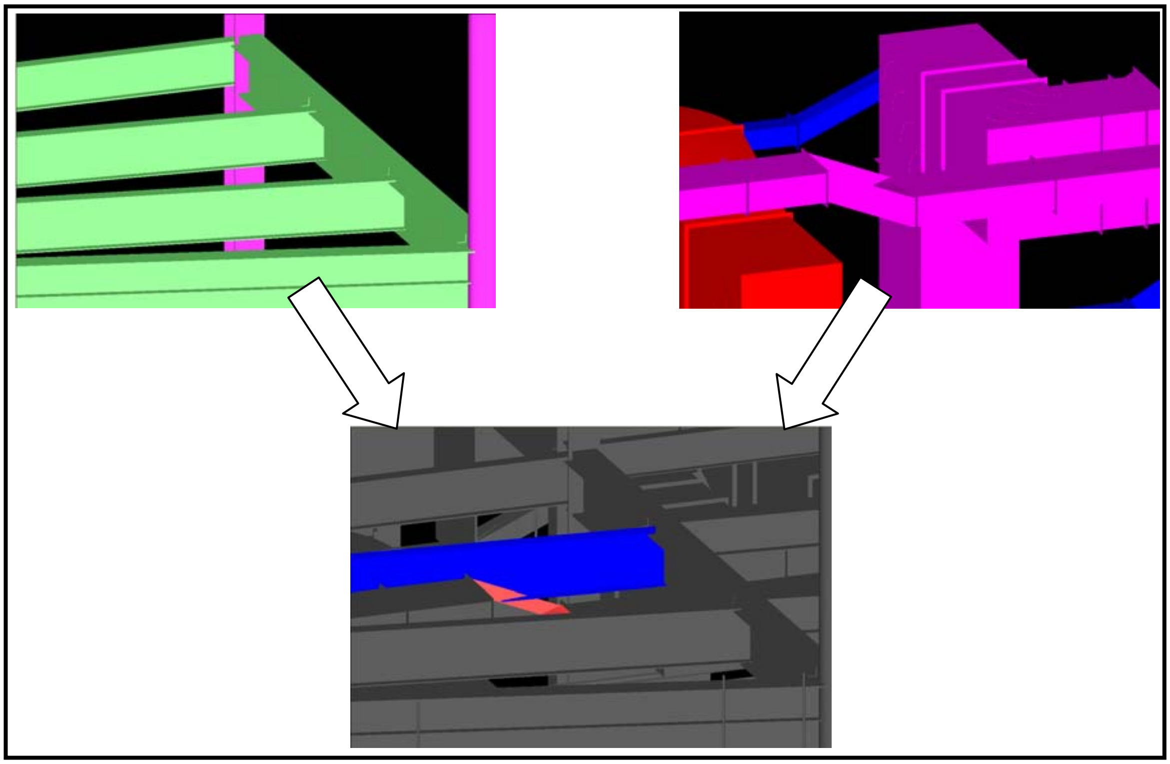

Figure 14: A steel model is compiled with a mechanical model and clash detection software is used to determine what pieces of geometry clash.

Case Study:

The New Dickinson School of Law project involves a complex architectural design that requires complex MEP systems of ducts, pipes, conduits, etc. to service the building. This requires an in-depth coordination process to catch all clashes and avoid as many field conflicts as possible. The traditional 2-D coordination process would likely take a great deal of time and would probably miss a number of trade clashes. The complexity involved in the design of this building project would only add to the difficulty of this type of coordination process.

In an attempt to make the lives of the contractors, owner, and arguably the design professionals easier, Gilbane opted to require all contractors, whose work was likely to affect the work of other trades, to submit 3-D coordination drawings for the New Dickinson School of Law. The trades included in this effort were: concrete, steel, curtain wall, mechanical, plumbing, electrical, fire protection, drywall, ceilings, elevators, and miscellaneous metals. This coordination process occurred over a few months from the time when the first contractor began modeling until the last contractor finished their coordinated model. Because of the time frame associated with this process, the MEP and related trades coordination process will be the focus of this case study.

The modelers from the mechanical, electrical, plumbing, fire protection, drywall, and ceilings were all interviewed. The goal of the interview was to get each of their perspectives on this type of coordination process. The following list of common questions was generated to ask each contractor involved with modeling for this coordination process:

1. How many years of experience have you had in your specific trade's coordination/construction field?

2. How many years of experience have you had in some different construction field?

3. For how many projects have you used some type of 3-D modeling to create your shop drawings?

4. Do you find that you are typically submitting shop drawings for projects in 3-D or are most projects still requiring 2-D shops in your experience?

5. Have you been putting in more hours/money into this effort because of the use of a 3-D coordination process?

6. As far as you can tell, has your trade encountered fewer problems in the field with regard to the other trades as a result of 3-D coordination?

7. What problems did you encounter as a result of using 3-D coordination? How did you solve them?

8. Do you feel that any trade (either from this project or from prior projects in your experience) tends to have an easier or more difficult time using 3-D MEP coordination?

9. Overall, what is your feel for 3-D coordination? Do you have any other recommendations or thoughts related to this process?

The goal of the questions was to determine a few things. Questions 1 – 4 sought to find out the experience and comfort level of each modeler with this type of coordination process. Questions 5 and 6 aimed to determine if this is a better coordination process in the contractors' eyes and if they had been seeing a time/money savings as a result of the process. Question 7 and 8 were intended to see what issues existed in the process and how these issues were dealt with. Finally question 9 was incorporated into the interview to obtain some open ended feedback from the contractors who had been involved in this process.

After contacting all of the modelers involved in this process, there were certainly a variety of answers to these questions. On the upside, none of the people I spoke to had anything overly negative to say about this process. Many had either constructive criticisms or problems related to either lack of experience or problems related to the infancy of the 3-D coordination technology.

One of the positive comments that was received about this type of coordination process was "I like to be able to show our employees a 'real' picture of what they are getting into. It is so much easier to explain what something is supposed to look like." For this project, the people actually doing the modeling of the shop drawings tended not to be the same people that were actually supervising construction. Therefore, in addition to the modelers knowing a substantial amount about the construction process to understand the real life constructability issues associated with their coordination models, it was also important that the modelers be able to convey their coordinated designs easily to their field personnel.

From my experience of working on site, it was evident that many people did take advantage of the 3-D model for seeing certain piping/duct layouts. There were a number of times when a foreman and superintendant would get frustrated when they were trying to make sense of a tangled mess of coordinated 2-D shop drawings. At these points, it made sense to open up the 3-D coordination model and orbit the area of interest and walk around to see it from a variety of angles to fully understand the geometry. This allowed the field personnel and the coordinators to remain on the same page with one another. Figure 15 shows a specific area where proper coordination of trades was critical. This main corridor in the lower level is where a majority of the piping/ductwork for the MEP systems runs.

Figure 15: Image of the coridor plenum space in the lower level of the building.

While there were certainly some positive outcomes of using this type of 3-D coordination process, like any new technology implemented in the real world, there were some issues voiced by the contractors about this new technology. One of the more negative comments related to this process was that “3-D coordination allows you to see more potential hits, but [is] very time consuming.” This seemed to be a fairly repeated sentiment from the comments received in the interviews. Unfortunately, since there is not another building exactly like the Law School using a 2-D coordination process to use as a control project for comparison, it is difficult to say for sure that this 3-D process would take more time than a 2-D coordination process. However, it would seem safe to assume that the main reason that this process takes as long as it does is because the software finds every clash in the geometry. In a matter of a few seconds, Navisworks can produce a list of every single building geometry clash. It does not, however, give a list of ways to fix each clash. Therefore, the coordination specialists still need to discuss each clash to determine an appropriate fix.

If the coordination process had been performed on 2-D drawings on a light table, the same time and effort would still have to be put in to determine how to fix each clash. If any time would have been saved during a 2-D coordination process it is likely that the time savings would have been due to the fact that only a fraction of the clashes would have been picked up. While this may mean less hours spent during coordination, it would likely mean many more hours (and dollars) spent in the field after field busts were discovered. Incidentally, the responses seemed to indicate that, on the whole, trades did feel that they were seeing fewer field clashes as a result of this coordination process.

Conclusions:

Overall it seems that the implementation of this 3-D coordination process on the new Dickinson School of Law was a good decision. At least as it relates to MEP coordination, there seemed to be more pros than cons associated with this process. It seems that the majority of the difficulties and hiccoughs that arose during this process were due to the complexity of the MEP systems and the architecture that created the challenges. Unfortunately, because of the nature of this building’s design, it is unlikely that a standard 2-D coordination process would have provided a smoother construction process. It is also important to note that even though there were some small issues that arose as a result of the new technology, there was nothing (due to the modeling technology or the complex design) that could not be modeled. Figure 16 shows the final model at the completion of this case study.

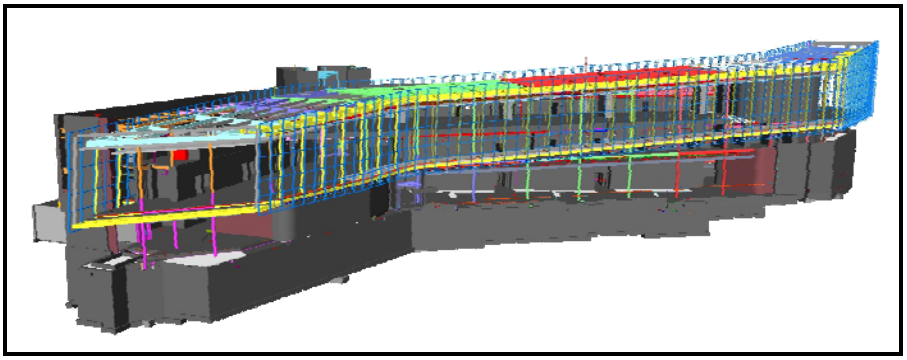

Figure 16: Image of the Coordination Model taken at the conclusion of research case study

Furthermore, looking at this study from the goal set forth at the genesis of this study of determining the general feeling of the contractors toward 3-D coordination and also which trade is the most likely to have trouble using this type of process, it is evident that there is not one cut and dry answer based on this case study. Overall, all of the contractors involved in this process felt that this type of coordination is here to stay and plan to participate in this type of coordination process again. The sentiment of “BIM sounds like a great idea, but I’m going to wait to see if it really catches on before I invest in that kind of technology,” which was mentioned by more than a few people from PACE events, career fairs, etc. was not seen during this case study. Most of the true criticisms of this case study indicated constructive ways to help make this process better rather than ways to do away with 3-D coordination and revert back to 2-D coordination processes. Given that the responses seemed to indicate that fewer field clashes were found as a result of this coordination method as well, it seems to reason that this may be a coordination method that will benefit Penn State in future projects as well.

INVESTIGATION 2 (INCLUDING ARCHITECTURAL BREADTH STUDY): ARCHITECTURAL REDESIGN OF MAIN CURTAIN WALL (CW-4)

Background:

The New Dickinson School of Law building has a series of curtain wall systems incorporated into the building design including an elaborate curtain wall that wraps the majority of the south face of the building (CW-4). This wall curves, tilts, and bends simultaneously. Clearly this feature is one of the most prominent architectural features designed for this project (shown in Figure 17). It is easy to understand how a curving glass box sitting atop a brick and stone base can be a very eye catching structure to grab the interest of potential new students and faculty driving by the facility. Some of the other aspects of the curtain wall, however, may not have nearly as much of an aesthetic impact on the building appearance and slight architectural redesigns may be able to save a significant amount of money on the building project.

Figure 17: Rendering of the south side highlighting the glass architectural curtain wall. Renderings courtesy of Polshek Partnership Architects.

This analysis involves discussions with different professionals currently working on the law school project from both the design and construction sides and also a select group of faculty in the Architectural Engineering department as well as the Architecture department at Penn State. Based on their suggestions and input, two potential curtain wall redesign ideas will be examined:

1. Eliminating the tilt on the curtain wall and running the mullions horizontally and vertically. This change essentially looks at how redefining the overall geometry of the curtain wall would affect the aesthetic and construction aspects of the project.

2. Eliminating the curved glass and aluminum mullions and utilizing segmented panes of glass and mullions instead. This change would look more on the details of the curtain wall to determine the ramifications of this change from a construction and architectural viewpoint.

The pros and the cons of each redesign suggestion will be discussed, but because the goal of this thesis is to meet Penn State's needs, a specific suggestion will not be made as to whether the proposed design should or should not have been used over the current architectural design. When this type of value engineering process is performed in real life the task of actually making the go/no-go decision would be left up to the owner. Therefore, the goal of this study will be merely to highlight the potential advantages and the potential disadvantages of each potential design revision.

Eliminate Tilt on Curtain Wall and Running Mullions Horizontally and Vertically

An option to be examined in this analysis is the possibility of removing the tilt on the curtain wall and running the curtain wall mullions horizontally and vertically. Along the length of the main architectural curtain wall, the glass and mullions tilt slightly from the vertical plane. This tilt changes along the length of the building. At its maximum tilt, the curtain wall is 3.5° off from the vertical. One proposed idea would be to eliminate this tilt. Figure 18 shows a detail of the potential design change. In addition to removing the tilt, it was suggested to also run the curtain wall mullions horizontally and vertically. This would allow for pieces of glass to be (closer to) rectangular with fewer trapezoidal panes.

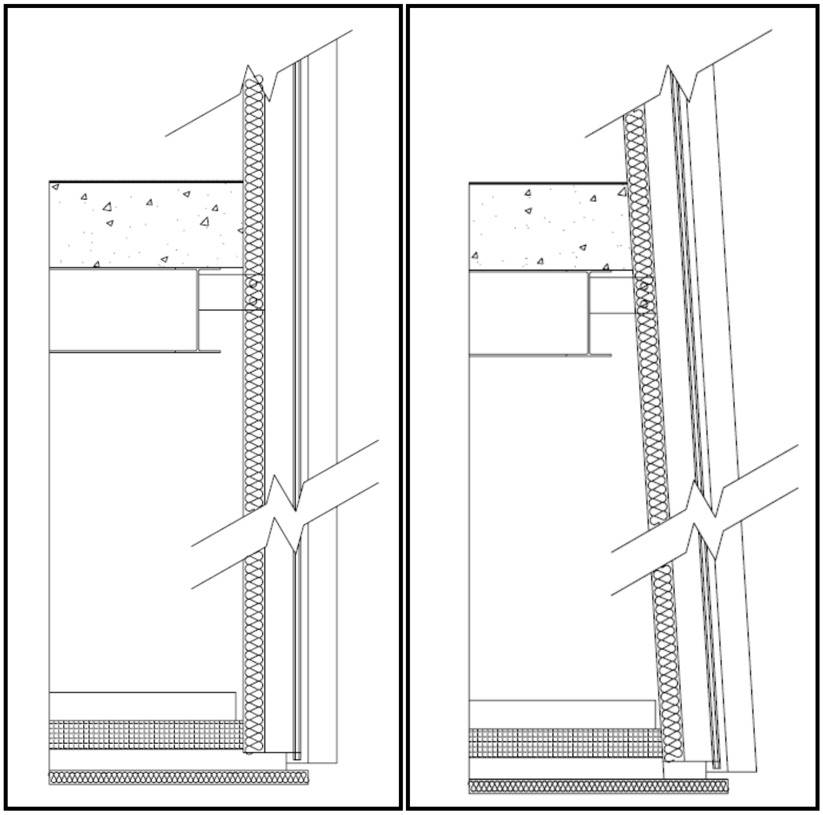

Figure 18: The proposed alternate curtain wall detail shown in comparison to the current design detail at its maximum tilt

Construction View

These changes could help in coordination efforts – especially those in the field. When workers and foremen are looking in the field for an idea of where a boundary of part of the curtain wall will be, they may look at a set of paper plans. Because the paper plans may be cut (for example) at 4' above the floor plane, the edge of the curtain wall on the paper at 4' above the floor will likely not be at the same location at 9' off of the floor plane. While it may be shown correctly in the 3-D coordination model, this information is not as accessible as a set of plans on top of the toolbox in the field.

In addition to coordination benefits, this could also make installation and inspection easier. The curtain wall is supported by the structural steel. If the wall was vertical everywhere it would be easier to plumb and align the steel members in the building. In addition to the steel crews, if the mullions were run horizontally and vertically, installation and inspection would likely be easier. Crews would not be forced to check drawings for every mullion to determine the appropriate tilt. This could improve the overall productivity for certain crews.

Because of the numerous construction advantages, this certainly seems to be a beneficial design revision from a construction point of view. In addition to the potential headaches and stresses that would be avoided with this revision a substantial cost and time savings could also be had. It is difficult to determine exactly how much time would be saved because this change would not affect the quantity of work performed, only the complexity of work. After discussing this potential design revision and its affect on cost with the construction management team, the estimated savings would be in the $1.1 million range. For a $60 Million dollar project, this is a fairly substantial savings which yields substantial benefits for the construction manager.

So it is quite clear that from a construction stand point, this change can be quantified and clearly offers a substantial benefit related to both time and money. From an architectural viewpoint, it is much harder to quantify a change. Instead, this change will be examined from a qualitative stand point.

Architectural View

After contacting one of the senior associates in Polshek Partnership Associates, I got some idea as to what the tilt added to the building aesthetic and why it was (in the architect's eye) a worthwhile feature.[3] As stated earlier, it is easy to see that the curtain wall on this building project is one of the (if not the) most prominent architectural features. While this curtain wall is probably the most prominent architectural feature when viewing the building from the outside, the library was determined to be the most prominent functional feature on the inside of the building.

Because this is a school of law, the designers felt that the library should be the functional and aesthetic focal point of the building. Therefore, the design team felt that the curtain wall should act to highlight the library's importance. Ergo, the designers did not want to compromise the design of this aspect of the building in any way.

[3] Mann, AIA LEED AP, Kate. Polshek Partnership Architects. "Dickinson School of Law CW-4 Feedback." 4 Mar. 2008.

During schematic design when this curtain wall tilt issue arose and discussions were held about the best way to design it, 3-D models were used to examine the effects of certain curtain wall changes as well as full, 1:1 scale, 15' x 20' paper drawings. When the different scenarios were examined the vertical mullions made the building seem as if it were "leaning backwards." From an aesthetic standpoint this backward lean went completely against the intent of the rising curtain wall. The design intent was to make the "glass box" on top of the building seem as though it was rising toward Mount Nittany in the distance.

Eliminate Curved Glass and Curved Aluminum Mullions

A second option that was discussed among the construction management team was eliminating the curved glass and aluminum mullions that run along the main architectural curtain wall. These curved glass panes and aluminum mullions would be replaced by flat segmented pieces. There are a few potential advantages and disadvantages to this type of system.

Construction View

This change may allow for a slightly shorter lead time for curtain wall materials. Because the current design calls for mullions and glazing with a radius, the fabrication time would likely be greater than the time to fabricate straight, segmented pieces because each piece along the curtain wall curves would have a slightly different radius and therefore, each would have to be custom fabricated. If every pane and mullion could be flat, the radius would not be a consideration at all during fabrication. This could also be advantageous if the design of the curtain wall would change as the project progresses. Because of these fabrication advantages, it is estimated that a change to flat glass panes would save approximately $170,000.

In addition to the fact that the fabrication time would be shortened by going with flat glass, it would also be easier to transport glass to the site. According to the curtain wall contractor onsite, because of the nature of curved glass, delivery trucks can only carry 10 crates of curved glass crates. However, the delivery trucks can carry anywhere from 30 to 50 crates of flat glass.[4]

Architectural View

From an architectural standpoint, this change does have a relatively significant impact on the look of the building. One of the basic premises used in architectural design is that the best way to highlight a building element is to surround it with elements that are unlike it. For instance, when looking at a building with a characteristic curve, one of the best ways to highlight the curve is to place the curve near straight elements. A different, but similar example of this premise can be seen in the photo of the IST building in Figure 19. To highlight the elevated portion of the building that bridges over Atherton Street, the architects decided to place straight, blocky columns on either side of the road to accentuate the curve.

Figure 19: A Westward view of the Information Sciences and Technology (IST) building. Image taken from imagearchive.psu.edu

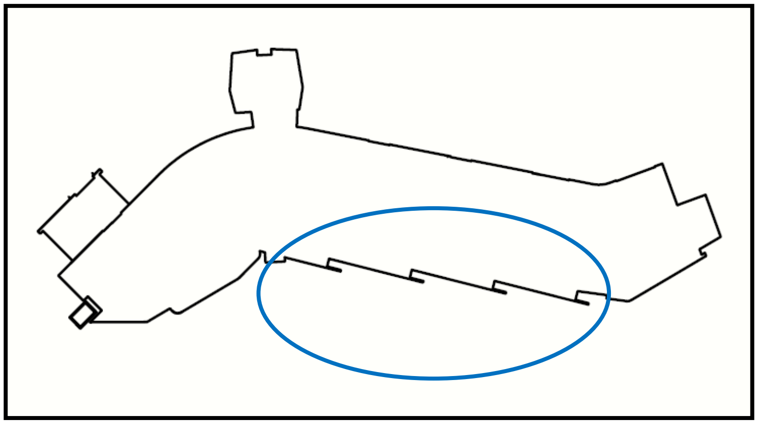

Figure 20: Ground floor building plan of the New Dickinson School of Law

On the New Dickinson School of Law, the architects also realized and employed

[4] McDonough, Jim., DM Products. Personal interview. 27 Feb. 2008.

this tactic on the façade of the building. There are a series of walls along the base of the building indicated in Figure 20 that have a very straight and segmented look. These "jagged walls" help add to curving, organic aesthetic of the glass curtain wall above. Therefore, if flat glass was used, it would counteract the curved effect that the architects are seeking to produce with this curtain wall to some extent.

Conclusions:

It is clear that there is a fairly substantial cost savings by using this change. This change may also cause a fairly significant aesthetic loss as well. At this point the decision falls on the owner to determine where their priorities lie. Because different people in OPP may have different feelings on what the building should look like and for what cost, it is important to consider where a viewer will be when considering the impact of a design change. The impact of this loss in sleekness will vary, when viewed from different areas.

For example, maybe the theory is that the sleek building curve serves to act as an eye catching mechanism to attract potential students and faculty driving on Park Avenue. From Park Avenue, the view of the building may be only minimally impaired (if at all) by switching to segmented glass. Therefore, if the looks of the building from Park Avenue still brings the potential Penn Staters (or Dickinsonians) into the building and the education and amenities in the building are what keeps them there, then arguably a segmented glass façade would not greatly hurt the overall design intent of the building.

On the other hand, maybe the feeling is that the façade should maintain its eye catching quality to a viewer as he or she is entering the building or as he or she is inside the library looking out of windows at one of the study carrels. In this case, some of the aesthetics of a curving glass box atop a rigidly straight base would be lost.

Investigation 3 (Including Mechanical Breadth Study): Analysis of Curtain Wall Glazing Alternative

Background

As discussed in Investigation 2, the New Dickinson School of Law has a substantial glass curtain wall that wraps the South face of the building façade. Because this wall is virtually all glass, it may be susceptible to a great deal of unwanted solar heat gain because it faces South. Currently a 1-3/16" thick double pane glazing assembly is being utilized on the majority of this main curtain wall. This glazing can be seen in Figure 21. One of the suggestions made to potentially save Penn State some money in the life of the building was to use triple pane glazing instead. The upfront cost would likely be more expensive, but it was unclear as to how long it would take for the glazing to pay for itself in annual energy savings. This investigation seeks to determine the payback period as well as the construction and design implications of going with this type of design change.

Figure 21: Double pane glazing being stored onsite until workers are ready to install it in the curtain wall.

Analysis

As with any aspect of any building project, it is important to consider the cost implications of any design change. There are a variety of factors that would potentially affect the total cost difference between the current glazing designed and the potential alternative glazing. For the purposes of this thesis, I will be focusing on the cost implications related to solar heat gain, but efforts will be made to identify other areas where changes affecting cost should be considered for a more complete analysis.

Looking first at the solar heat gain and insulation cost differences associated with a triple pane glazing versus a double pane system, it is clear that the triple pane system offers a life cycle cost savings. Two different analyses were performed to demonstrate the cooling cost effects of the two different glazings. The first analysis demonstrates the effects of the two types of glass in the middle of August, which is the time of year for State College when the peak load is the most likely to be reached. The second analysis looks at the typical yearly cooling loads on the building as a result of the two types of glass.

Performance Under Worst-Case-Scenario Conditions

In State College, peak solar gain occurs in August. By utilizing the Solar Intensity and Solar Heat Gain Factors for 40° North Latitude from the ASHRAE Handbook – Fundamentals, it is possible to determine the typical maximum heat gain typically seen by a glass wall.[5] Because this wall curves, in two places forming 3 main faces of curtain wall 4, there are two small walls that face Southeast and 1 large segment of the wall that faces South Southwest. Therefore, the total face of the glass will be estimated to face South Southeast.

To properly perform this calculation, it was necessary to perform a glazing takeoff for the main curtain wall. After performing this takeoff, it was determined that the square footage of glass on the south face of the curtain wall was 12,561 SF. The takeoff procedure is included in Appendix B of this report. In addition to the glass quantity, it was also necessary to obtain the solar coefficient of the glass. Upon further research, it was determined that the shading coefficient of the double paned glass installed on the project was 0.39 and the shading coefficient of a standard three pane glass is 0.28. The chart in Figure 22 shows the heat gain calculations for August 21 in State College.

[5] ASHRAE Handbook - Fundamentals. Atlanta, Ga.: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1985.

August 21	SSE				August 21	SSE		
Time	SHGC	S.C.	Heat Gain		Time	SHGC	S.C.	Heat Gain
600	17	0.39	6.63		600	17	0.28	4.76
700	70	0.39	27.3		700	70	0.28	19.6
800	118	0.39	46.02		800	118	0.28	33.04
900	151	0.39	58.89		900	151	0.28	42.28
1000	165	0.39	64.35		1000	165	0.28	46.2
1100	160	0.39	62.4		1100	160	0.28	44.8
1200	138	0.39	53.82		1200	138	0.28	38.64
1300	99	0.39	38.61		1300	99	0.28	27.72
1400	56	0.39	21.84		1400	56	0.28	15.68
1500	31	0.39	12.09		1500	31	0.28	8.68
1600	23	0.39	8.97		1600	23	0.28	6.44
1700	16	0.39	6.24		1700	16	0.28	4.48
1800	5	0.39	1.95		1800	5	0.28	1.4
		TOTAL	409.11				TOTAL	293.72
		Area of Glass	12561				Area of Glass	12561
		BTU/HR	5138830.71				BTU/HR	3689416.92
		BTU/HR Per Ton of Cooling	12000				BTU/HR Per Ton of Cooling	12000
		Tons of Cooling Load	428.2				Tons of Cooling Load	307.5

Figure 22: Calculations showing affect of using a triple pane glass system over the double paned system installed on a peak load summer day.

It can be seen in this chart that double pane glass will require 428.2 tons of cooling to offset the solar heat taken in by this type of glazing. The triple pane glazing would require only 307.5 tons of cooling load to offset the heat taken in, however. At less than 72%, the amount of solar heat taken in by the triple pane glass is significantly less than the double paned glass. Clearly this demonstrates that the triple pane glazing offers a substantial energy savings during the especially hot summer months.

Life Cycle Performance

Looking now at the life cycle cost associated with these types of glazing a different method of energy calculation was used. TRACE 700 v4.1 software was used to determine the expected annual cooling costs related to this glazing. The area of the building, area of glass, location of building and a variety of other variables were entered into the software to identify the climatic factors that would affect the heat gain. Overall, the comparison of the two types of glazing were very similar. The only real difference between the two calculations was derived, because of different U-values and shading coefficients.

As mentioned earlier, the shading coefficients for the double and triple pane systems were 0.39 and 0.28, respectively. The U-values for the double and triple pane systems were 0.28 and 0.22, respectively. When the TRACE software was used, it was determined that the yearly cooling cost based only on the curtain walls would be approximately $7,090 for the double pane glass and $3,520 for the triple pane glass. This means that the triple pane would save approximately, $3,500 per year. This is based on a suggestion received to price energy at $400 per ton of cooling.[6] This is a substantial savings in cooling cost. However, to truly see the value of this savings, it must be compared to the upfront extra cost for the triple pane curtain wall.

From talking to industry members, it sounds like triple pane glass costs roughly 25% more than double pane glazing.[7] The double pane glazing on this project costs roughly $40 per SF. Therefore, triple pane will be priced at $50 per SF. With 12,561 SF of curtain wall glazing area, the total upfront costs for double and triple pane glazing would be roughly $500,000 and $625,000, respectively. This would mean that the payback period for the triple pane glass (based on cooling load savings) would be about 35 years.

This may or may not be an attractive option to the university. Because this building will likely be in existence for at least 35 years the university may see it as an attractive alternate to the double pane glazing. Then again, 35 years is a relatively long time to have money tied up in an investment that is only paying for itself very slowly. One thing for the university to think about when considering this payback period is the cost of energy. With rising energy costs and decreasing fossil fuel supplies, it is likely that the cost per ton of cooling will increase. As the energy cost increases, the payback period for the triple pane glazing over the double pane glazing would decrease. Regardless of how the university interprets this data, however, as stated earlier, is to simply provide the facts to the owner for them to make a final decision.

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[6] Freihaut, PhD, James D., The Pennsylvania State University. Personal interview. 28 Mar. 2008.

[7] Bloom, Edward., Thornton Tomasetti. "Triple Pane Glazing Question." 19 Mar. 2008.

Additional Direct and Indirect Costs Associated with Glazing Alternative

From a construction standpoint, triple pane glass would likely not add a substantial cost. Initially it was thought that if the double pane glass could be lifted by hand, but triple pane glass would require a crane to lift the lites into place. This would likely slow the curtain wall assembly process and create a loss in productivity. In actuality, with only a few exceptions, the glass lites are large enough in this building that workers will not be able to lift them by hand regardless of whether they use double or triple pane glazing. This means that a crane will already be needed on site during curtain wall construction, so the use of triple pane glazing will not substantially increase the cost of onsite construction.

One additional indirect cost that would likely be affected by using triple pane glazing instead of double pane would be the building structure. Currently, steel strong backs support the load of the glazing. These strong backs can be seen in Figure 23. Double pane glazing has a self-weight of approximately 280 Lb/lineal foot of curtain wall. Triple pane glazing would result in a load of approximately 335 Lb/lineal foot of curtain wall. This is an increase of over 50 Lb/lineal foot. It is likely that the steel strong backs would need to be sized up to account for this added glazing weight. There would be an additional cost to the owner for this extra structure.

Figure 23: Image from inside of the building at CW-4 showing steel strong backs at study carrels.

From a mechanical standpoint, there is potential for savings by going with the triple pane glazing system as well. Because this alternative glazing can save upwards of 120 tons of cooling at peak loading during the summer (a savings of over 25% as compared to the double pane glass), there is potential for the mechanical cooling equipment to be sized down. Because this study only constitutes a mechanical breadth and not totally redesigning the cooling system, it was not examined in this analysis. In real life, this could be a significant savings to the owner.

Conclusions:

After performing this analysis, it is clear that there is a substantial upfront cost associated with this type of glass. Extra costs are associated with the both the glass itself, and the structural steel strong backs supporting the curtain wall. With these increased costs, however, comes an increased annual cooling savings. While the payback period from this change seems relatively long, with rising energy costs, the actual payback period could be significantly decreased.

INVESTIGATION 4: ANALYSIS OF ALTERNATIVE UTILITY TUNNEL CONSTRUCTION PROCESS

Background

Penn State runs its campus utilities to all buildings on its University Park campus. For the purposes of the New Dickinson School of Law, these utilities came from the South side of the site. This would mean that the utilities would have to be run under both Park Avenue and Bigler Road. Figure 24 shows a map of the intersection of Park Avenue and Bigler Road and the utility tunnel to be constructed relative to the building.

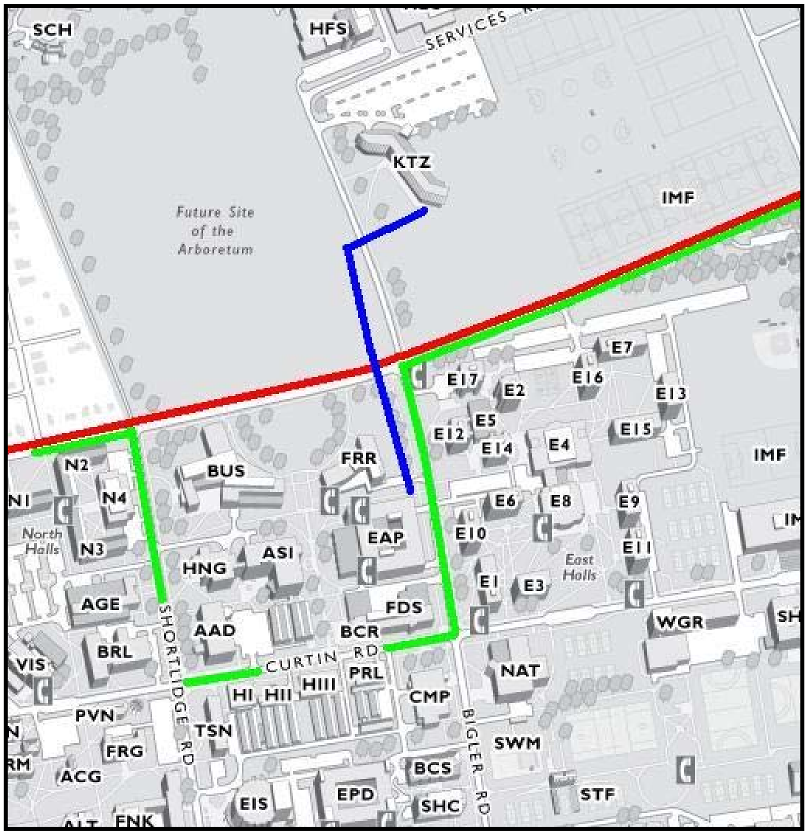


Figure 24: Map showing detoured Eastbound traffic in Green, Westbound traffic in Red and the utility path in Blue. Image taken from campusmaps.psu.edu

Typically, this would mean that the construction manager would have to contact Penn State, determine an appropriate time frame to close down the roads, shut the roads down, and construct the utility tunnel accordingly. Unfortunately, for this project, this was not such a simple task. Park Avenue is a state road, not a university road. Therefore, specific permission had to be obtained from Pennsylvania to shut down/dig up the road. One of the stipulations of the permits issued by the state was that westbound traffic would have to be able to maintain its use of Park Avenue. Therefore, Eastbound traffic would have to be detoured South at Shortlidge Road, East on to Curtain Road, North on to Bigler Road where it would rejoin with Park Avenue. In addition to the state requirement to allow westbound traffic to maintain use of Park Avenue, the state also required that the work on this road to be performed when the road was partially shut down be performed 24 hours per day, 7 days per week until completion.

Anyone who was in State College during the summer of 2007 and experienced this detour at rush hour would say how unpleasant this detour was for all eastbound traffic. Unfortunately, curtain road was not built to handle the kind of traffic loads seen on Park Avenue. The four-way stop intersection at Curtain and Bigler Roads was an especially unpleasant intersection at peak traffic hours.

In addition to the difficulty associated with this detour, construction crews building the utility tunnel were forced to build it in two halves. Half of Park Avenue was dug on the South side of Park Avenue where construction of the first half of utility tunnel was performed. This meant that westbound traffic moved normally through the Bigler/Park intersection. After the first half of the tunnel was constructed, however, the hole dug had

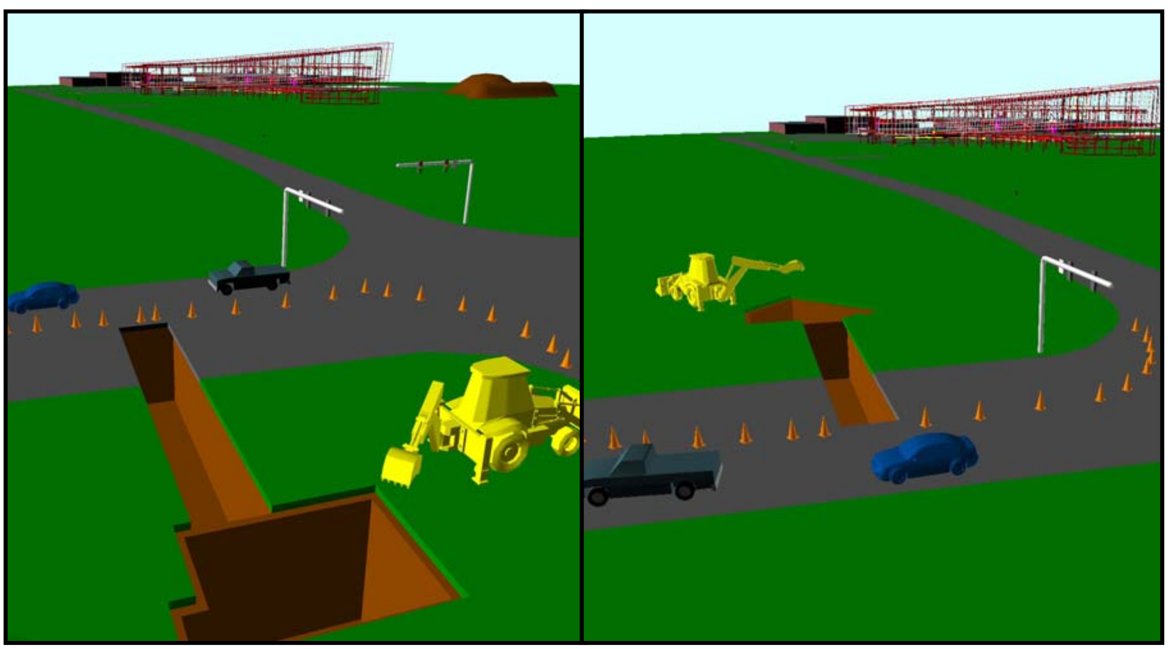


Figure 25: Images from 4-D model showing traffic and digging during utility tunnel construction.

to be backfilled, and repaved. Then westbound traffic was rerouted to the South side of the Park Avenue so the North side could be dug up and constructed. This process (in Figure 25) seemed to add time and a loss of productivity because the utility tunnel construction process had to essentially be completed twice.

As a method to help alleviate this problem for Penn State's employees, students, athletic camp attendees, and construction teams, the suggestion was made to not close down Park Avenue at all. Instead of digging up the road, it was proposed to bore under the road and construct the utility tunnel while traffic continued to maintain use of Park Avenue above. To investigate the feasibility of this type of construction a few considerations needed to be made.

1. Given the location of the project, size of the tunnel and a myriad of other variables affecting the construction of this utility tunnel, it would need to be determined if it would even be possible to bore under the road instead of digging it up.

2. Initially it seemed to reason that because neither Park Avenue nor the traffic on Park Avenue would be disturbed by this process, permits would not be necessary to obtain. Investigations would have to determine if this was, in fact, the case and if so, how many months could be saved by omitting the permitting time.

3. In addition to feasibility from a construction standpoint, this alternative would need to be considered from a monetary standpoint to determine if it would save Penn State significant time and money.

Analysis

As mentioned earlier, the first thing to make certain of is that this process would, indeed, be possible for this project. After speaking with the sitework contractor, it was determined that it would be possible, but not as easy to perform as the current tunnel construction process. Initially one might think to look at a labor intensive method because of the relatively small amount of work and high cost for mobilization of equipment. This labor intensive method would, in fact, be a less expensive way to perform this process. The problem with a labor intensive method, however, is that while workers were digging under the road, additional workers would have to be right behind the diggers placing the precast concrete tunnel for support. Unfortunately, even if the workers were placing the concrete tunnel as close behind the diggers as possible, there would still be a small length of tunnel where the workers would be covered only by soil. Because of the risk of a cave in, neither OSHA nor any responsible CM would allow this type of process to occur.

The next logical boring option would be to look at obtaining a tunnel boring machine. The tunnel boring machine would essentially dig the tunnel on one side of the road and after a portion of the tunnel was dug, the machine would automatically place the concrete tunnel in the hole after digging. Because workers would not be working in the tunnel until after concrete walls were placed, the workers would be safe to work inside the tunnel with no additional OSHA requirements that would need to be considered. This would allow for a safer utility construction process.

So this process is possible using a machine like the one described above. The boring machine required to perform this type of process would be extremely expensive, however. Mobilization costs of the machine alone would have been over $300,000.[8] Considering that the whole utility tunnel process cost a little over half a million dollars, it is apparent that boring using a tunnel boring machine would be a substantial added cost to the project.

So ultimately, it became clear that this process of boring a tunnel under Park Ave. would be possible, but, because a capital intensive method would have to be used for safety reasons, the cost would be far greater. In addition to the cost of the equipment, additional difficulties would be introduced to the process because the contractor, who performed the

[8] Croyle, Mike. Stone Valley Construction, Inc. Personal interview. 27 Mar. 2008.

work using the original construction process, would not have the capability to perform the work using the tunnel boring process. Instead, a specialty contractor would have to be hired that would have access to the necessary tunnel boring machine.

Looking at this alternative construction process now, from a time savings standpoint, the findings did not seem to support the initial inference that permitting time would be reduced. Unfortunately, it was discovered through conversations with the site work contractor that, even though Park Avenue would not be disturbed by this construction process, it was still necessary to obtain state permits. The state requires a Highway Occupancy Permit for all work that would either work on or around state roads. Therefore, the 5-6 months that were required to obtain permits initially, would still be a necessary wait even if the boring process had been used.

So after hearing that this process will not save any schedule time as initially predicted and will cost substantially more money, one might draw the conclusion that boring under the road would never be a good option for Penn State. This, however, might be a flawed conclusion to draw. The goal of the analyses in this thesis is to deliver the project in the best way for the owner specifically. So looking specifically at Penn State, it is a fact that (on football Saturdays) Penn State is the third largest city in Pennsylvania. One of the major arteries for facilitating the flow of football traffic to Beaver Stadium is Park Avenue. Had this process been delayed by a few weeks, utilities would have had to be run during the season opener. Under this type of circumstance, there may have been good reason to go with this type of construction method to allow for Park Avenue to remain fully open during the utility tunnel construction process.

Another option for Penn State that was suggested during the investigation of this tunnel boring option was to bore under the road without boring the tunnel. This would mean that holes would be bored under the road and sleeves would be placed in these holes. The different utilities would then be run through these sleeves. Obviously, with this type of process, OPP would not be able to access the pipes as easily under Park Avenue. If the university wanted to access these pipes at a later point, they would have to trench along the pipe runs away from Park Avenue and slide out the desired pipes to replace the faulty pipe.

Admittedly, this is less convenient for the university than the current design, but while there is easy access under Park Avenue to deal with potential leaks and any other maintenance issues that may arrive, the majority of the utilities run to the building still have no access other than digging up the pipes. While this may seem like a hassle for Penn State, it would be able to save approximately $250,000 for the university. This method would actually be the cheapest method for the university – even cheaper than digging to install the tunnel in two halves. In addition to the upfront, construction savings with this type of method, this could potentially save money over the life cycle of the building through better insulation of the piping. By running chilled water, hot water, and steam in the same tunnel space, some thermal transfer is bound to occur. It is possible to minimize this transfer by using insulation, but if the utilities were separated by soil, there is a better chance at minimizing thermal transfer between the utilities.

Conclusions:

After examining the feasibility of this option of boring the utility tunnel under Park Avenue, it was determined that it is feasible. However, while it is feasible from a construction standpoint, it may not be feasible from an economic standpoint. This process would have cost roughly 60% more than the process actually used. In addition to this high cost addition, this alternative process would not save any significant amount of time during the permitting process.

With mostly negative comments received about this process, Penn State would not likely give the go-ahead for this option. However, if this process was delayed a few weeks and this activity would have to be performed during football season, the university might see a much bigger benefit in either boring the tunnel, or omitting the tunnel and simply boring sleeves through Park Ave. to run all utilities through.

CONCLUSIONS:

There were several analyses that were looked at in detail in this assignment. The purpose behind each was to determine a way to better meet and exceed Penn State's needs. Some of the studies proved to be positive and helpful. Others may or may not be helpful depending on how the university sees the issue. In the real world, construction managers are looked to provide data and suggestions about design, constructability issues, and delivery methods so that the owner may be better educated to make a good decision to meet their needs. The construction manager is not likely to be the one responsible for actually making the decisions about the issues described. Therefore, in trying to keep with this theme of pleasing the owner, the outcomes of these studies will be to provide concrete data for Penn State's consideration.

BIM is, and will continue to be, a buzzword in the AEC community. Depending on everyone's unique interpretations of Building Information Modeling, one could argue that BIM was or was not used on this project. In many of the models used for coordination there was no actual information embedded into the model geometry. There is however an undeniable element of information told more quickly and efficiently through the use of 3-D models. As mentioned in the analysis these models may take longer to model than a standard 2-D drawing would. However, once the models were made, the benefits were numerous.

Nearly every clash was detected in electronic format rather than in the form of a field clash. Workers onsite, in the office, and from other companies could know exactly what the construction intentions were of any trades. Based on this case study, it certainly seems to indicate that 3-D coordination may be highly advantageous for Penn State to require on future projects.

Looking now at the curtain wall studies that were carried out, it seems that from an architectural point of view, there are two design options that could have different levels of impact. Removing the tilt of the mullions and running them vertically and horizontally, would save a significant amount of money. It would do so, however, at the expense of the overall building aesthetic. From a construction point of view, this change would save time, money, and field headaches. From an architectural point of view, however, running the mullions vertically and horizontally would make the building appear as if it were leaning backwards, which would detract from the overall rising aesthetic of the curtain wall.

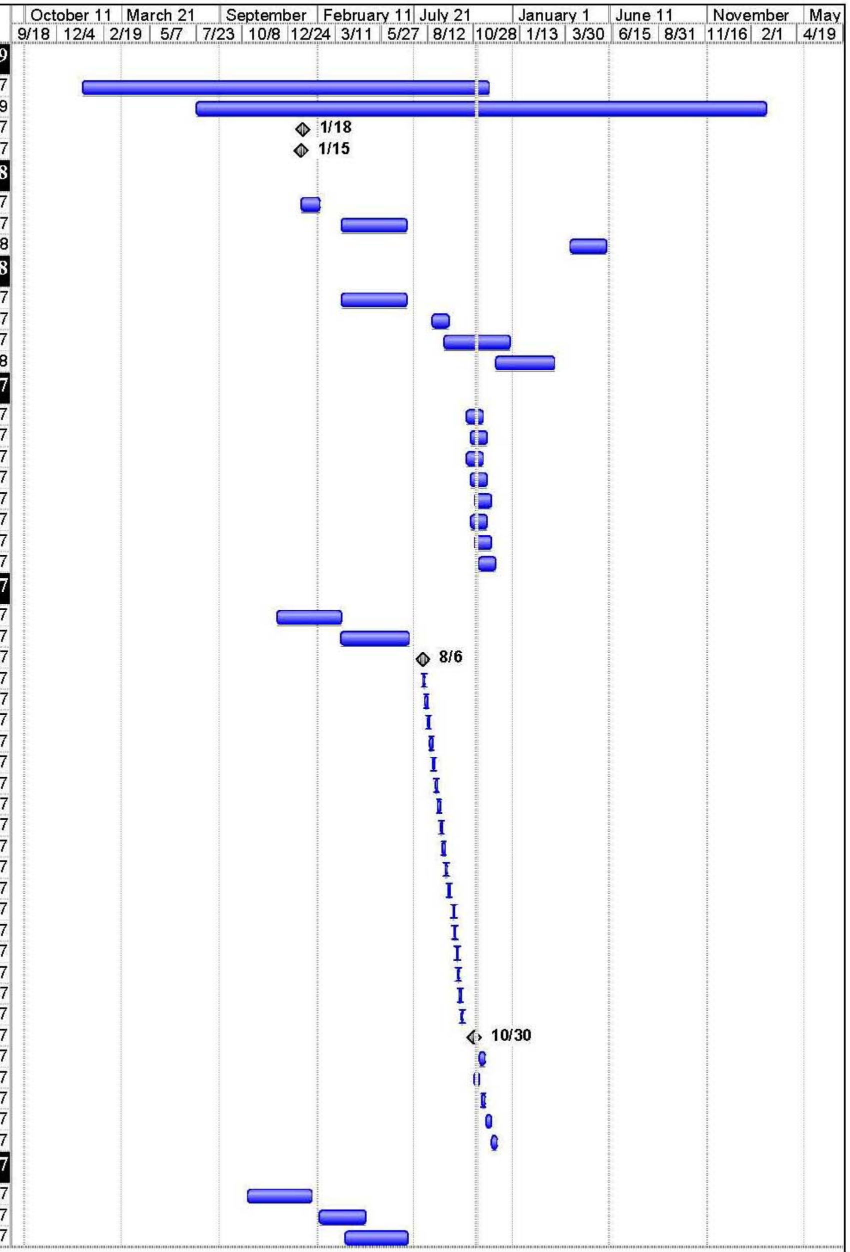
The other architectural curtain wall alternative that was examined was changing the curved glass to flat glass panes. This change would save approximately $170,000 and could be slightly easier to install. While this is not a huge savings, it may also not greatly detract from the building's appearance, architecturally. From a close viewpoint to the building, it would definitely take away from the curving aesthetic of the main curtain wall, but from farther away (perhaps at the Park Ave.) there may be little to no change in the building appearance.

It is important for OPP to be informed not only about the glass geometry, but also the glazing makeup. Currently there is a double paned window system installed. Based on the loads generated from solar gain, they may be able to save $3,500 annually by switching to a triple pane glazing system. At this rate, the triple pane glazing would have approximately a 35 year payback period. While this may sound like a fairly long time, it would also be important to mention to Penn State that if and when the price of energy goes up, the payback period of this glass will become shorter and shorter.

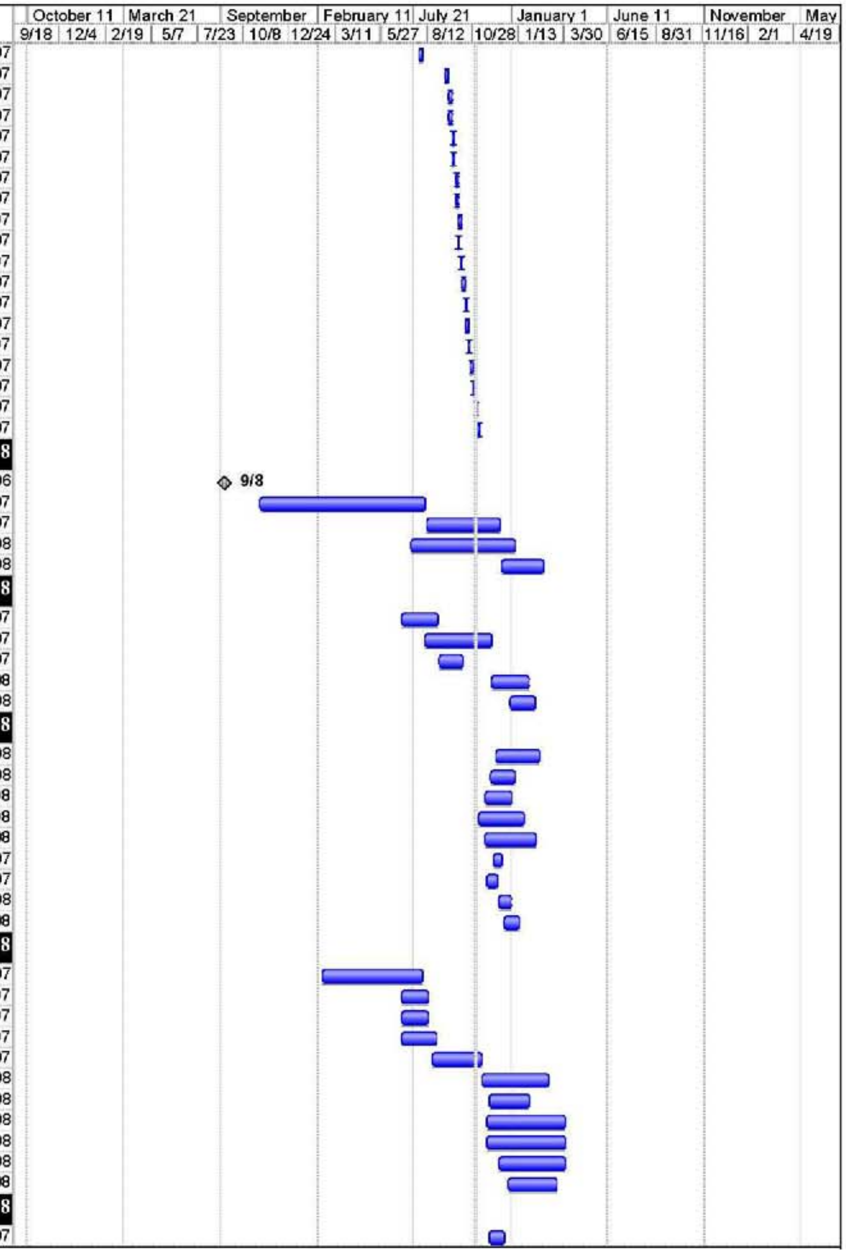
Finally, the option of boring under Park Ave to construct the utility tunnel was looked at as an option for the university. The construction method that was used in reality for this activity was to dig up half of Park Avenue, while traffic was rerouted to the other side of the road, construct the utility tunnel, patch and pave the road, and then repeat the process on the other side of the road. The main advantage of boring under Park Avenue to place the utility tunnel is that it would allow Park Avenue to remain fully open. As it turns out, boring the tunnel under Park Ave would be significantly more money than digging. Penn State would most likely not opt to bore under Park Ave under the circumstances. If, however, the situation was slightly different such that the construction of the utility tunnel got delayed, this process may make more sense for the university. If the utility tunnel construction process had to occur during move-in week for students or a home football game for Penn State, it would be much harder for Penn State to shut down Park Avenue. The detour on Park Avenue was a hassle for motorists on Park during the relatively light summer months, it would be nearly impossible during the annual peaks of traffic flow.

APPENDIX A:

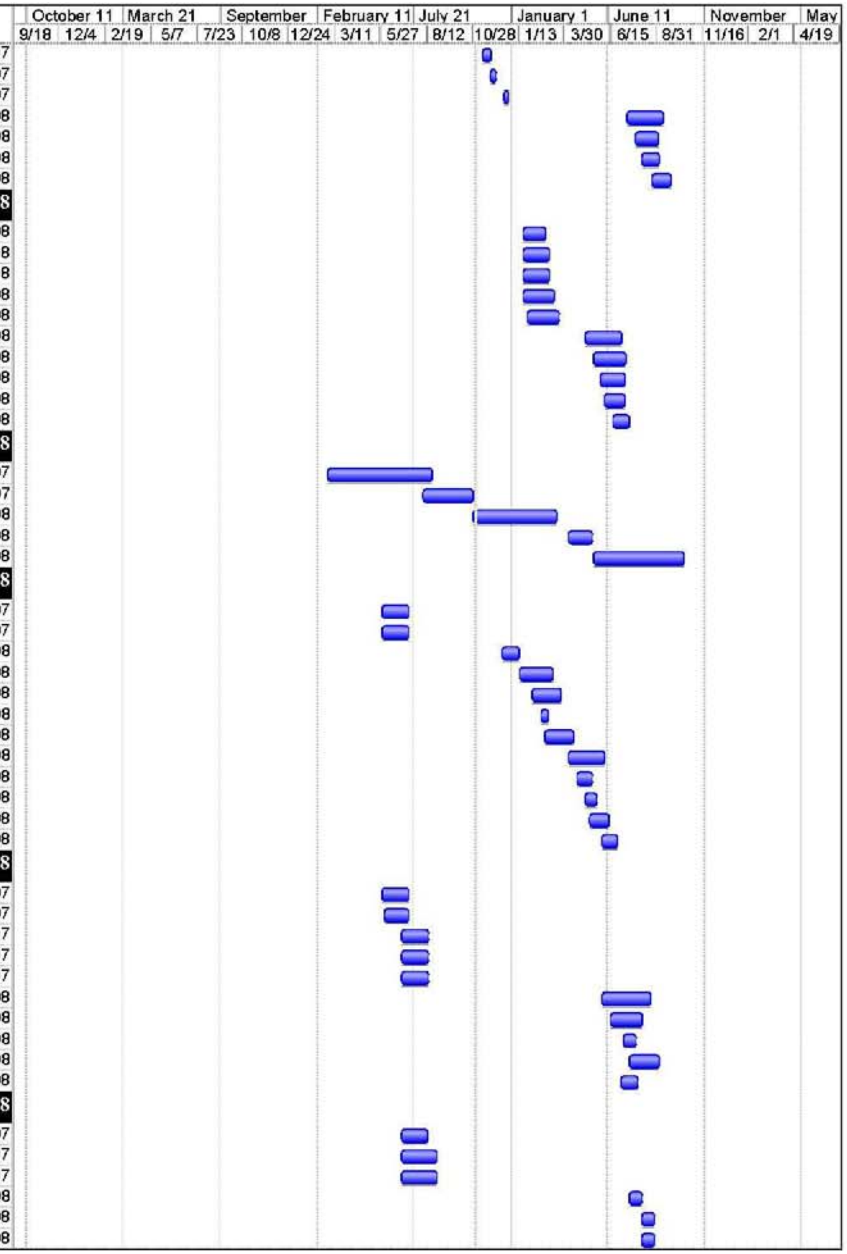
ID	Task Name	Duration	Start	Finish
1	**PRE-CONSTRUCTION**	**815 days**	**Mon 1/16/06**	**Fri 2/27/09**
2	Design Phase	485 days	Mon 1/16/06	Fri 11/23/07
3	Construction Manager Hired	680 days	Mon 7/24/06	Fri 2/27/09
4	Groundbreaking Ceremony	0 days	Thu 1/18/07	Thu 1/18/07
5	Procurement of Subcontractors Begins	0 days	Mon 1/15/07	Mon 1/15/07
6	**SITE WORK**	**365 days**	**Mon 1/15/07**	**Fri 6/6/08**
7	Excavation	23 days?	Mon 1/15/07	Wed 2/14/07
8	Bid and Award Landscaping Contractor	77 days?	Fri 3/23/07	Mon 7/9/07
9	Landscaping	45 days?	Mon 4/7/08	Fri 6/6/08
10	**MASONRY**	**253 days**	**Fri 3/23/07**	**Tue 3/11/08**
11	Bid and Award Site Masonry Contractor	77 days?	Fri 3/23/07	Mon 7/9/07
12	Fab/Deliver Site Masonry	20 days?	Tue 8/21/07	Mon 9/17/07
13	Fab/Deliver Building Masonry	80 days?	Mon 9/10/07	Fri 12/28/07
14	Exterior Masonry/Stone	70 days?	Wed 12/5/07	Tue 3/11/08
15	**EXTERIOR FRAMING**	**35 days**	**Wed 10/17/07**	**Tue 12/4/07**
16	Ground Level Exterior Framing	20 days?	Wed 10/17/07	Tue 11/13/07
17	Ground Level Exterior Sheathing	20 days?	Wed 10/24/07	Tue 11/20/07
18	Mezzanine Level Exterior Framing	20 days?	Wed 10/17/07	Tue 11/13/07
19	Mezzanine Level Exterior Sheathing	20 days?	Wed 10/24/07	Tue 11/20/07
20	Second Floor Exterior Sheathing	20 days?	Wed 10/31/07	Tue 11/27/07
21	Second Floor Exterior Framing	20 days?	Wed 10/24/07	Tue 11/20/07
22	Third Floor Exterior Framing	20 days?	Wed 10/31/07	Tue 11/27/07
23	Third Floor Exterior Sheathing	20 days?	Wed 11/7/07	Tue 12/4/07
24	**STEEL**	**262 days**	**Wed 12/6/06**	**Thu 12/6/07**
25	Bid and Award Steel Contractor	77 days	Wed 12/6/06	Thu 3/22/07
26	Steel Shop Drawings	82 days?	Thu 3/22/07	Fri 7/13/07
27	Steel Erection Begins	0 days	Mon 8/6/07	Mon 8/6/07
28	Steel Sequence 1	3 days?	Mon 8/6/07	Wed 8/8/07
29	Steel Sequence 2	3 days?	Thu 8/9/07	Mon 8/13/07
30	Steel Sequence 3	3 days?	Tue 8/14/07	Thu 8/16/07
31	Steel Sequence 4 & 5	3 days?	Fri 8/17/07	Tue 8/21/07
32	Steel Sequence 6	3 days?	Wed 8/22/07	Fri 8/24/07
33	Steel Sequence 7	3 days?	Mon 8/27/07	Wed 8/29/07
34	Steel Sequence 8	3 days?	Thu 8/30/07	Mon 9/3/07
35	Steel Sequence 9	3 days?	Tue 9/4/07	Thu 9/6/07
36	Steel Sequence 10 & 20	3 days?	Fri 9/7/07	Tue 9/11/07
37	Steel Sequence 10A & 11	3 days?	Wed 9/12/07	Fri 9/14/07
38	Steel Sequence 12 & 13	3 days?	Mon 9/17/07	Wed 9/19/07
39	Steel Sequence 14	2 days?	Tue 9/25/07	Wed 9/26/07
40	Steel Sequence 15	2 days?	Thu 9/27/07	Fri 9/28/07
41	Steel Sequence 16	2 days?	Mon 10/1/07	Tue 10/2/07
42	Steel Sequence 17	2 days?	Wed 10/3/07	Thu 10/4/07
43	Steel Sequence 18	2 days?	Fri 10/5/07	Mon 10/8/07
44	Steel Sequence 19	2 days?	Tue 10/9/07	Wed 10/10/07
45	Topping Out Ceremony	0 days	Tue 10/30/07	Tue 10/30/07
46	Basement Spray on Fireproofing	7 days?	Thu 11/8/07	Fri 11/16/07
47	Ground Level Spray on Fireproofing	7 days?	Tue 10/30/07	Wed 11/7/07
48	Mezzanine Level Spray on Fireproofing	5 days?	Mon 11/12/07	Fri 11/16/07
49	Second Floor Spray on Fireproofing	7 days?	Mon 11/19/07	Tue 11/27/07
50	Third Floor Spray on Fireproofing	7 days?	Wed 11/28/07	Thu 12/6/07
51	**CONCRETE**	**278 days**	**Wed 10/18/06**	**Fri 11/9/07**
52	Bid and Award Concrete Contractor	77 days	Wed 10/18/06	Thu 2/1/07
53	Foundations	56 days	Wed 2/14/07	Wed 5/2/07
54	FRP Foundation Walls	75 days?	Thu 3/29/07	Wed 7/11/07



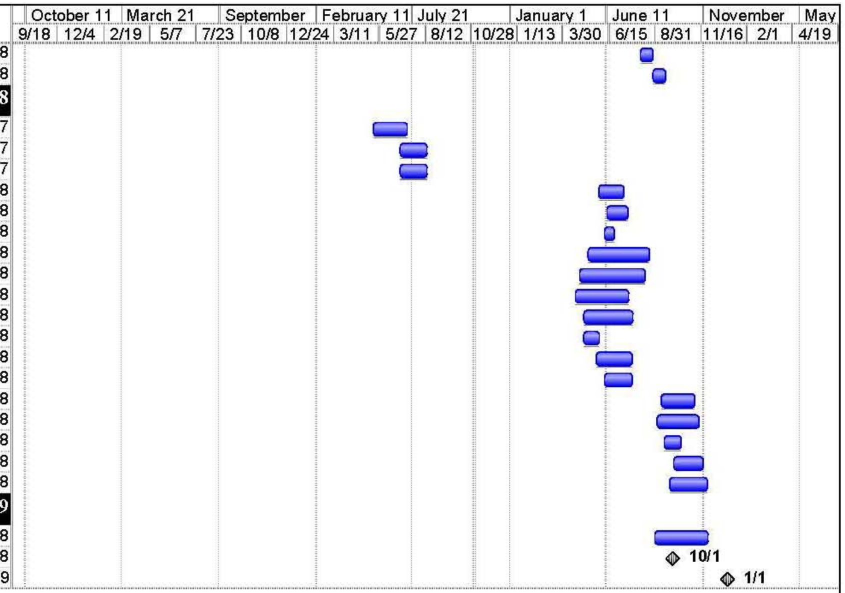
ID		Task Name	Duration	Start	Finish
55		Basement SOG	5 days?	Tue 7/31/07	Mon 8/6/07
56		Slab on Metal Deck 1st Floor Col Line 20-16	4 days?	Thu 9/13/07	Tue 9/18/07
57		Slab on Metal Deck 2nd Floor Col Line 20-16	4 days?	Wed 9/19/07	Mon 9/24/07
58		Slab on Metal Deck 1st Floor Col Line 16-14	4 days?	Wed 9/19/07	Mon 9/24/07
59		Slab on Metal Deck 2nd Floor Col Line 16-14	4 days?	Tue 9/25/07	Fri 9/28/07
60		Slab on Metal Deck 1st Floor Col Line 14-11	4 days?	Tue 9/25/07	Fri 9/28/07
61		Slab on Metal Deck 2nd Floor Col Line 14-11	4 days?	Mon 10/1/07	Thu 10/4/07
62		Slab on Metal Deck 1st Floor Col Line 11-7.5	4 days?	Mon 10/1/07	Thu 10/4/07
63		Slab on Metal Deck 2nd Floor Col Line 11-7.5	4 days?	Fri 10/5/07	Wed 10/10/07
64		Slab on Metal Deck 1st Floor Col Line 7.5-4	1 day?	Fri 10/5/07	Fri 10/5/07
65		Slab on Metal Deck 2nd Floor Col Line 7.5-4	1 day?	Wed 10/10/07	Wed 10/10/07
66		Slab on Metal Deck 1st Floor Col Line 4-1	4 days?	Thu 10/11/07	Tue 10/16/07
67		Slab on Metal Deck 3rd Floor Col Line 20-16	3 days?	Wed 10/17/07	Fri 10/19/07
68		Slab on Metal Deck 2nd Floor Col Line 4-1	4 days?	Wed 10/17/07	Mon 10/22/07
69		Slab on Metal Deck 3rd Floor Col Line 16-14	3 days?	Mon 10/22/07	Wed 10/24/07
70		Slab on Metal Deck 3rd Floor Col Line 14-11	3 days?	Thu 10/25/07	Mon 10/29/07
71		Slab on Metal Deck 3rd Floor Col Line 11-7.5	3 days?	Tue 10/30/07	Thu 11/1/07
72		Slab on Metal Deck 3rd Floor Col Line 7.5-4	3 days?	Fri 11/2/07	Tue 11/6/07
73		Slab on Metal Deck 3rd Floor Col Line 4-1	3 days?	Wed 11/7/07	Fri 11/9/07
74		**CURTAIN WALL**	**382 days**	**Fri 9/8/06**	**Mon 2/25/08**
75		Curtain Wall Sub Procured for Design Assist	0 days	Fri 9/8/06	Fri 9/8/06
76		Complete Curtain Wall Shop Drawings	200 days?	Mon 11/6/06	Fri 8/10/07
77		Fab and Deliver Curtain Wall	90 days?	Mon 8/13/07	Fri 12/14/07
78		Install Curtain Wall 4 North	125 days?	Wed 7/18/07	Tue 1/8/08
79		Install Curtain Walls 1, 2, 3, 5, 7	51 days?	Mon 12/17/07	Mon 2/25/08
80		**ROOFING**	**161 days**	**Mon 7/2/07**	**Mon 2/11/08**
81		Green Roof Shop Drawings	45 days?	Mon 7/2/07	Fri 8/31/07
82		Roofing	81 days?	Fri 8/10/07	Fri 11/30/07
83		Fab and Deliver Green Roof	30 days?	Mon 9/3/07	Fri 10/12/07
84		Install Green Roof	45 days?	Fri 11/30/07	Thu 1/31/08
85		Install Coping/Flashing	31 days?	Mon 12/31/07	Mon 2/11/08
86		**MECHANICAL**	**73 days**	**Thu 11/8/07**	**Mon 2/18/08**
87		Third Floor Ductwork	52 days?	Fri 12/7/07	Mon 2/18/08
88		Second Floor Ductwork	30 days?	Wed 11/28/07	Tue 1/8/08
89		Mezzanine Level Ductwork	33 days?	Mon 11/19/07	Wed 1/2/08
90		Ground Level Ductwork	55 days?	Thu 11/8/07	Wed 1/23/08
91		Basement Ductwork	62 days?	Mon 11/19/07	Tue 2/12/08
92		Basement Mechanical Equipment	11 days?	Mon 12/3/07	Mon 12/17/07
93		Ground Level Mechanical Equipment	13 days?	Thu 11/22/07	Mon 12/10/07
94		Second Floor Mechanical Equipment	15 days?	Wed 12/12/07	Tue 1/1/08
95		Third Floor Mechanical Equipment	18 days?	Fri 12/21/07	Tue 1/15/08
96		**ELECTRICAL**	**292 days**	**Mon 2/19/07**	**Tue 4/1/08**
97		Bid and Award Elevator Contractor	121 days?	Mon 2/19/07	Mon 8/6/07
98		Bid and Award Telecom Wire and Equipment Contr	33 days?	Mon 7/2/07	Wed 8/15/07
99		Bid and Award Security Wire and Equipment Contra	33 days?	Mon 7/2/07	Wed 8/15/07
100		Bid and Award Audiovisual Contractor	43 days?	Mon 7/2/07	Wed 8/29/07
101		Switchgear Shop Drawings	60 days?	Wed 8/22/07	Tue 11/13/07
102		Switchgear Fabrication and Delivery	80 days?	Wed 11/14/07	Tue 3/4/08
103		Basement Elec. And Fire Alarm	50 days?	Mon 11/26/07	Fri 2/1/08
104		Ground Level Elec and Fire Alarm	94 days?	Thu 11/22/07	Tue 4/1/08
105		Mezzanine Level Elec and Fire Alarm	94 days?	Thu 11/22/07	Tue 4/1/08
106		Second Floor Elec and Fire Alarm	80 days?	Wed 12/12/07	Tue 4/1/08
107		Third Floor Elec and Fire Alarm	58 days?	Fri 12/28/07	Tue 3/18/08
108		**PLUMBING**	**226 days**	**Thu 11/15/07**	**Thu 9/25/08**
109		Basement Sanitary and Vent Piping	20 days?	Mon 11/26/07	Fri 12/21/07



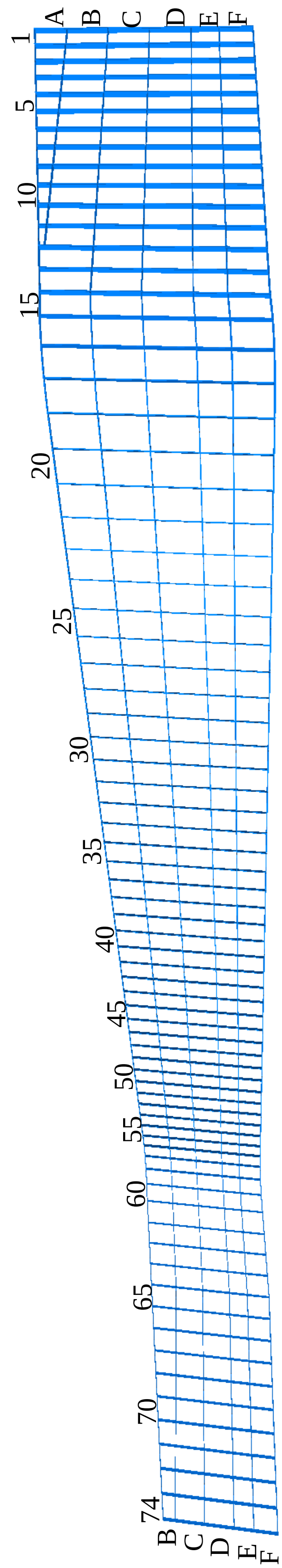
ID	Task Name	Duration	Start	Finish
110	Ground Level Sanitary and Vent Piping	10 days?	Thu 11/15/07	Wed 11/28/07
111	Second Floor Sanitary and Vent Piping	7 days?	Wed 11/28/07	Thu 12/6/07
112	Third Floor Sanitary and Vent Piping	5 days?	Fri 12/21/07	Thu 12/27/07
113	Basement Fixtures and Finishes	45 days?	Mon 7/14/08	Fri 9/12/08
114	Ground Level Fixtures and Finishes	29 days?	Mon 7/28/08	Thu 9/4/08
115	Second Floor Fixtures and Finishes	21 days?	Fri 8/8/08	Fri 9/5/08
116	Third Floor Fixtures and Finishes	24 days?	Mon 8/25/08	Thu 9/25/08
117	**FIRE PROTECTION**	**128 days**	**Tue 1/22/08**	**Thu 7/17/08**
118	Basement Sprinkler Rough-In	28 days?	Tue 1/22/08	Thu 2/28/08
119	Ground Floor Sprinkler Rough-In	32 days?	Tue 1/22/08	Wed 3/5/08
120	Mezzanine Sprinkler Rough-In	32 days?	Tue 1/22/08	Wed 3/5/08
121	2nd Floor Sprinkler Rough-In	38 days?	Tue 1/22/08	Thu 3/13/08
122	3rd Floor Sprinkler Rough-In	39 days?	Tue 1/29/08	Fri 3/21/08
123	Third Floor Sprinkler Heads/Drops	45 days?	Mon 5/5/08	Fri 7/4/08
124	Second Floor Sprinkler Heads/Drops	40 days?	Mon 5/19/08	Fri 7/11/08
125	Mezzanine Sprinkler Heads/Drops	30 days?	Fri 5/30/08	Thu 7/10/08
126	Ground Floor Sprinkler Heads/Drops	25 days?	Fri 6/6/08	Thu 7/10/08
127	Basement Sprinkler Heads/Drops	20 days?	Fri 6/20/08	Thu 7/17/08
128	**ELEVATORS**	**427 days**	**Thu 3/1/07**	**Fri 10/17/08**
129	Bid and Award Electrical Contractor	124 days?	Thu 3/1/07	Tue 8/21/07
130	Elevator Shop Drawings	60 days?	Tue 8/7/07	Mon 10/29/07
131	Elevator Fabrication and Delivery	100 days?	Tue 10/30/07	Mon 3/17/08
132	Elevator Shaft Walls	30 days?	Mon 4/7/08	Fri 5/16/08
133	Elevator Rail and Cabs Installation	110 days?	Mon 5/19/08	Fri 10/17/08
134	**INTERIOR FRAMING**	**282 days**	**Thu 5/31/07**	**Fri 6/27/08**
135	Bid and Award Interior Framing Contractor	32 days?	Thu 5/31/07	Fri 7/13/07
136	Bid and Award Drywall Contractor	32 days?	Thu 5/31/07	Fri 7/13/07
137	Basement Level Interior Framing	20 days?	Tue 12/18/07	Mon 1/14/08
138	Third Floor Interior Framing	40 days?	Wed 1/16/08	Tue 3/11/08
139	Second Floor Interior Framing	35 days?	Wed 2/6/08	Tue 3/25/08
140	Mezzanine Level Interior Framing	8 days?	Thu 2/21/08	Mon 3/3/08
141	Ground Level Interior Framing	35 days?	Wed 2/27/08	Tue 4/15/08
142	Third Floor Drywall, Tape, & Sand	45 days?	Mon 4/7/08	Fri 6/6/08
143	Second Floor Drywall, Tape, & Sand	20 days?	Mon 4/21/08	Fri 5/16/08
144	Mezzanine Level Drywall, Tape & Sand	15 days?	Mon 5/5/08	Fri 5/23/08
145	Ground Level Drywall, Tape, & Sand	25 days?	Mon 5/12/08	Fri 6/13/08
146	Basement Level Drywall, Tape & Sand	20 days?	Mon 6/2/08	Fri 6/27/08
147	**FLOORING**	**332 days**	**Thu 5/31/07**	**Fri 9/5/08**
148	Bid and Award Interior Glass and Glazing Contractc	32 days?	Thu 5/31/07	Fri 7/13/07
149	Bid and Award Ornamental & Misc. Metals Contract	30 days?	Mon 6/4/07	Fri 7/13/07
150	Bid and Award Interior Stone Floor Contractor	33 days?	Mon 7/2/07	Wed 8/15/07
151	Bid and Award Floor Coverings Contractor	33 days?	Mon 7/2/07	Wed 8/15/07
152	Bid and Award Terrazzo Flooring Contractor	33 days?	Mon 7/2/07	Wed 8/15/07
153	Third Floor Flooring	60 days?	Mon 6/2/08	Fri 8/22/08
154	Second Floor Flooring	40 days?	Mon 6/16/08	Fri 8/8/08
155	Mezzanine Level Flooring	15 days	Tue 7/8/08	Mon 7/28/08
156	Ground Level Flooring	36 days?	Fri 7/18/08	Fri 9/5/08
157	Basement Flooring	20 days?	Fri 7/4/08	Thu 7/31/08
158	**MILLWORK**	**319 days**	**Mon 7/2/07**	**Thu 9/18/08**
159	Bid and Award Millwork Contractor	32 days?	Mon 7/2/07	Tue 8/14/07
160	Bid and Award Library and Casework Contractor	43 days?	Mon 7/2/07	Wed 8/29/07
161	Bid and Award High Density Shelving Contractor	43 days?	Mon 7/2/07	Wed 8/29/07
162	Basement Millwork	15 days?	Fri 7/18/08	Thu 8/7/08
163	Ground Floor Millwork	15 days?	Fri 8/8/08	Thu 8/28/08
164	Mezzanine Millwork	15 days?	Fri 8/8/08	Thu 8/28/08



ID	Task Name	Duration	Start	Finish
165	Second Floor Millwork	15 days?	Fri 8/8/08	Thu 8/28/08
166	Third Floor Millwork	15 days?	Fri 8/29/08	Thu 9/18/08
167	**GENERAL TRADES**	**400 days**	**Fri 5/18/07**	**Thu 11/27/08**
168	Bid and Award Metal Panels Contractor	41 days?	Fri 5/18/07	Fri 7/13/07
169	Bid and Award Paint/Wall Coatings Contractor	33 days?	Mon 7/2/07	Wed 8/15/07
170	Bid and Award Signage Contractor	33 days?	Mon 7/2/07	Wed 8/15/07
171	Ground Level Ceiling Finishes	30 days?	Fri 5/30/08	Thu 7/10/08
172	Basement Ceiling Finishes (Grid, Lights, Diffusers,	25 days?	Fri 6/13/08	Thu 7/17/08
173	Mezzanine Level Ceiling Finishes	12 days?	Mon 6/9/08	Tue 6/24/08
174	Second Floor Ceiling Finishes	75 days?	Mon 5/12/08	Fri 8/22/08
175	Third Floor Ceiling Finishes	80 days?	Mon 4/28/08	Fri 8/15/08
176	Third Floor Painting	65 days?	Mon 4/21/08	Fri 7/18/08
177	Second Floor Painting	60 days?	Mon 5/5/08	Fri 7/25/08
178	Mezzanine Level Painting	20 days	Mon 5/5/08	Fri 5/30/08
179	Ground Level Painting	44 days?	Mon 5/26/08	Thu 7/24/08
180	Basement Painting	34 days?	Mon 6/9/08	Thu 7/24/08
181	Basement Punchlist	40 days?	Fri 9/12/08	Thu 11/6/08
182	Ground Level Punchlist	50 days?	Fri 9/5/08	Thu 11/13/08
183	Mezzanine Level Punchlist	20 days	Wed 9/17/08	Tue 10/14/08
184	Second Floor Punchlist	35 days?	Fri 10/3/08	Thu 11/20/08
185	Third Floor Punchlist	45 days?	Fri 9/26/08	Thu 11/27/08
186	**CLOSEOUT**	**89 days**	**Mon 9/1/08**	**Thu 1/1/09**
187	Testing and Commissioning	65 days?	Mon 9/1/08	Fri 11/28/08
188	Substantial Completion & C. of O.	0 days	Wed 10/1/08	Wed 10/1/08
189	Punchlist Complete	0 days	Thu 1/1/09	Thu 1/1/09



APPENDIX B: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Curtain Wall 4 South Face

Row	Column	Area	Unit
A	1	29	SF
A	2	27	SF
A	3	25	SF
A	4	23	SF
A	5	21	SF
A	6	18	SF
A	7	16	SF
A	8	14	SF
A	9	11	SF
A	10	9	SF
A	11	7	SF
A	12	5	SF
B	1	38	SF
B	2	38	SF
B	3	38	SF
B	4	38	SF
B	5	38	SF
B	6	38	SF
B	7	38	SF
B	8	38	SF
B	9	38	SF
B	10	38	SF
B	11	38	SF
B	12	38	SF
B	13	42	SF
B	14	39	SF
B	15	35	SF
B	16	35	SF
B	17	34	SF
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B	19	37	SF
B	20	38	SF
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B	60	36	SF
B	61	42	SF
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B	66	33	SF

B 67	31 SF
B 68	29 SF
B 69	27 SF
B 70	25 SF
B 71	23 SF
B 72	21 SF
B 73	19 SF
B 74	17 SF
C 1	38 SF
C 2	38 SF
C 3	38 SF
C 4	38 SF
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F 67	31 SF
F 68	31 SF
F 69	31 SF
F 70	31 SF
F 71	31 SF
F 72	31 SF
F 73	31 SF
F 74	31 SF

Total 12561 SF