Thesis Final Report

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Construction Management

University of Maryland Physical Sciences Complex

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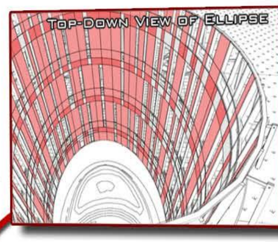
Faculty Consultant: Dr. Anumba

Physical Sciences Complex

Basic Information
$80 million
158,068SQFT
5 above ground stories
2 basement levels
53 new laboratories
1208 days Construction
5/25/2010 to 9/13/2013
CM/At Risk, GMP

Project Team
Owner: University of Maryland
Architect: HDR Inc.
CM Agency: Gilbane Inc.
Structural Engineer: Hope Furrer LLC
Civil Engineer:Goldin and Stafford LLC
Mechanical: Denver-Elek Inc.
Electrical: Mona Electric Group
Fire Protection: Capitol Sprinklers Inc.

Construction:
- Phase two of a three phase plan by the university to expand the sciences.
- Clever use of a crane inside of the large elliptical opening through all construction.
- Deep excavation for two-tiered basement that will house microresearch laboratories.


Top-Down View of Ellipse

Architecture:
- Unique "open" interior curtain wall: An elliptical glass facade follows an elliptical path through the interior of the building.
- Designed for natural light.
- Large hallways for social and acedemic gatherings.
- Bridges the gap between a traditional brick look and sharp modern


Ground level covered outdoor area


Ellipse Section Through Office

Structural:
- 3'6" Diameter Caisson, deep foundation.
- 17" thick total slab on grade thickness (vibration cancelling).
- Post-tensioned concrete beams and girders on all floors.
- 1-way concrete slab for each floor.

Electrical:
- 480Y/277V, 4000A Switchgear supplies 167 panelboards with power.
- Designed peak operating load of 3230KVA.
- New transformer to have a max load of 3750KVA.
- Redundant back-up of two 750KW diesel generators.

Mechanical:
- Three 23,000CFM VAV AHU (Type 1 Labs)
- Two 48,000CFM VAV AHU (Type 2 Labs, Under ground)
- Three 21,000CFM VAV AHU (Underfloor air system)
- One 13,500CFM VAV AHU (Mechanical building)
- Two custom, 800 ton centrifugal water chillers.
- One 2-cell 4,800GPM water tower (Roof)

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http://www.engr.psu.edu/ae/thesis/portfolios/2013/jcm362/

Gilbane

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Executive Summary

This report contains the documentation and studies associated with four in depth areas of analysis as well as two minor breadth studies for analysis for the University of Maryland Physical Sciences Complex, located in College Park, MD.

Analysis 1 – Elliptical Curtain Wall Material/Design Alteration and Constructability

The curtain wall is overly complex. The current design uses hundreds of custom sized panes of glass, where only a few overlap in dimensions and color. An architectural design change will allow for *significant* cost savings, but at the same time will not impact the functional aspect of the façade which is too allow light in the interior of the building and provide for a unique office/classroom space experience.

Analysis 2 – Elliptical Curtain Wall Schedule Reduction

The elliptical curtain wall that makes up the interior facing façade of the PSC has been the source of many headaches and time delays for the PSC. Problems range from incomplete design drawings, delayed deliveries, inconsistent materials, and errors in labor management. A revised schedule of installation of the system will mitigate many of these problems, as well as a coordinated effort to erect the wall modularly can drastically change schedule delays originally imposed by these problems.

Analysis 3 – Exterior Façade Energy Collections via Concentrated Photo Voltaic

Among the design of the PSC are two very large curtain walls. One wall is south facing, and as such, has significant potential for solar energy collections. Modern photovoltaic technology, as well as a specifically designed curtain wall system that incorporates concentrated photo voltaic (CPV) technology, can allow for large year-round energy savings via solar collection, while at the same time not completely eliminating the aesthetic view from the interior of the building.

Analysis 4 – Multi-shift Work Schedule Reduction

The PSC is an academic building, and as such, is used primarily in the academic semesters of the fall and spring. The completion date for the PSC is set for September of 2013, after the semester begins. By tightening up the schedule by having longer work days, close to 14 hours, using two crews, the building can have a substantial completion date far earlier than September of 2013. This will allow the university to use the building and have it fully staffed before the spring semester and depending on the analysis, during the summer prior as well, bringing increased revenue to the university.

Credits and Acknowledgements

Ms. Rose Abousaid – Gilbane Co. PSC Project Engineer

Dr. Chimay Anumba – Penn State AE

Mr. Tom Kanuck – Helioptix LLC

Mr. Alphonso Lopez – Sentech Architectural Systems Inc.

Mr. Bob Mathews – Mathews Architectural Concepts

Mr. Bill O’Donnel – Local 401 Iron Workers Union

Mr. Patrick Peters – Gilbane Co. PSC Façade Project Manager

Mr. John Pierce – Berkowitz Glass Co.

Mr. John Shedaker – Shedaker Metal Arts

Mr. Robert Specter – University of Maryland

Introduction & General Building Information

The University of Maryland Physical Sciences Complex is expected to be the most advanced, state-of-the-art research facility for biophysics and molecular science in the United States. At 158,000 square feet and 5 above ground stories and two basement levels, the project will house 27 laser and condensed matter labs, 18 preparation labs, and 9 biophysics labs, as well as offices, lounges, study centers, class rooms, and spacious hallways. The nature of the experiments and research that will take place requires that the PSC have absolute control over the lab environment. This includes air, temperature, and exceptional vibration cancelling. This poses a challenge to construction. In order for nano-research to yield accurate and successful results, a way to shield the underground labs from the vibrations induced by traffic, walking, and mechanical units must be used.

The project is the second phase of a three phase plan developed by the University of Maryland. The phases are designed to expand the scope of what the campus can research and bring about scientific interest in the academic community and provide potentially ground breaking research for the world. The building rests between two existing science complexes and will replace the existing parking lot. The PSC is designed to attach to the existing Computer Science and Space building (CSS) through a series of minor renovations and will introduce an entirely new mechanical building for the immediate surrounding buildings.

The PSC also features a slew of sustainable design concepts including a green roof and recycled materials. UM aims to achieve a Silver rating on the LEED scoreboard.

Notable characteristics of the PSC include the large elliptical curtain wall opening in the center of the building, a 100% accessible green roof, and a large outdoor ground level storefront plaza.

The project is being administrated by Gilbane Co. as CM at risk under a GMP contract. Gilbane holds 32 trades in total, and works side by side with the architectural firm, HDR Inc. The project cost is currently at $99 million.

Client Information

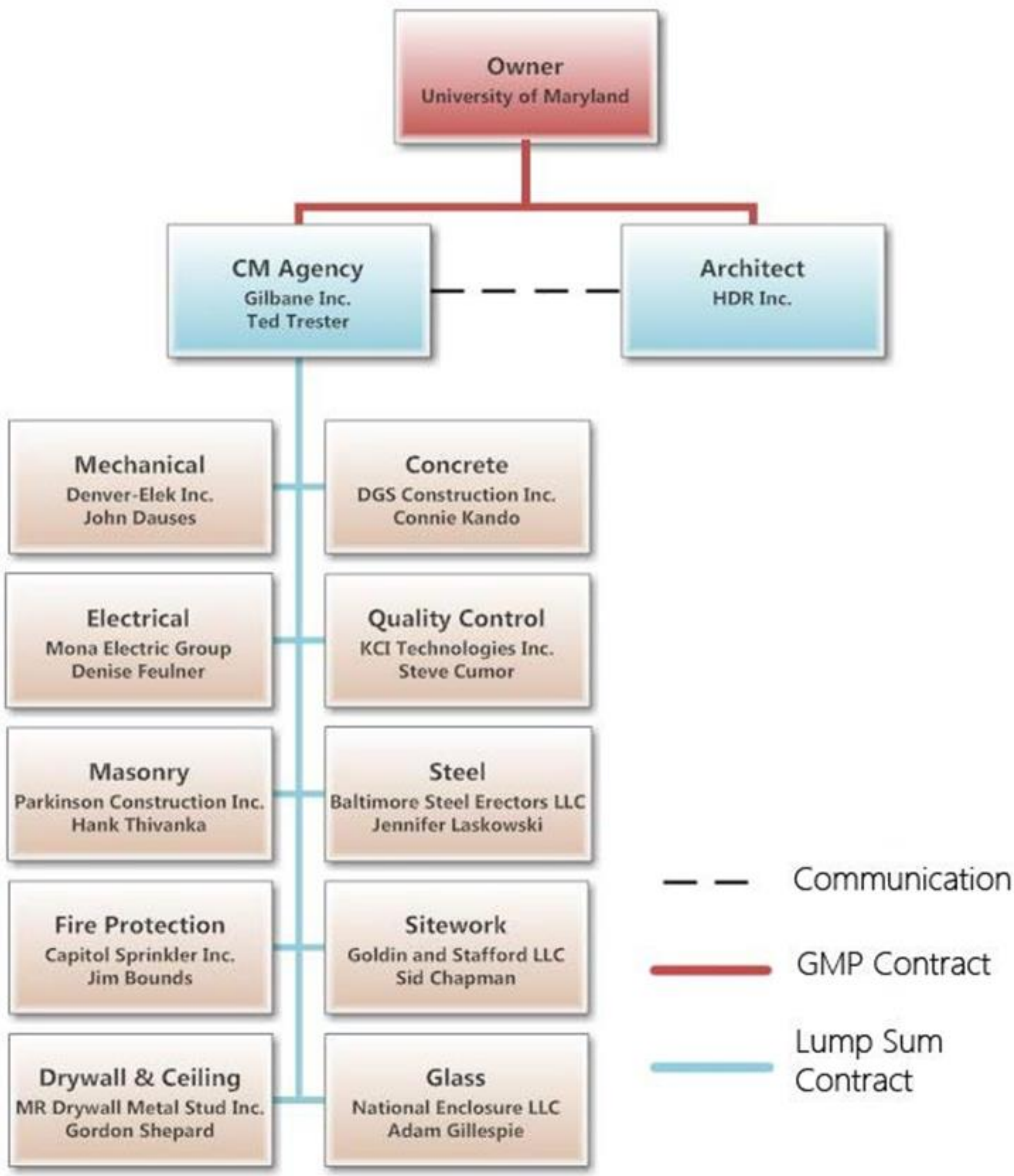
The owner of the Physical Sciences Complex is the University of Maryland. UM is determined to create the most advanced, state-of-the-art science complexes in the United States. It is the second phase of a three phase project developed by UM to strengthen their role in scientific advancements. With the aging of the Computer and Space Sciences building and Institute for Physical Sciences and Technology building, the college has dedicated a large investment into giving the sciences a new breadth of freedom.

The project its self is receiving 80% of its funding from University of Maryland while the other 20% is from the 2009 American Recovery and Reinvestment Act (ARRA). The 20% funding is being used to develop the Type 2 “Enhancement” labs.

UM has made it clear that a fall 2013 deadline is critical to the mission success of its phased planning. Many scientific programs, faculty, and staff are planning on moving in September of 2013 to begin experiments and careers.

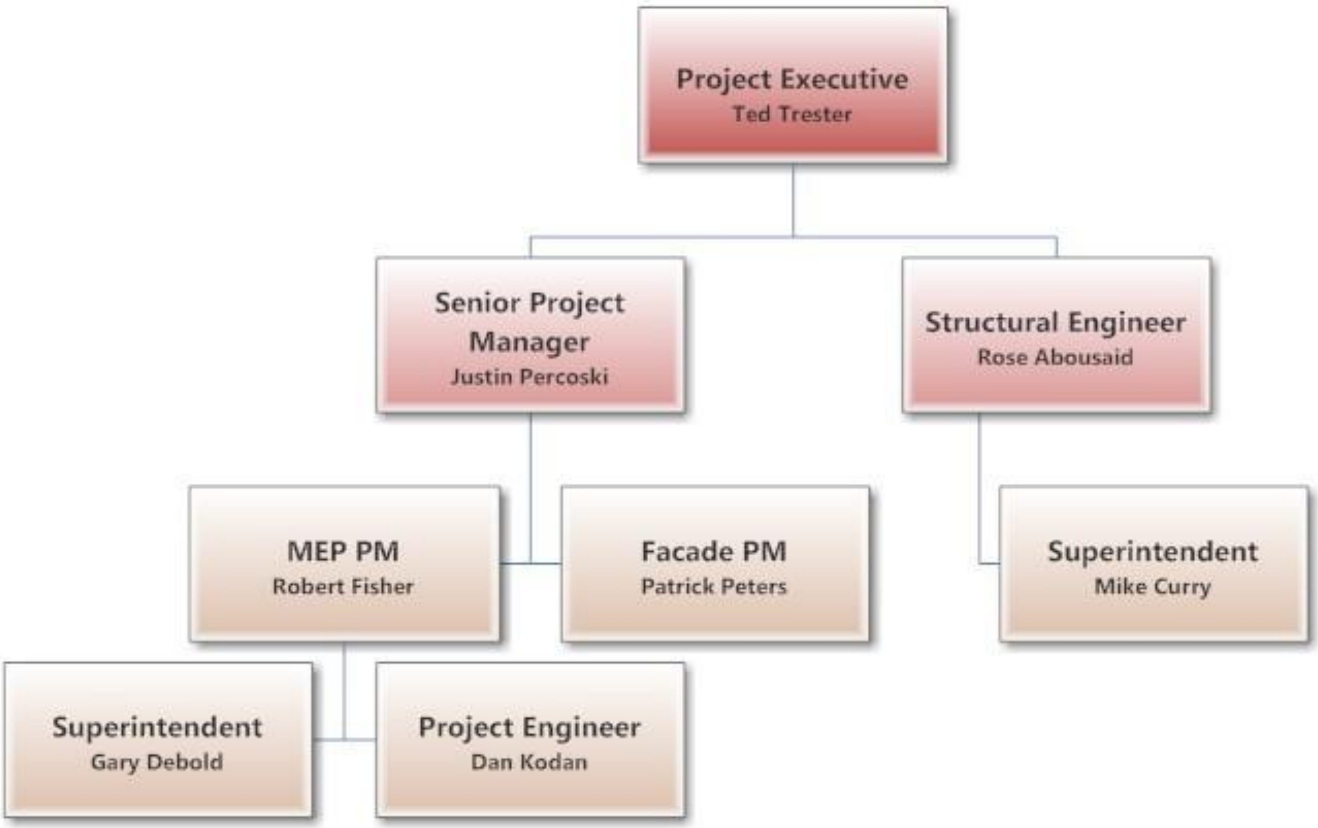
Project Delivery Plan

The delivery method for the PSC is straight forward and easy to follow. The University of Maryland holds two GMP contracts. The first is with Gilbane Inc. as CM at risk. The second is with HDR Inc., the architectural design firm for the project. From there, Gilbane holds lump sum contracts with 32 trades. HDR and Gilbane do not hold a contract with one another and communicate through the university for coordination and design feasibility. Below is an organizational chart illustrating the parties involved in project delivery and how they relate to one-another. Included are only a few of the 32 contracts held by Gilbane, while HDR holds none with any specialty trades or contractors.



Staffing Plan

Below is the Gilbane staffing organization for the PSC project. There are two superintendents on site, Gary and Mike. Gary is responsible for MEP coordination and communication with MEP trades while Mike is responsible for structural coordination and communication. While the chart suggests that each person has a responsibility to report to the next highest block, direct communication between staff is highly encouraged for project success.



Detailed Project Schedule

The schedule for the Physical Sciences Complex and the new mechanical building is organized into a zone by zone format. This method of organization is more efficient than a traditional by-trade schedule because of the complexity of the project and amount of concurrent work that takes place. Each zone is representative of a major portion of work in the building. Multiple zones are occupied at the same time with a peak of 180 workers on any given day. Below is a compressed schedule of major zones for the project.

Task Name	Duration	Start	Finish
Sitework	**751 days**	**Thu 6/3/10**	**Thu 4/18/13**
PSC Main Building	**732 days**	**Thu 8/19/10**	**Fri 6/7/13**
Excavation	**162 days**	**Thu 8/19/10**	**Fri 4/1/11**
Sub Basement	**463 days**	**Mon 6/6/11**	**Wed 3/13/13**
Basement	**570 days**	**Thu 3/3/11**	**Wed 5/8/13**
Ground Floor	**374 days**	**Mon 10/24/11**	**Thu 3/28/13**
1st Floor	**397 days**	**Thu 12/1/11**	**Fri 6/7/13**
2nd Floor	**350 days**	**Fri 12/23/11**	**Thu 4/25/13**
3rd Floor	**330 days**	**Mon 1/16/12**	**Fri 4/19/13**
Roof Level	**214 days**	**Fri 2/3/12**	**Wed 11/28/12**
Façade	**483 days**	**Mon 1/3/11**	**Wed 11/7/12**
Elevators	**114 days**	**Thu 4/19/12**	**Tue 9/25/12**
MEP Risers	**101 days**	**Tue 2/14/12**	**Tue 7/3/12**
Stairs	**187 days**	**Mon 3/5/12**	**Tue 11/20/12**
Mechanical Building	**549 days**	**Wed 4/6/11**	**Mon 5/13/13**

Detailed schedules can be viewed in Appendix C. Site-work consists of sediment erosion control, demolition, and new utility lines. Sediment erosion control is a major factor to the success of the PSC. The current layout of the site is very compact and prone to run-off. Proper measures to reduce storm water damage and pooling of water are taken. The demolition of the existing site improvements is also key. The current parking lot, curb, and electrical shed are demolished prior to excavation.

The main building, the Science Complex itself began excavation August 19, 2010.

General Building Information

Building Name	University Of Maryland Physical Sciences Complex
Location and Site	College Park, MD
Building Occupant	University of Maryland
Occupancy Type	1A (PSC), 1B (Existing)
Size	158,000 SF
Floors	4 above grade, 2 below
Dates of Construction	June 3, 20120 – September 23, 2013
Overall Cost	$99 Million
Delivery Method	Design-Build

Primary Project Team

Owner	University of Maryland
Project Administrator	Gilbane Inc.
Design/Build	HDR Inc. (Formerly CUH2A)
Structural	Hope Furrer, LLC
Civil	A Morton Thomas and Assoc.
Mech/Elec/Plumbing	Global Engineering Solutions

Architecture
The University of Maryland Physical Sciences Complex breaks the mold for conventional education buildings. It is set apart by a large elliptical opening that pierces the building all the way from the roof to the ground level. This architectural feat is designed to open up the inner hallways to natural light. There are offices and several classrooms on the upper floors with a direct connection to this elliptical façade. The façade itself consists of custom made 1" glazing of several types which include ventilated, insulated, and tinted (red).

The structure extends two levels into the ground and utilizes an array of vibration cancelling building techniques so that molecular experimentation can take place with high accuracy.

The UMPSC will attach to the existing Institute for Physical Science and Technology, which is undergoing renovations to accommodate the space.

Zoning
According to the Maryland-National Capital Park and Planning Commission based out of Prince George's County Planning Department, the UMPSC is zoned as Rural Residential as of June 2010. The planning department indicates no height or lot restrictions for this type of development.

Building Facades

The elliptical opening and the north and south faces of the building consist of a metal and glass curtain walls. The glazing for the elliptical façade is 1" custom sized glazing while all other glass is insulated 1" glazing. The elliptical curtail wall glazing is arranged in a semi-checkerboard pattern between clear laminated glazing and red tinted glazing. Along the north and south faces of the building are aluminum sunshades and fins. The curtain wall also features an operable aluminum window with an opening limiter for ventilation and safety. The curtain walls are supported by a series of post tensioned concrete columns and beams.

Fig.1 Perspective of elliptical curtain wall from ground level.

The west wing's exterior is a masonry wall system with a red brick veneer and features operable windows similar to those found on the north and south curtain walls.

Roofing

The roof largely consists of a green roof and utilizes five assembly types. Generally speaking, there is a planting assembly, a gravel assembly, a concrete paving assembly, a grass assembly, and a bituminous assembly for drainage. Each assembly consists of 6" tapered insulation and protective membranes. The difference between the planting and grass assemblies is a larger volume of soil for vegetation to take root in. The roof is intended as a social attraction. The roofing systems will be supported by a concrete slab on metal deck.

Construction

The most notable construction method for the PSC is the location of the single tower crane for all work. It is located in the center of the ellipse façade in the interior of the building. The building is erected around this tower crane, and upon completion of the roof, was removed with another mobile crane. Other notable concerns for construction include the tie-in to the existing CSS building. This required a minor retrofitting and renovation of the existing CSS building.

Structural System

The structural system of the PSC is primarily post-tensioned concrete beams and slabs. The basement levels are framed with 14" thick concrete slabs with #4 epoxy coated bars at 12" on center top and bottom in the lab enclosures, and 8" thick slab in the hallways. This reinforced slab bears on top of a 3" unreinforced slab that rest on 6" of granular base material. Moving up, the ground floor framing consists of a 12" thick two-way concrete slab with a mixture of post-tensioned and conventionally tensioned beams. The other floors have 7" slabs as well as post-tensioned and conventionally tensioned beams. The post-tensioning tendons are #7 bars. A typical drop panel bay for the slab system is approximately 11’x7’x10”. There are also several HSS steel columns to reinforce certain areas of the building.

Fire Protection

Fire protection comes in the form of a wet pipe system for the entire building. Stairwells are equipped with standpipe risers and fire hose connections at each level of the PSC. The wetpipe system is a quick response system in areas where fire suppression is critical including Type I and Type II labs. The alarm system is an all-electronic system that monitors conditions in the building. It is capable of automatically pressurizing stairwells, releasing magnetic fire and smoke doors, recalling elevators to safe floors, and closing appropriate dampers. The pumps themselves are electrically driven centrifugal fire pumps rated at 50 psi. They are capable of delivering 500 gallons per minute and operate at 25 horse power and 1770RPM.

Transportation

The PSC is equipped with two full service elevators that are encased in 4 layers of 3/16” aluminum shielding. Each elevator travels the whole height of the building including the two basement levels. There are also six sets of staircases in total. There are two existing stairs, two spiral stairs, and two service/fire escape stairways.

Communications/Security

The PSC is equipped with the standard array of communication hardware and wiring. Included in each lab and office space are the appropriate wall mounted jacks for Ethernet and phone. Tied into the typical telecommunications systems is a state of the art security system. This security system is designed to connect to the existing police command center on campus and is capable of monitoring access controls, alarms, CCTV (video surveillance), identification credentials, and store digital surveillance records.

Building Systems Summary

Work Scope	Required (Y/N)
Demolition	Y
Structural Steel Frame	Y(Partial)
Cast in Place Concrete	Y
Precast Concrete	Y
Mechanical System	Y
Electrical System	Y
Masonry	N
Curtain Wall	Y
Support of Excavation	Y

Demolition

The existing area located between the Computer and Space Science (CSS) building and Institute for Physical Science and Technology (IPST) building must be demolished. Located here are two large parking lots and a small mechanical/electrical building for the IPST. The first phase of demolition will commence with the removal of all asphalt in the parking lot and the immediate area of Farm Drive connected to these parking lots. During demolition activities, an ADA acceptable path will be provided along Farm Drive. Both the CSS and IPST buildings will continue to be operational during all construction activities. After successful completion of asphalt and curb removal, a large portion of underground utilities will be demolished and removed from site.

Structural Steel Frame

The PSC utilizes a few members of structural steel through the building. While primarily relying heavily on post-tensioned beams and girders and reinforced concrete columns, the PSC has several steel columns and horizontal members to support curtain wall. These columns, consisting of various HSS sizes are used in critical areas where space is key. Along the perimeter of the building horizontal members are utilized to support the curtain wall.

Cast in Place Concrete

All foundation walls, grade beams, beams, girders, and slabs are made using cast in place concrete of 4000 PSI while all columns from basement level to roof are 5000 PSI. Slabs above grade are 7”. Drilled caissons running the exterior edge of the building are 3’6” in diameter while caissons located internally are 3’. These caissons will support a thick slab on grade measured 14” in depth. The 14” slab will connect to the caisson caps and be cushioned by a smaller, un-reinforced 3” concrete slab below. The slab depth at these locations is higher than normal. The sub-basement which houses many science labs is required to have minimal vibrational interference from surrounding mechanical units, structures, traffic, and natural earth vibrations. For this reason, custom formwork will be used to ensure accurate pouring results.

Precast Concrete

While the PSC does not utilize precast concrete primarily, the mechanical building on the north-west end of the site will. The mechanical building uses precast concrete for an architectural appearance only, not for structural support. In order to lift steel members and precast pieces a tower crane is utilized. The tower crane is located *inside* the building. The large cut out in the center of the PSC created by the stylistic ellipse that characterized the building will serve as a swivel point for the crane. The crane its self is a 79 kW, 140' tall, 213' jib, 22,000lb max capacity tower crane. It sits upon a 4' thick, 10'x10' reinforced concrete bed and is supported by four C40 caissons that were placed during the foundation phase.

Mechanical

The PSC utilizes standard variable air volume systems to supply heating and cooling to zones. Three 23,000 (6,000 outside) CFM air handling units are dedicated to the Type 1 laboratories, two 48,000 (20,000 outside) CFM units for Type 2 labs, three 21,000 CFM (5,000 outside) units to the under floor systems, and one 13,500 CFM unit for the mechanical building. Type 1 labs are above ground, exposed to light, and will be used for small scale experimentation and learning. They are located on the second and third floors of the building and consume more square feet than Type 2 labs. Type 2 labs will be used for laser based experiments, biochemical research, and micro-matter research. It is imperative that the air quality, flow, and pressure of these underground labs remain absolutely stable if accurate research is to take place. Two 24,000 CFM heat recovery units will work in conjunction with the air handling units to conserve energy.

Two custom made centrifugal water chillers are located in the mechanical wing of the PSC. The chillers each have a capacity of 800 tons and a nominal flow rate of 1,600 GPM. A single 2-cell cooling tower will be located on the west roof of the PSC with a flow capacity of 4,800 GPM.

Sixteen 625 CFM fan coil units, located several mechanical rooms through the structure will supply both warm and cool air using the water from the chiller and the heat exchanged water (from the campus steam lines) respectively.

Future additions to the mechanical systems are planned for phase 3 of University of Maryland's campus expansion which will include two additional cooling towers, three plate & frame heat exchangers, and one additional chiller.

Electrical

Both the PSC and CSS will be powered by a new electrical system located inside of the new mechanical building. The main switch board for the PSC will provide 480Y/277V, 4000A service to the building. A new 3750 KVA transformer will supply a calculated load of 3230

KVA to the breaker. Because of the large addition of the mechanical building, existing electrical utility lines must be demolished and new ones put into place to handle the increased load.

Building power is guaranteed by two diesel powered generator that can supply 750KW, 938KVA power to the PSC building. Upon failure of service, within 10 seconds the generator will supply power to the building's vital systems.

The PSC will also be equipped with a state-of-the-art security system that includes surveillance, card access, and automated alarms for fire, break-in, and power failure.

Curtain Wall

The curtain wall systems for the PSC are most assuredly the defining form factor of the PSC. The west wing of the PSC is comprised of a metal and class hanging curtain wall on the exterior, and an elliptical tapered curtain wall on the interior (the interior curtain wall wraps around the elliptical opening). Designed by HDR Inc., the interior ellipse is intricate and challenging. With nearly each piece of glazing being a custom shape, there is little room for error. The sloped curtain wall is attached to the structure with a metal plate that is anchored into the slab. Proper insulation and fire-stop installation is accounted for.

The exterior curtain wall, which covers the north and south walls, is similar in concept with regards to anchoring but does not have a slope. The interior curtain wall will be assembled in place, while the exterior wall will be preassembled and hoisted via crane into position.

The exterior of the east wing of the PSC is a brick veneer that is shored to the wall by way of steel angles that are anchored to the slab.

Unique Features

The University of Maryland Physical Sciences Complex is a state-of-the-art scientific establishment. The PSC is anticipated to receive a Silver LEED rating. In order to accomplish this, the PSC has several notable features:

- A green roof to reduce heat island effects and collect rain water for reuse with non-potable water fixtures.
- Low emitting construction materials as well as 20% of its materials from recycle.
- Automatic lighting controls.
- Under floor ventilation systems that are designed to boost efficiency in heating and cooling.
- Large portion of lighting received from internal façade.

Project Cost Evaluation

Total Square Footage: 158,058 SQFT

Building Construction Costs: $67,063,310
Construction Cost per Square Foot: *$424.29/SQFT*

Total Project Costs: $99,383,363
Total Cost per Square Foot: $628.78/SQFT

Major Building Systems:

Major Building Systems		
System	Cost	Cost/SQFT
Structural Concrete	$9,037,247	$57.17
Masonry	$1,233,220	$7.80
Structural Steel	$1,398,048	$8.85
Mechanical/Plumbing	$19,217,151	$121.58
HVAC Controls	$3,020,782	$19.11
Electrical	$12,393,022	$78.40
Lab Casework	$1,847,364	$11.69

RS Means Square Foot Estimate: *$39,026,500*
RS Means Cost per Square Foot: *$247/SQFT*

The RS means estimate was done using a typical price per square foot of a 5 story hospital complex with a basement. Because of the intricate nature of this project, a comparison to a hospital is a much better fit than a comparison to an office building or college laboratory of similar dimensions. The large demand for mechanical and electrical equipment, as well as the specialized construction, more appropriately matches the demand found in a 5 story hospital. However, even with this assumption and partial correction, the square foot cost given by an RS Means estimate is only 58% of the actual building costs. The discrepancy can be explained by the details of the PSC. The table above shows that a large portion of the costs of the PSC comes from MEP. These costs are uniquely higher than normal. The PSC aims to house state of the art labs, and as such required state of the art coordination, equipment, and construction. Furthermore, the PSC has a deeper foundation than most other commercial structures. The additional cost of excavation, shoring, concrete, and equipment is not accounted for in an RS Means estimate.

RS Means MEP Assemblies Cost Estimate: $5,084,382

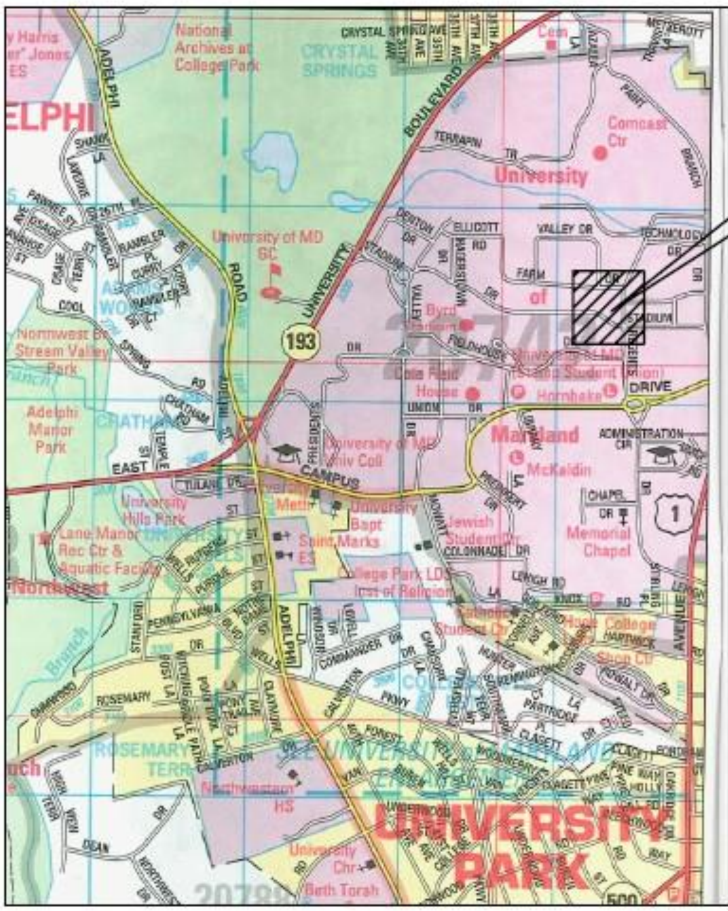
The RS means assembly estimate returned a cost which is significantly lower than the actual MEP costs. There are several reasons for this. The first and most substantial reason is that the chillers and cooling tower are custom built. While the difference can be accounted for by comparing the custom unit's values to those found in the assemblies cost data, the price for the custom units will still be higher. Secondly, the security system accounts for over half of the electrical costs. The cost of the security system is confidential.

Comparison of values

The estimated costs for the Physical Sciences complex are below the actual cost of the building. While several reasons were already discussed in detail above, the most noticeable cause for this discrepancy is the shear uniqueness of the building. The PSC is not a cookie-cutter structure that can be easily valued by looking at typical cost data. This is also the reason that Gilbane Inc. is entrusted with such a project. The mechanical systems, electrical systems, architecture, and general sustainability of the project put it above and beyond any other structure that could be called a college laboratory.

Site Conditions and Planning Summary

The new University of Maryland Physical Sciences Complex is set on the north-east end of the college campus and will bring new life to a time-weathered area (see Figure 2 below). The site is set upon an existing parking lot that will be demolished and in between two existing buildings that will continue to be operational during construction. (See Appendix A for more detailed site maps).



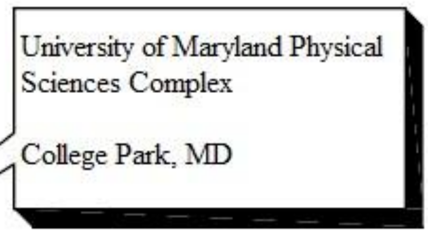


Fig.2 Site Location Map

Because the surrounding buildings will continue normal operations, space is extremely tight. The initial mobilization will place all job trailers on the north-east end of construction activities, approximately 150 yards away. The existing road, Stadium Drive, will serve as traffic access for deliveries of equipment, materials, and personnel. Construction traffic will enter the south end of the site via Stadium drive, and exit turning back onto stadium drive. The surrounding roads are rather narrow, therefor construction traffic must use the appropriate path so as not to risk damaging the vehicles or surrounding architecture and injuring pedestrians. Parking has been provided for workers off-site in a parking lot south-west of the site. Notice in Figure 3 on the next page how the site sits between several structures, all of which will require full access.

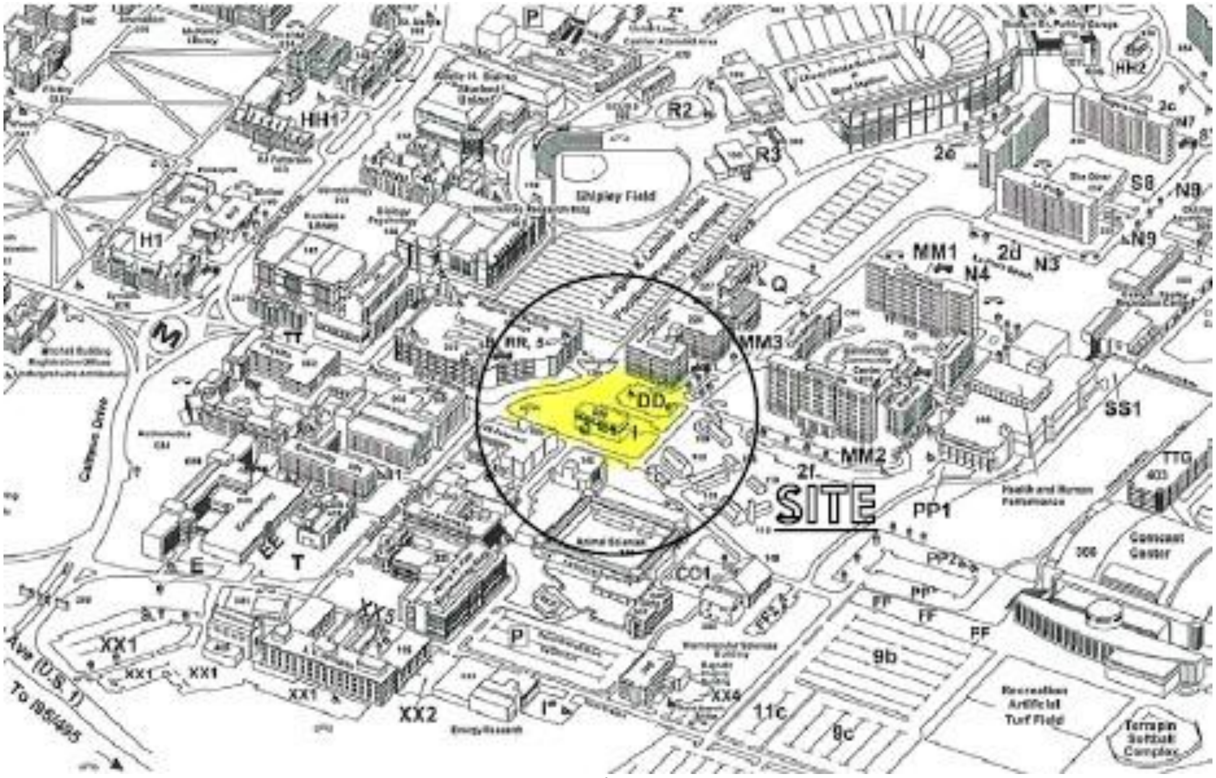


Fig.3 Zoomed Location Map

During the demolition phase, all debris and waste materials will be stowed at the south end of the site near the construction traffic entrance. During the two weeks of demolition, trucks are scheduled to take the field debris. Farm Drive will be torn up and new utility lines will be set. During this process, Farm Drive will be narrowed two half its width, and demolition will take place in two phases, both laying new utilities and repaving the surface.

When construction of the actual building begins, a large crane will be used as the primary means of hoisting. This crane rests in the center of the PSC and has a radius of 213’, large enough to lift and deliver materials to both the west and east wing of the PSC and the mechanical building. Scaffolding will be utilized primarily on the new mechanical building. Moving in a pattern as indicated in Appendix A. Scaffolding will not be used on the PSC. The curtain wall will be lifted into place with the crane, and secured from personnel inside the building. The prefab brick veneer of the east wing will be constructed in a similar manner.

Local Conditions Summary

Soil conditions are important to consider when designing the PSC. The area it is located in is known for clayey soils and excessive settlement. In a geotechnical analysis which involved the boring samples of 15 locations across the site, the soil at elevations that correspond to shallow footings was determined to be loose sand and soft clay. While it is feasible to compact the soil to allow for stable spread footings, it was determined that drilled caissons that extend to the stable consolidated clay at deeper elevations was more cost efficient. With column loads of approximately 1800 kip and a spacing of roughly 28' by 28', it was determined that 3' diameter drilled caissons that support a 500psf skin friction can be used. Figure 4 shows the locations of the boring samples with regards to the proposed area of construction.

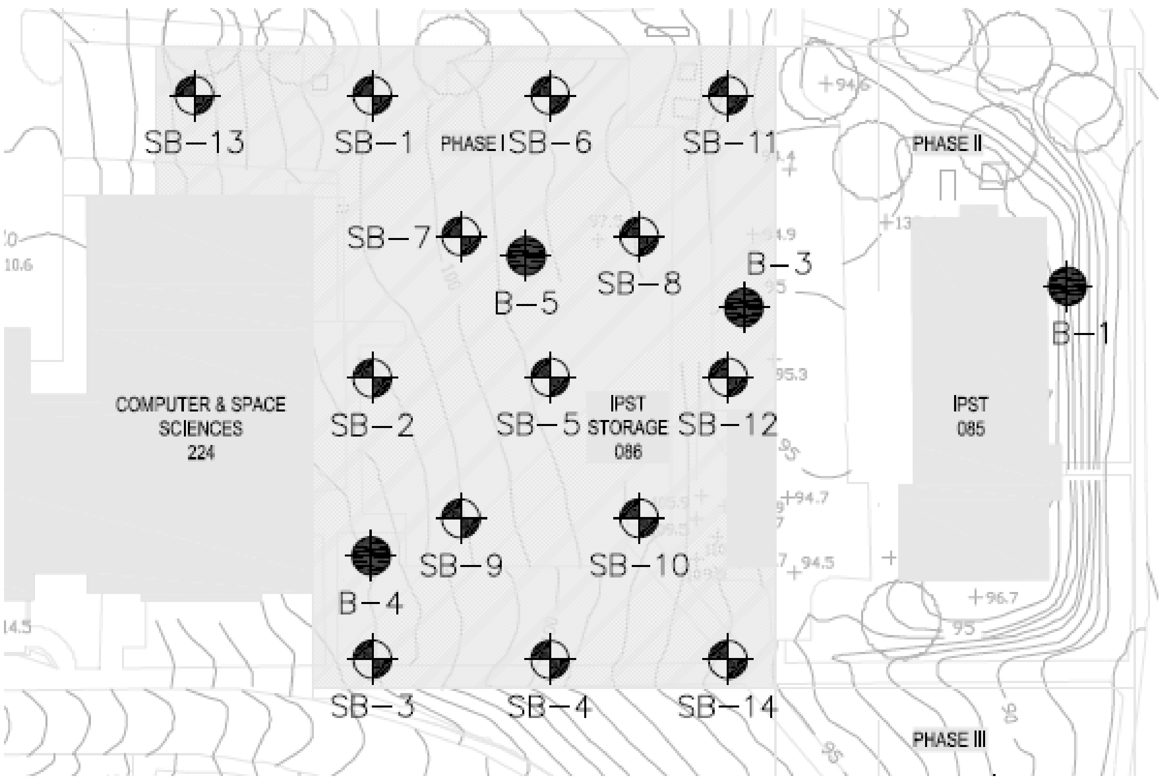


Fig.4 Core Drilling Map

Dewatering is also an important factor when excavating in this area. The soils in this area are low permeability, fine-grained soils with layers of saturated, high permeability soils that act as perched water zones. While the subsurface water pressure is not high enough to cause a flash flood, it is suggested that the water table be kept at least 3' below the lowest excavated surface to reduce risk of damaged equipment or cave-in. In order to accomplish this, a deep-well dewatering system will be used in conjunction with large pumps. Because these areas of perched water cannot be fully discovered by the conventional means of soil boring, the dewatering process should account for any excess, undocumented areas.

General Conditions Summary

A general conditions estimate was performed using information provided in RSMeans. This estimate includes costs for insurance, contingency, bonding, temporary power and utilities, cranes/hoists, inspections & testing, rubbish removal, clean-up, trailers, and field personnel. The total value of the general conditions estimate comes to $7,010,403.64 which is approximately 7% of the project cost. Gilbane holds contracts with 32 trades for construction. Many of the typical general conditions items such as small tools are handled by the subcontractor.

The personnel consists of three field engineers, four project managers, and two superintendents. The combined value comes to $3,487,250.00. This value is roughly 50% of the total general conditions estimate. The values for the contingency, insurance, and performance bonds were calculated as a percentage of the total project cost. Combined, this value comes to $2,016,000.00. Also included in the estimate is the cost for a 24/7 webcam. This webcam records live data and archives a picture of the building and site every 20 minutes. More details of the general conditions estimate and the breakdown of it can be found in Appendix B.

Analysis Topic #1: Elliptical Curtain Wall Redesign and Constructability

Problem:

The elliptical curtain wall of the PSC has been the source of much frustration and concern for the project team. The curtain wall was overdesigned, and as such, has been extremely costly to the construction of it. 20% of the funding for this project came from the 2009 ARRA government program. Investing such a large sum of money into a characteristic design may seem like an idea worthwhile, but at a second glance it can be seen as a deficit to the learning facilities functionality rather than benefit. It is worth considering tgat the money saved by implementing a more cost-savvy, less complicated façade would make room for other, more advanced classrooms, teaching areas, and labs located not just in this building, but in other areas of the campus as well.

Research/Investigations:

The colossal cost of the elliptical façade became an apparent problem to when doing a detailed estimate of the façade of the building. See Appendix D for the detailed façade estimate. This estimate was created using collaborative information from two different manufacturers. The estimate was created using help solicited from MAC (Mathews Architectural Concepts), where Bob Mathews, the president of the company, was instrumental in providing cost details and values. Mr. Mathews provided the contact information for Mr. John Pierce, of Berkowits Glass Inc. Given that the glass has in-layered translucent and opaque coloring, must be cut to custom shapes, little of which overlap, and is installed in the “interior” of the building, it was determined that the overall cost of such a system was $205/SF. The total estimated cost to fabricate and install a façade like this should be approximately $2,000,000.

Steve Sommers was the project manager for NEC working at the PSC. Through Mr. Sommers, it was discovered that the actual cost of materials, fabrication, and installation for the elliptical façade was $4,875,000. This is more than double the estimate cost of the installation. In a long interview with Mr. Sommers, several things were noted that made the cost of the façade hugely overvalued. Each pane of glass was ordered oversees where an Italian company manufactured the specially sized glass with a very long lead time. The glass also turned out to not be heat-soaked properly. Heat soaking is the process where the glass undergoes a temperature change to ensure that the tempered glass will not explode from the module while on the building. Typically a passing ratio is 5 in one thousand panes can fail, and still be acceptable to the construction. Because the original design included so many custom panes, and so many of them broke after installations began, there were massive delays and lead times on the project. Often times a façade or glass company will order excess panes to allow for accidental breaks while installing or shipping. Given the nature of the varying amounts of different glass sizes, it was impossible to order excess panes.

Solution:

It is apparent that the complex and over designed nature of the façade is the root of many frustrations for NEC and the management team at Gilbane. A redesigned the elliptical façade was created to bring the cost of materials down, the installation costs down, and to facilitate a quick and easy turn around for the company responsible for the manufacturing and installation of the elliptical curtain wall.

Figure 5 below is the original design intent of the elliptical curtain wall.

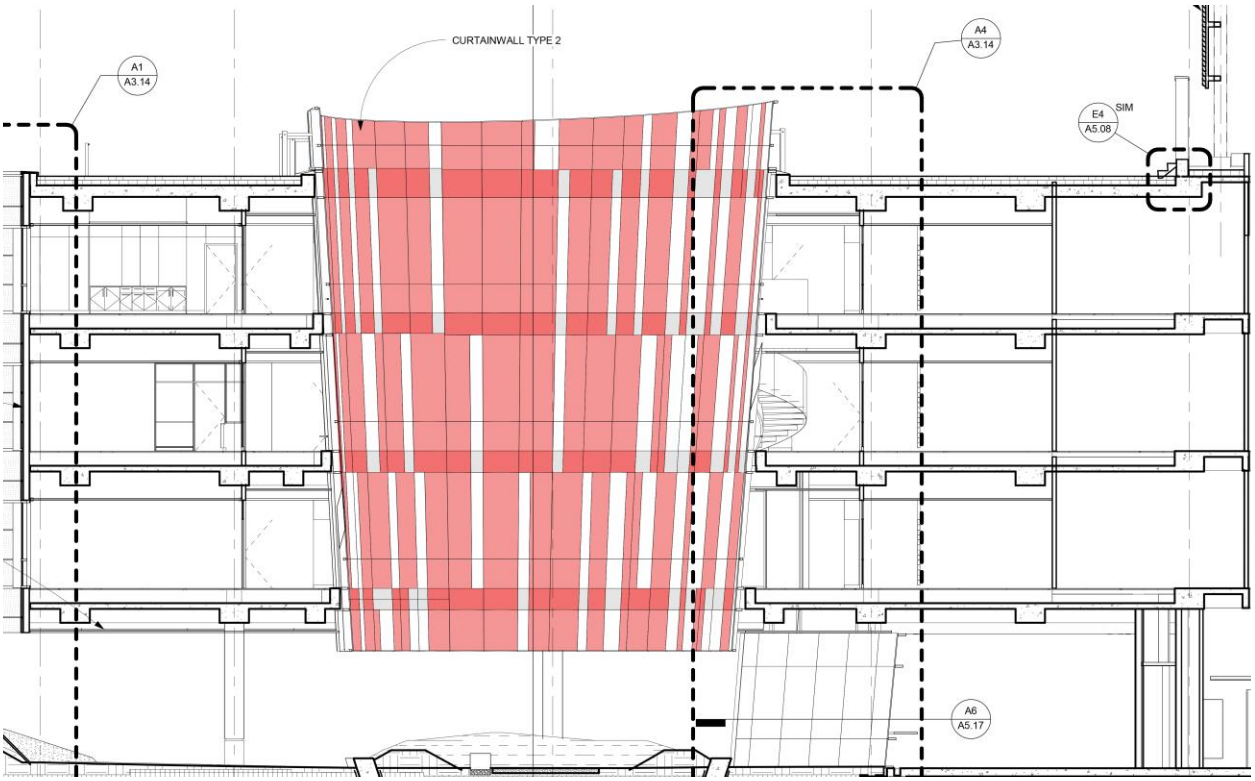


Fig.5 Original Design Section

On the next page is Figure 6, an elevation of the shop drawings NEC produced for this design.

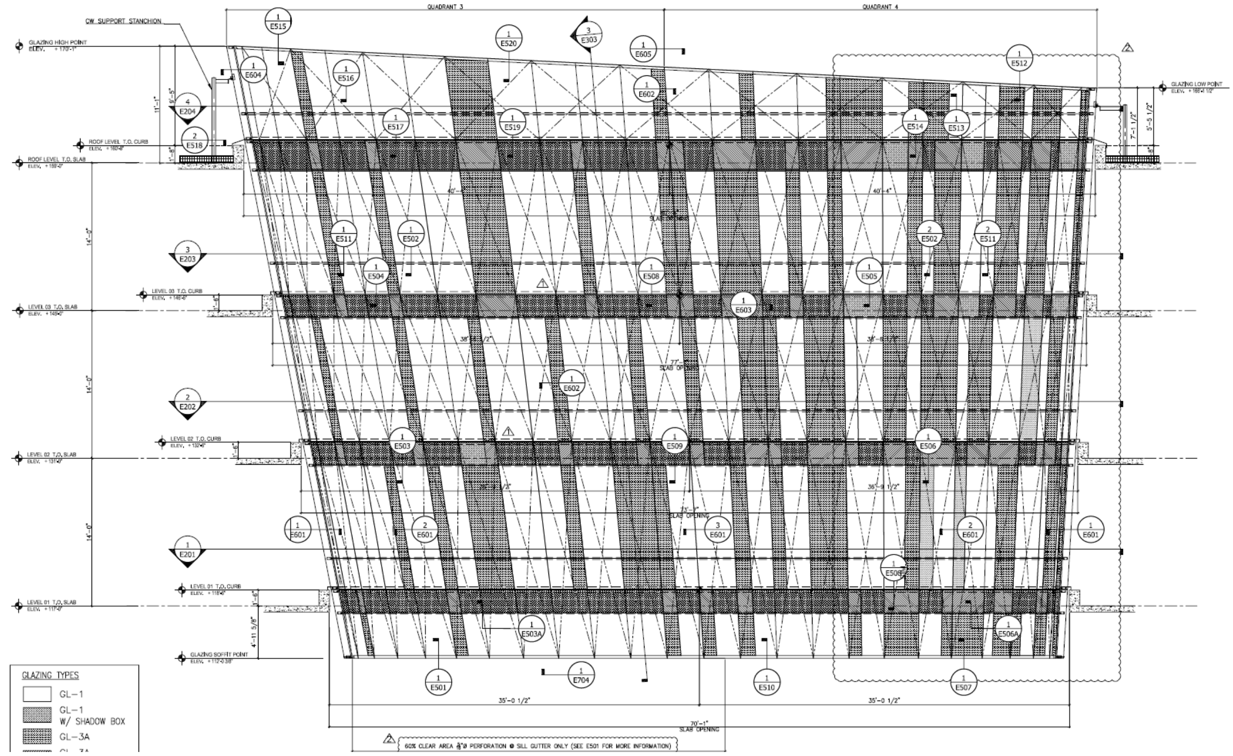


Fig.6 Original Design Shop DWG Section

The sheer complexity of the design can easily be seen just by a simple elevation. There are sections and details for almost every joint on the façade. The drawing package created by NEC solely for this façade ended up being 89 pages of details, sections, and elevations.

This is a lot of detail, coordination, and hours dedicated to a façade that only building occupants will see.

A model was created to show what may be an acceptable compromise to having an interior façade could be in lieu completely eliminating the façade for more classroom, lab, office, work, study, and storage space.

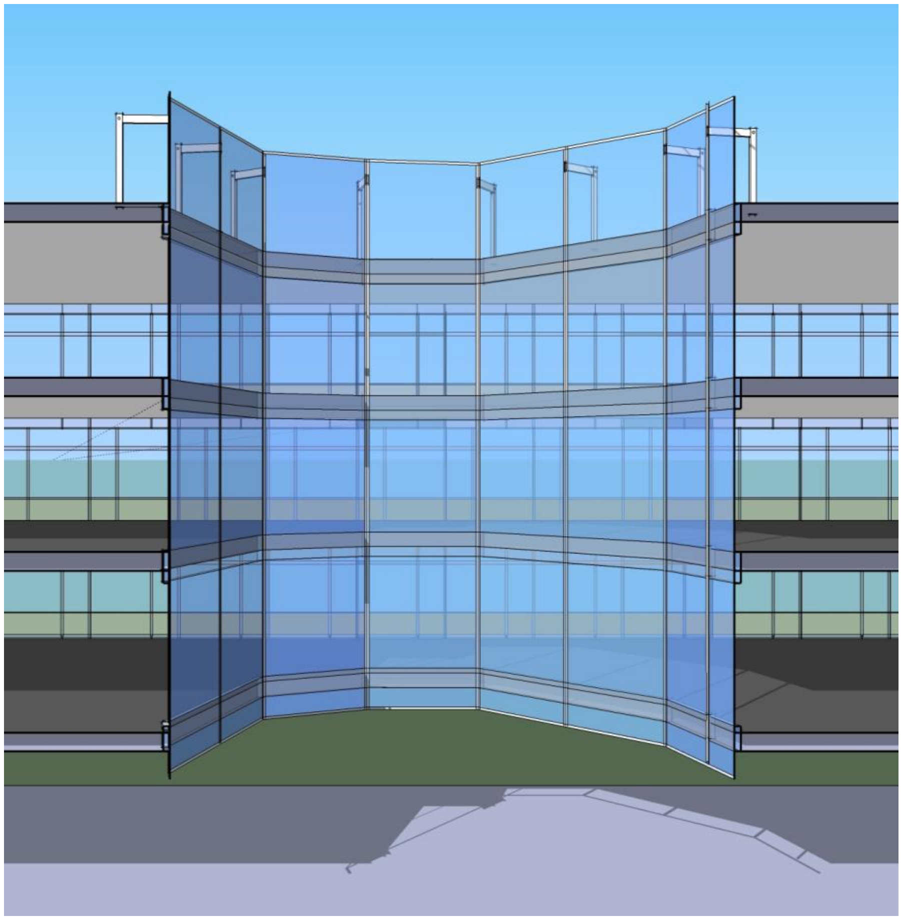


Fig.7 Original Design Shop DWG Section

Above is Figure 7, a section of the elliptical façade according to the changes that were made. The façade can be made out 3 types of modular pieces that can be assembled in a shop, shipped to the field, and fastened together.

In the image on the next page you can see where these modules are located.

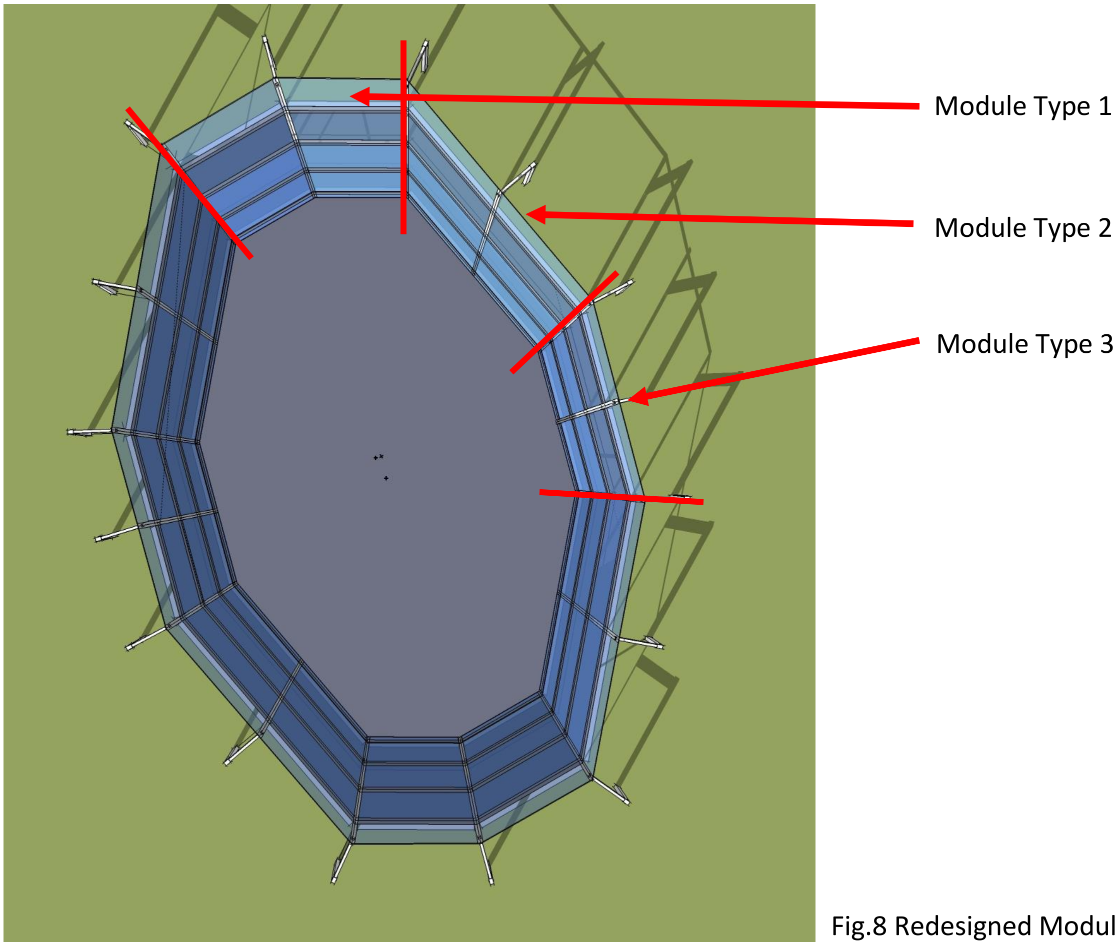


Fig.8 Redesigned Module Locations

In Figure 8 above, you can see that there are only three different types of modules that make up this façade. This vastly reduces the cost of construction. No longer are dozens of custom modules with custom sized glass created to account for the odd and oblong shape of the original design.

Module Type	Size	Quantity
1	14’Hx11.5’W	16
2	14’Hx12.5’W	32
3	14”Hx9’W	16

There are only three modules, as indicated by the table above, with various quantities. A system like this is far more manageable to construct and control, and greatly reduces the probability of error.

This system also greatly reduces the installation time and cost by allowing each module to have the same base and header connection.

Figure 9 below shows a typical connection section for the original façade design.

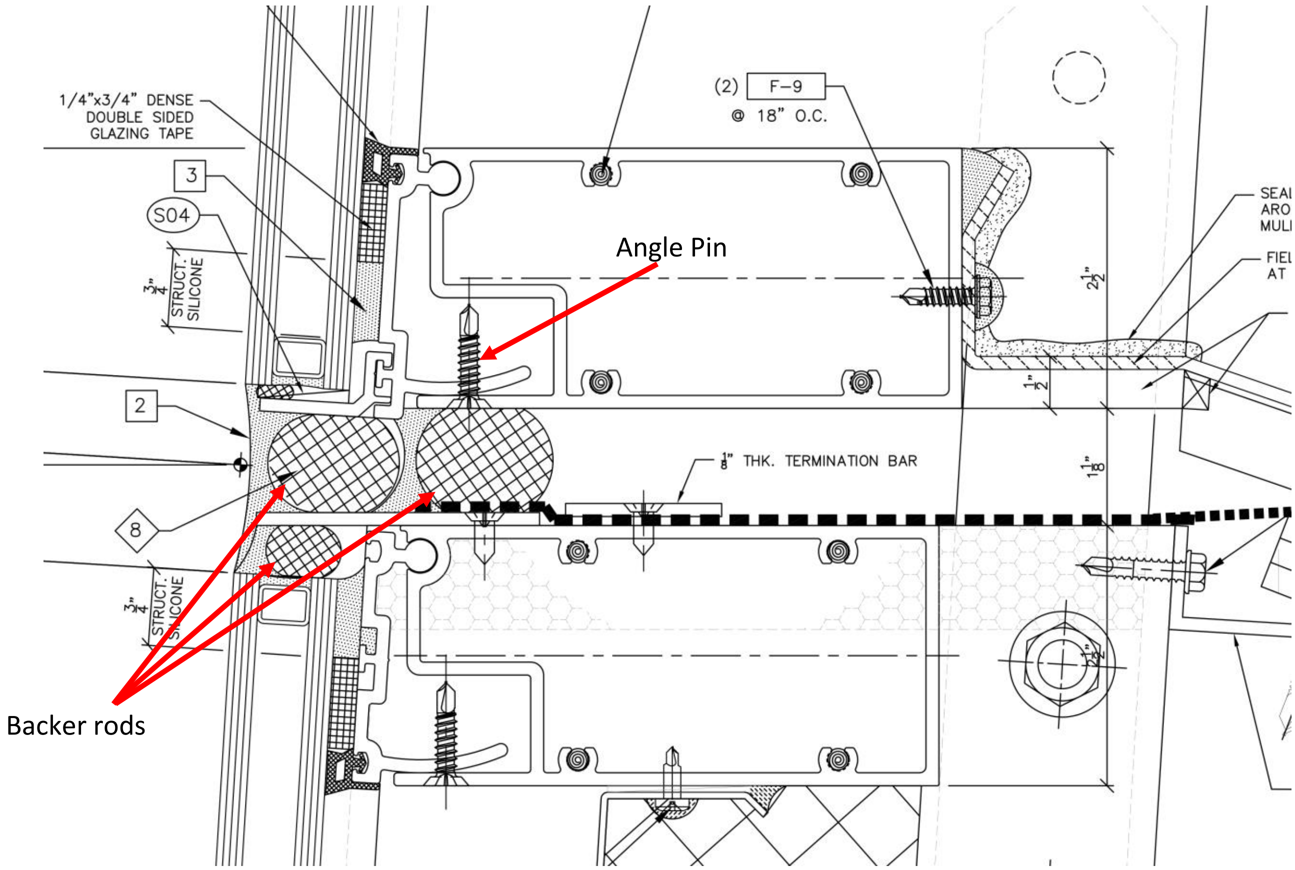


Fig.9 Original Design Header Detail

In this detail, you can see that there is significant steps taken to insulate and wet-proof the façade. Three backer rods are used as well as a pin to hold the angle of the façade. This system relies heavily on field work to complete the installations. Completing more work in the shop will always yield more cost savings to the manufacturer and the project team. On the next page you will find the connection detail that was revised that will allow for the modules in the new system to be installed very quickly with minimal work in the field (wet sealing, pinning, etc).

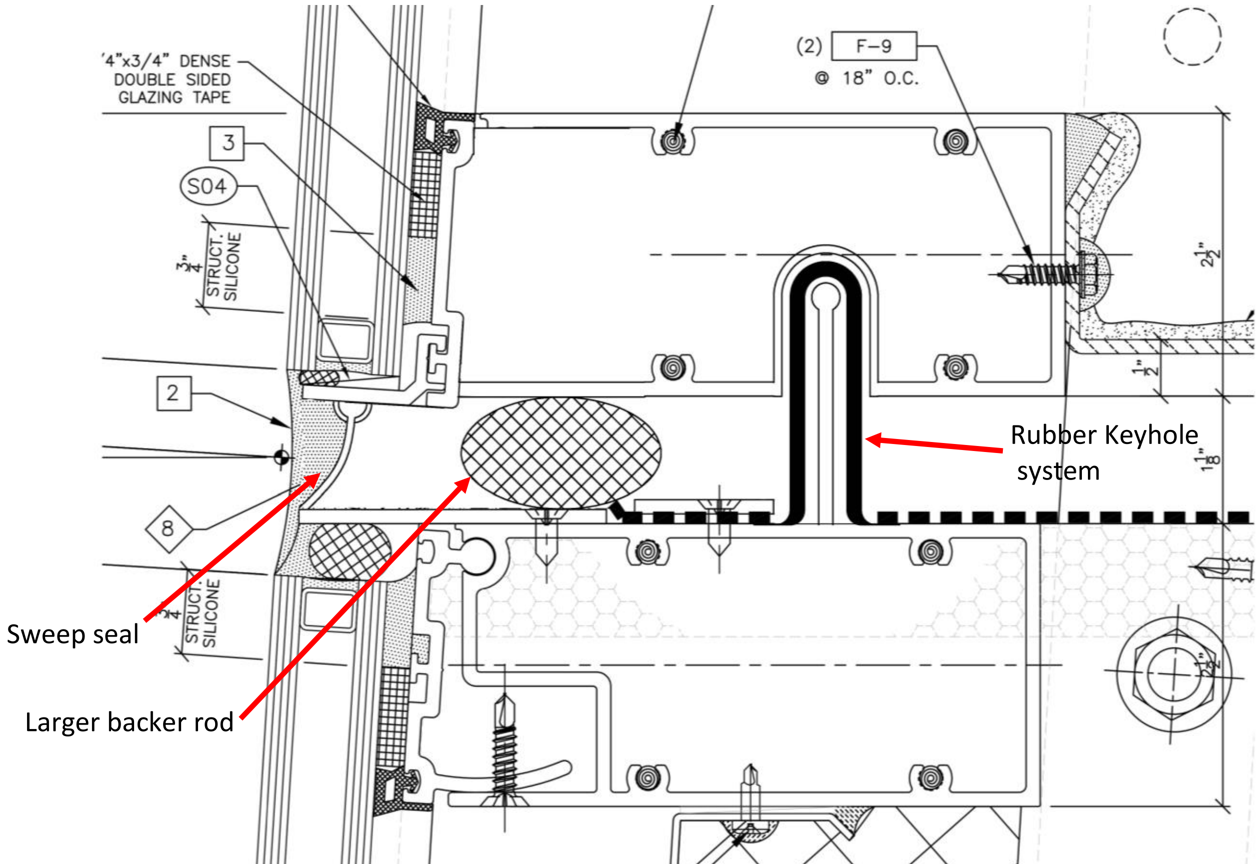


Fig.10 Redesign Header Detail

There are a couple changes in the revised detail above (Figure 10) that will make a large impact on cost. First, because the new design has a constant angle to each piece of glazing, there is no longer a need for an extrusion piece with a pin to hold a varying degree angle. Instead, an extrusion with a fixed angle can be used to eliminate the work necessary to measure and secure the angle pin. Second, the top and bottom extrusion pieces now fit together by use of a keyhole system. The rubberized layer of insulation will cover this pin on the top of the bottom module, and the bottom of the top module will slide over top, creating a rigid connection as well as a water-tight seal. Two secondary seals are also apparent. The larger backer rod is placed during installation before the top module is lifted onto the bottom module, and because there is a built in sweep seal, there is less work required for crews to do finish installation work while on the exterior of the building.

This connection will be the same for each module, and adjustments will not be required in the field as they were on the original design system. Using this method, entire modules can be fabricated and assembled in a shop and shipped to the field and easily secured.

Cost Savings:
After creating the new design, Mr. Mathews and Mr. Pierce were consulted to get a new estimate for the revised design. The module sizes are small enough such that the price for the glass and fabrication does not scale exponentially and freight will remain manageable.

Using the exact same square footage, it was determined that a cost per square foot of $110/SF was a valid price point for this type of system using the expert analysis and opinions of both Mr. Mathews and Mr. Pierce. This puts the new design cost at $1,100,000 with all things included. This is a drastic difference between even the estimated cost of the original façade system, let alone the $5,000,000 price point of the actual completed installations for it.

The breakdown of the problems associated with the original system will be covered in another analysis topic later in this document.

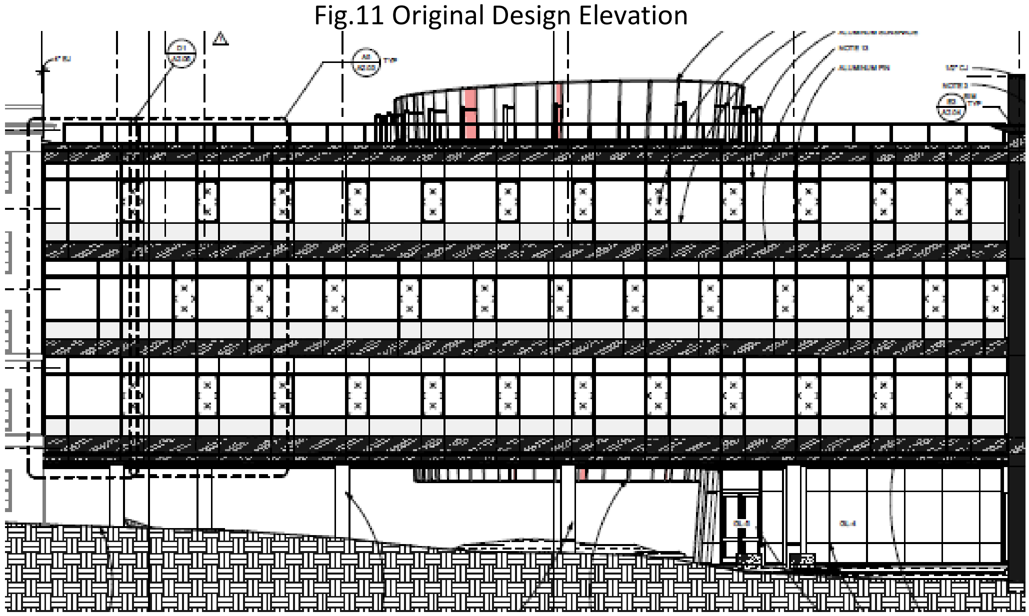
The estimated cost savings for switching to a simpler design which achieves the same result is approximately $3,775,000.

Architectural Breadth:

Though briefly covered in the above section, the design alteration to the elliptical façade is significant. A very noticeable architectural change has taken place, but not so much as to compromise the core goal of the elliptical façade, which was to bring natural light to the center of the build with which all traffic flows. The purpose of this architectural change was to reduce the complexity of the design and lower costs of engineering, materials, and installations.

On the next few pages are side by side design comparisons with comments about each figure.

Fig.11 Original Design Elevation



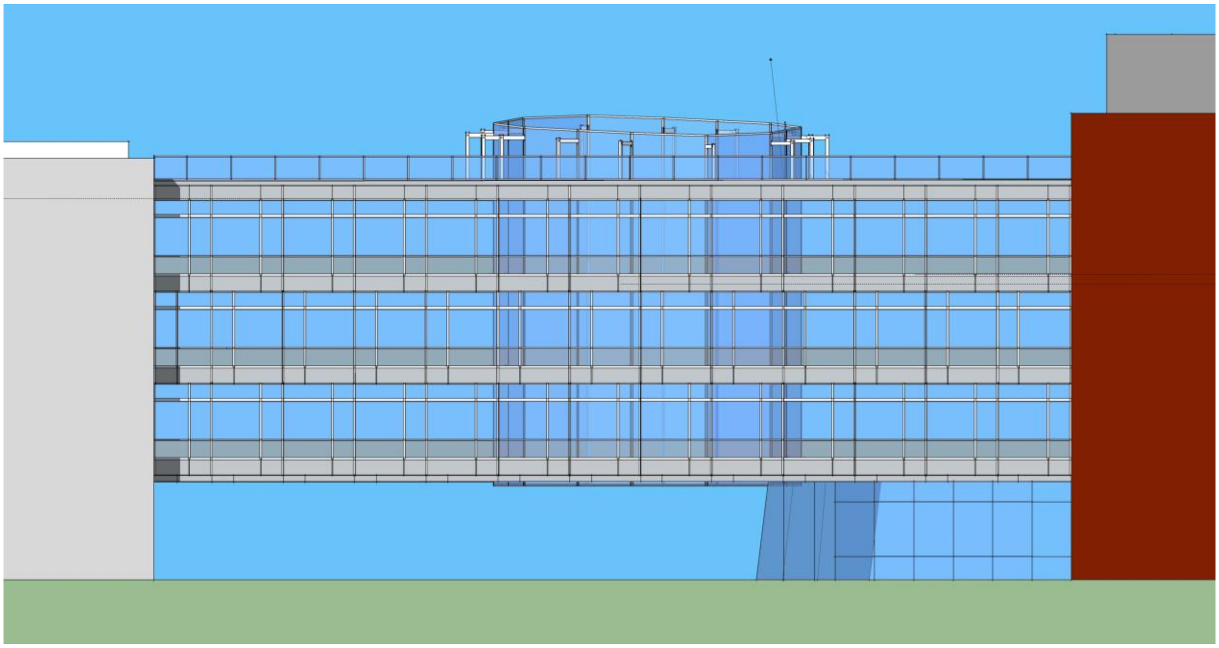


Fig.11 Redesign Elevation

The above figures (10 & 11) are two parallel projected elevations of the original design, then the new design. The two facades are the same in diameter and in size. The new design does not have varying degrees of glazing angles. A vertical shaft that brings in just as much light as the previous design will create for the exact same effect. Many of the occupants will never give a second thought about the elliptical façade. Many others will not even notice a difference between the two facades. Often, architectural concepts are borne with the idea that others are just as infatuated with design and architecture as the creator, sometimes to the detriment of the occupants. This open the opportunity to look at alternative designs that may yield cost savings.

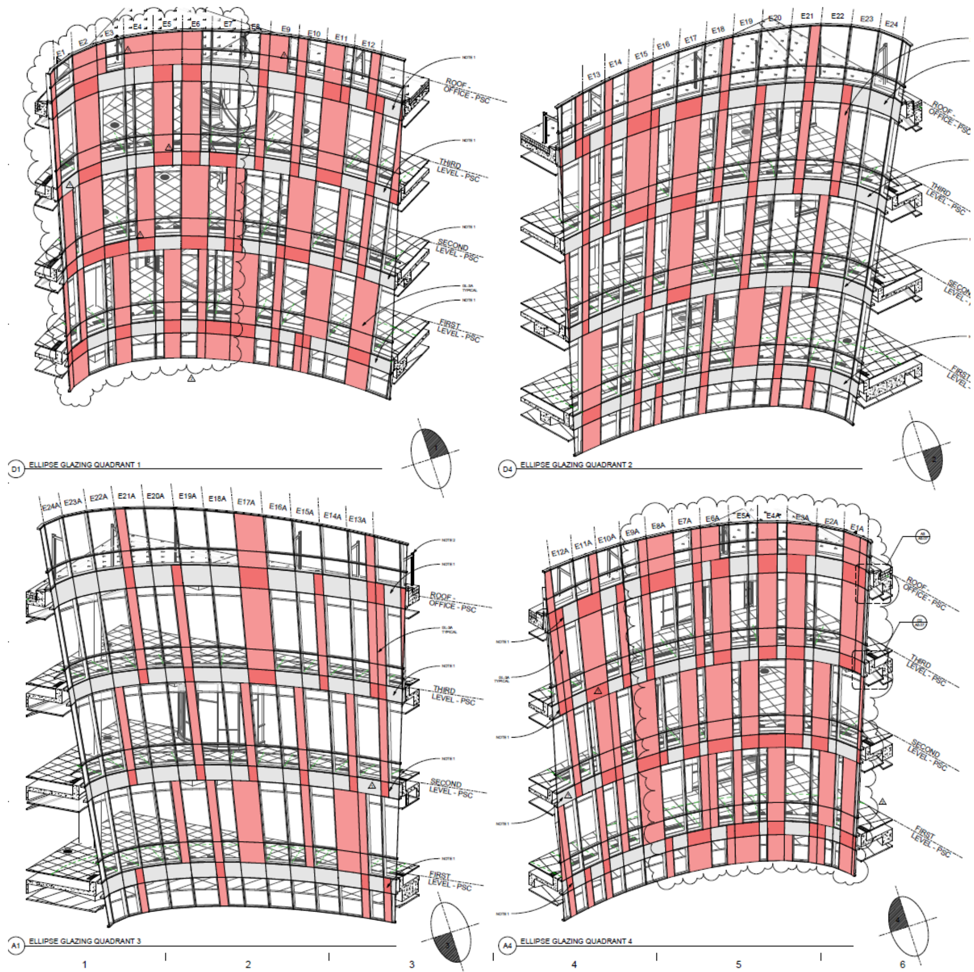


Fig.12 Original Design Façade Quadrants

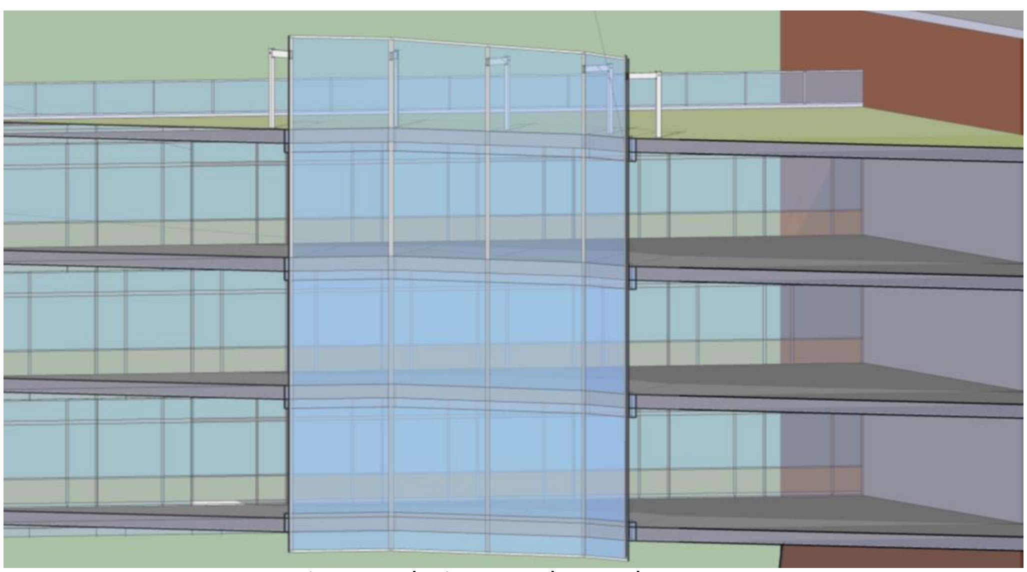


Fig.13 Redesign Façade Quadrant

See next page for notes.

The figures (12 & 13) on the previous page show the original quadrants of the elliptical façade and the new. The new façade has a single quadrant that is replicated 4 times to form a whole ellipse. That extra, massive, layer of complexity is removed with this simple change.

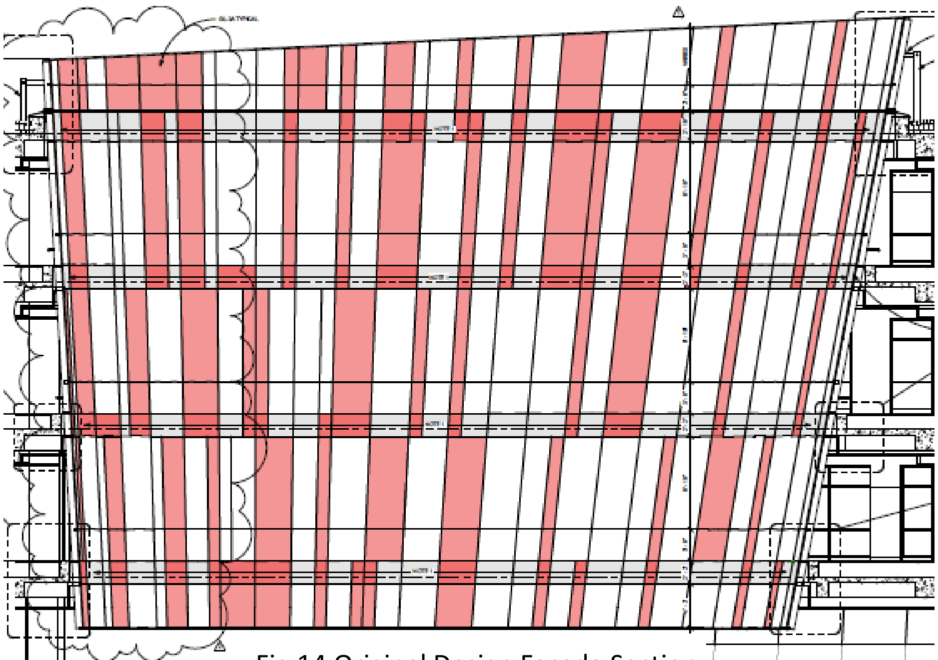


Fig.14 Original Design Façade Section

This last figure (14) is a section through the center of the building with the original design. You can see that the angle of the glazing changes depending on where one might be located on the perimeter of the façade. This requires the more expensive extrusion pieces that were noted earlier that utilized the angle pin.

Conclusion/Summary:

The PSC suffers from a focus on design rather than function. The PSC is an academic facility and as such, the primary goal of the facility should be to enrich the learning experience and studies at the university. The above analyses indicate that the project could have been further value engineered to provide a more rich learning experience for the occupants.

A savings of nearly 4 million dollars, as indicated by my research and analysis, could be used to boost other areas of academic interest in the facility, which in itself, and entire analysis topic for another major.

Analysis Topic #2: Elliptical Curtain Wall Schedule and Error Reduction

Problem:
This analysis will focus on the short comings of the original designed façade system. Patrick Peters, the Façade PM for Gilbane on the PSC project, made it clear that the façade and curtain wall has been the source of much headache for the team (already addressed in the previous analysis). There is major room for improvement on the delivery schedule for the façade system, which will ultimately result in cost savings for the team.

Research/Investigation:
As stated previously, discussions with Patrick Peters led to some areas of focus for the façade system. Below are the major areas of concern that Mr. Peters thought could be improved on.

1) The façade system utilizes glass made from Italy. The glass in particular is only available in Italy at these sizes with in-layered opaque and translucent colors. The glass is tempered and heat soaked for quality, but a company 5,000 miles away is hard to maintain quality control over from the remote office in Maryland for the PSC construction team. Not only this, but the lead times on custom glass sizes can be anywhere from 5-10 weeks. With a project as complex as the PSC, a series of incorrect sized glass, or glass that arrives broken from the carrier, or breaks during or after installation due to poor quality control, can hugely set back the project.

   As a matter of fact, the original water-tight date for the project was to be August of 2012. Due to the setbacks originating from the issues as described above, the water-tight date of the façade was on June of 2013. Only after this point could other major trades like the electricians move in to start finalizing their rough in work.

2) At a later discussion with Mr. Peters, he made it clear that there were problems with the glass in the elliptical curtain wall. The glass was starting to pop out and crack. As it turns out, the glazing in the modules for the curtain wall were many different sizes (due to the changing slope of the glass as covered in the previous analysis), and as a result of the slowly changing angle of the glazing, some pieces were not installed in the appropriate module. In other words, the glazing pieces change in height from one to the next by as little as a 1/16". Pieces were used in areas where they should not have been, and as construction continued, the façade settled and pieces began exploding and cracking out of the modules. And, as stated in the previous point, the massive lead times created significant delays.

Upon my site visit in February of 2013, there were 8 pieces of glazing that had ruptured and were replaced with temporary weather proof membranes until the new glass arrived.

3) The third issue with the façade is the method of installation. As noted in the general history and description found earlier in this document, there was a large tower crane placed in the center of the building (within the elliptical façade) that was used for many various installation and material storage activities on the project by multiple trades. Each trade would have to request time on the crane. Both the exterior and interior façade systems were installed using this crane. The exterior façade took 5 weeks to install, and the interior façade took ten weeks to install. The price of the crane use incurred by Gilbane is $36,812 per month (as noted in the general conditions estimate in Appendix B). This means that for the total install of the façade, the cost of the crane for this associated trade was $138,045. There is another method of installation that will cut down this cost by at least half that will be discussed further below.

Fortunately for the integrity of this report, but not so fortunately for the project team, there is a very large area for improvement regarding the general materials and installation of the façade.

Solution:

This section will address the solutions to the problems in order they were listed.

1) Façade quality control and lead times from Italy.

   Often glass suppliers and manufacturers are noted as approved suppliers or manufacturers in the specs of a particular project. Through research, it was found that no such clause listed this company, Focchi, as the approved supplier. This opens the door for other companies to supply. Correcting the problem of exceptionally long lead times and the ability to quality control materials in person can be as easy as finding a local, or at least Western hemisphere based, glass supplier. In this area of interest, Mr. Mathews was instrumental in guiding further analysis. Two glass suppliers were referenced by Mr. Mathews for further analysis.

   A) J.E Berkowitz Glass was the first manufacturer. Mr. John Pierce, the director of sales for the PA/East coast region, was available for an interview. There were two major things gleaned from discussions with Mr. Pierce. First, the lead time on the glass for the PSC should have been no more than two weeks. Second, the units of glass should have been properly heat-soaked and inspected by a representative of NEC (National Enclosure Company).
   B) Sentech Architectural Systems, the second company contacted, is a company based out of Texas. Mr. Mathews opened the doorway to discussions with Mr. Alphonso Lopez, one of Sentech's senior project managers. Mr. Lopez

ultimately reiterated the same thing as the other supplier. He also commented on the complexity of the system its self (covered in analysis topic 1) and noted that something so complex should have never even considered off-shore materials. He explained that in his own experiences that the higher the complexity, the longer the job takes exponentially. Compound this with the fact that the job must meet certain accreditations, certifications, and legal parameters surrounding the partial government funding, there is a huge delay in getting work done in a timely manner.

Although it may be difficult to speculate on what *could* have been a more seamless and easier approach to the façade installations using the information provided by Mr. Mathews and Mr. Lopez, there are a few assumptions that can be made given best possible outcomes if changes were made at the beginning of the project. By switching to a US based supplier, lead times would have been cut to a fraction of the original. Also, by switching, quality control over heat-soaking breakage could have been observed more closely, mitigating the delays imposed by ruptured glass. It would not be unwise to say that had the change to simply use a local supplier been made, the water tight date of the building would have been on or before the original August 2012 mark.

2) Glass breakage.

Although briefly covered in the previous point, there were glass breakages on the project after installation. This was caused by two problems, the lack of proper quality control on the tempered glazing, and the installation of incorrect glazing in certain modules. The issue of quality control was explained in the previous point. The issue of installation still remains. The glazing was received and assembled into the custom modules by NEC, the façade subcontractor. Mr. Peters explained that the glazing they received was not labeled properly. Because of the enormous lead times and the communication barrier created by 5,000 miles of ocean and land as well as language, they proceeded to install the glazing to the best of their ability. Although mostly accurate, it did not stop at least 8 panes to rupture from their modules after installation. The solution to this is to either reassess the design (done in analysis topic 1), or not install the glazing until a representative from Focchi was able to inspect what was delivered, which creates an even longer artificial lead time.

3) Crane installation.

Stated earlier, the cost of the crane utilization was approximately $138,000 for the façade alone. A very simple solution to this is to purchase, and install custom rigging for, an electric hoist for the façade. A typical hoist for a project of this size can run from $9,600 to $12,500 depending on the supplier, size, and mobility.[10] Custom rigging for would take two days to install and set up the hoist. After this, the only cost to the installation team is electricity, which is near negligible for this application.

The estimated cost of the hoist ($12,500) plus the rigging (3 men for 2 days and materials, $6000) comes to approximately $18,500. This is a stark comparison to the $138,000 for the crane usage, and results in a savings of $119,500.

Conclusion/Summary:

With the solutions outlined above, the estimated cost savings for the project team is $122,500 plus speculative cost savings associated with glass breakage. The schedule can be reduced to a theoretical value of only 3 weeks for installations. Without further insight into the negotiations between contractors to subcontractor to supplier, it is difficult to gauge the actual cost savings for the project. However, it is clear that with these simple changes, that huge liabilities and negative impacts to the project could have been mitigated.

Analysis #3 Topic: HCPV façade

Problem:

The exterior walls of the Science Complex lack any method of capturing solar energy. One wall in particular, the south facing façade, is perfect for integrating solar collection arrays onto the façade system. The advent of modern high concentrated photovoltaic (HCPV) cells creates an opportunity for many new constructions to implement HCPV systems. The failure to recognize or design an alternative system incorporating HCPV systems is a problem this analysis intends to address.

Research/Investigations:

The idea to implement solar arrays into the curtain wall of a structure first became apparent during an investors meeting with a company called “Helioptix,” who has graciously supplied information for use in this report. There are several factors to the success and economical payback period associated with implementing state-of-the-art HPCV façade systems.

First and foremost, the building must have a south facing wall, while in the northern hemisphere. The plans indicate that this wall is perpendicular to the south direction.

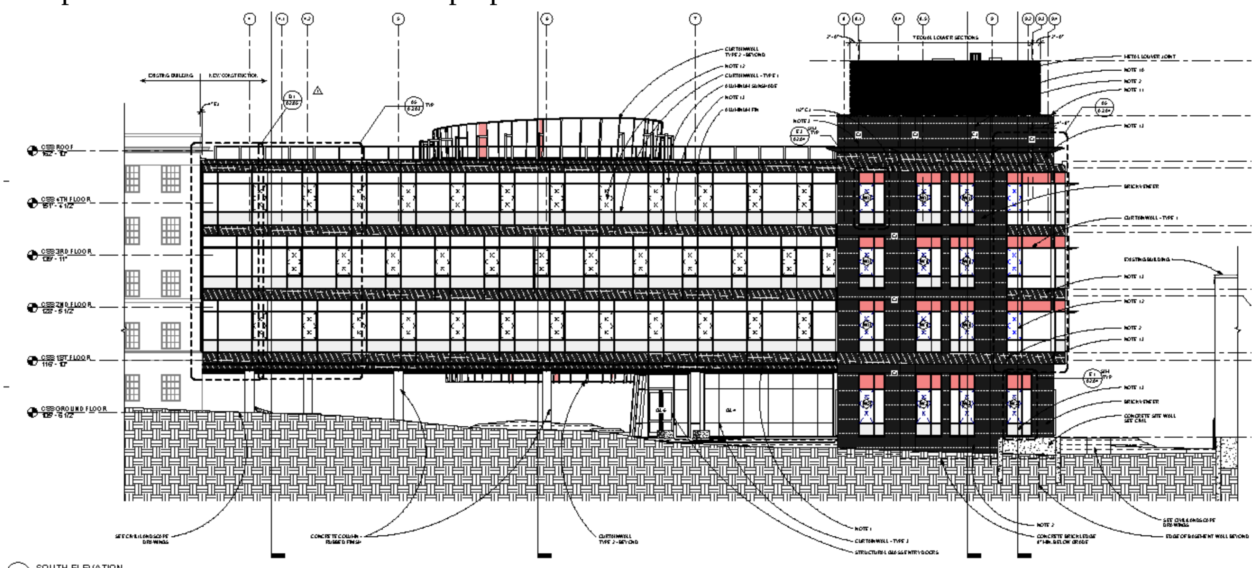


Fig.15 Original Design Façade Elevation

The second thing that would allow for a HPCV façade would be a clear view of the sky. This means that no other buildings or obstacles such as hills or other geography be obstructing any of the view to the south sky. The site plans indicate that there is a multistory parking garage 205’ away from the south wall of the Sciences Complex. The parking garage has a maximum elevation of 40’. The topographical difference in the two buildings is +6’ to the garage. The lowest point on the façade of the Science Complex is 12’ from the topographical elevation. The altitude angle of the sun during the winter solstice, the lowest it will ever be, at 9am, is 14°.[1] The angle created by the Complex and the garage is 16.5°. This means that for the very vast majority of the time, the Complex will have a full view of the sky. See Appendix E for calculation details.

The third and last thing that is necessary to economically implement an HCPV façade system is to consider the total sunny and partly sunny days in a given area.

	% Sun	Total Hours
January	51	155
February	55	164
March	56	215
April	56	231
May	56	255
June	62	277
July	64	290
August	62	264
September	60	222
October	58	206
November	51	159
December	49	145
Annual	57	2582

	Sunny	Partly Sunny	Total Days With Sun
January	8	8	16
February	8	7	15
March	8	9	17
April	8	9	17
May	8	10	18
June	8	11	19
July	9	12	21
August	9	11	20
September	11	9	20
October	12	8	20
November	8	8	16
December	8	7	15
Annual	105	108	213

Fig.16 Sun Days and Hours for Maryland

The above diagrams (Figure 16) show the total hours of sun, and the total days with sun in Maryland.[2]

The typical energy usage for a building of this type is approximately $2.44/SF for a commercial/office building.[3] This brings the energy cost of the sciences complex to approximately $385,000. Because the complex is not 100% operational all year long, the cost for electricity can be reduced by roughly 20% to account for less workload during the summers. This brings the total estimated cost to $308,000 per year in electrical costs. A solar collection array can significantly impact the cost of the electrical per year given these three aforementioned prequalifying criteria.

Solution:

Introducing an array of HCPV cells in a façade for the south side of the building seems to be an economical and modern way of reducing energy costs, and reducing the carbon footprint of the building. At the moment the current, best HCPV module operates at 40% efficiency.[4] The sun has an average irradiance value of 850 watts per square meter in the Maryland area. This means that of the theoretical 850w/m^2 irradiance value, the HCPV module converts 40% of it to electrical energy given optimal conditions. Using the data collected so far, the theoretical energy collection can be calculated for the south facing façade of the Science Complex.

Maryland has 57% full sun exposure, the sun produces 850w/m^2, a module has 40% efficiency, and the total square meters of the south façade comes to 370m^2. Using this information, an average of 4.65kWh/m^2/day can be calculated (See Appendix F for calculations). The south facing façade will generate 631,423kWh per year. Given the standard rate of electricity in the College Park, Maryland area of $.135/kWh, this comes to a theoretical cost savings in energy of **$84,778 per year.**

In addition to generating this electricity, the heat created by the module due to the high concentration of sunlight, can also be utilized. The system must be cooled regardless, so the façade system incorporates a heat exchanger to allow the heated water created by the HCPV modules to be exchanged with other mechanical systems (more information on this later).

The HCPV Module

A high concentrated photovoltaic module is a solar collection module designed to maximize the energy collection of the sun and boasts a much higher efficiency rate than older, more standard solar panels.

Figure.17: Typical HCPV Ground Array[5]

The above figure shows a typical array of HCPV modules used to generate electricity. While they have been growing in usage over the last decade, they are only rarely used in façade systems as a synergistic entity on a building. Each module consists of multiple cells; the above picture has 30 cells per module in that instance. Each cell has a typical set up that is very similar to the diagram on the right. A Fresnel lens focuses the sunlight hundreds of times

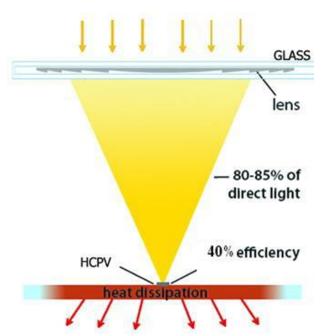


Figure.18: HCPV Lens Diagram[4]

on a HCPV receptor which generates the electricity. This produces heat and is often dissipated by an in-line water cooling system. While it is not easy to modify the standard set up to be used as a façade in a building, it has been done by a few companies and provides enormous benefits.

Typically each module has a motorized mounting system that will align the entire module to capture as much sun as possible. This is not possible in a building so, instead, each cell within the module will track the sun so that the overall width and dimensions of each module relative to the building does not change. Below is an image, courtesy of Helioptix, that shows an early prototype installation made in 2009 at Syracuse University.

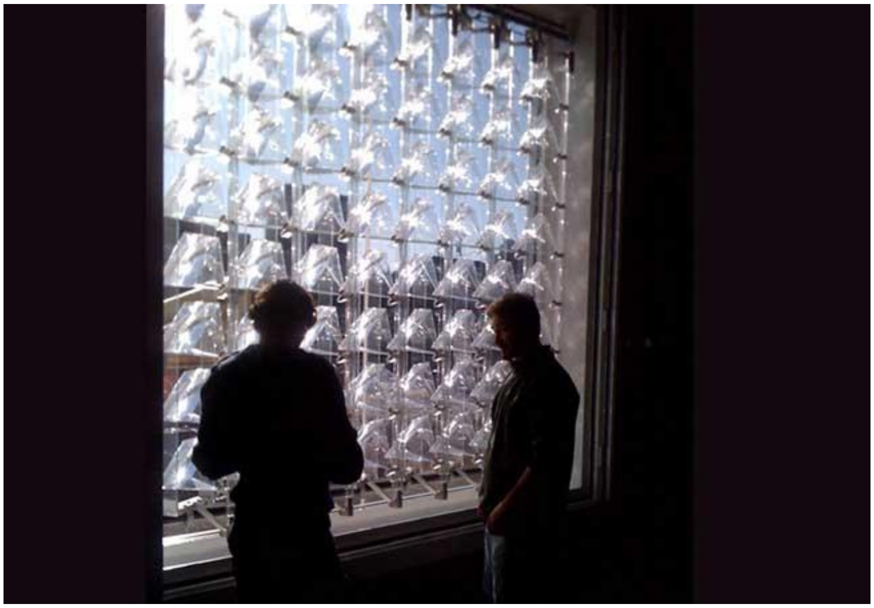


Figure.19: Syracuse HCPV Façade Functional Mock-up

Each cell is attached to a grid system that moves to rotate all cells. What is most notable about this installation is that it allows for building occupants to still see outside of the window. Although somewhat limited, ambient natural sunlight can still fill the room with light even when the system is generating power. This allows for an aesthetic approach to integrated solar systems.

There are notable advantages to having an integrated HCPV system. The first is the obvious power generation. Secondly, it creates an additional layer of thermal protection for the building with a larger air pocket that houses the entire assembly. Third, it allows the liquid cooling system to be locally heat exchanged with the building's other HVAC systems.

Installation Costs

Typically, the cost to purchase and install ground mounted HCPV systems is approximately $1500/m^2.[6] An HCPV façade system is more expensive, but not unreasonably so. In an interview with Tom Kanuck of Helioptix, he stated that the associated cost of the large façade systems that they are currently planning is approximately $325 per square foot. Other costs associated are additional inverters and heat exchangers, and the associated maintenance and training costs for building staff to maintain this system.

This places the rough cost of the façade at $1,294,150 if it were to implement a full HCPV system.

The below figure indicates, via highlighted area, the total surface that will receive HCPV modules (similar to the one shown in figure.19)

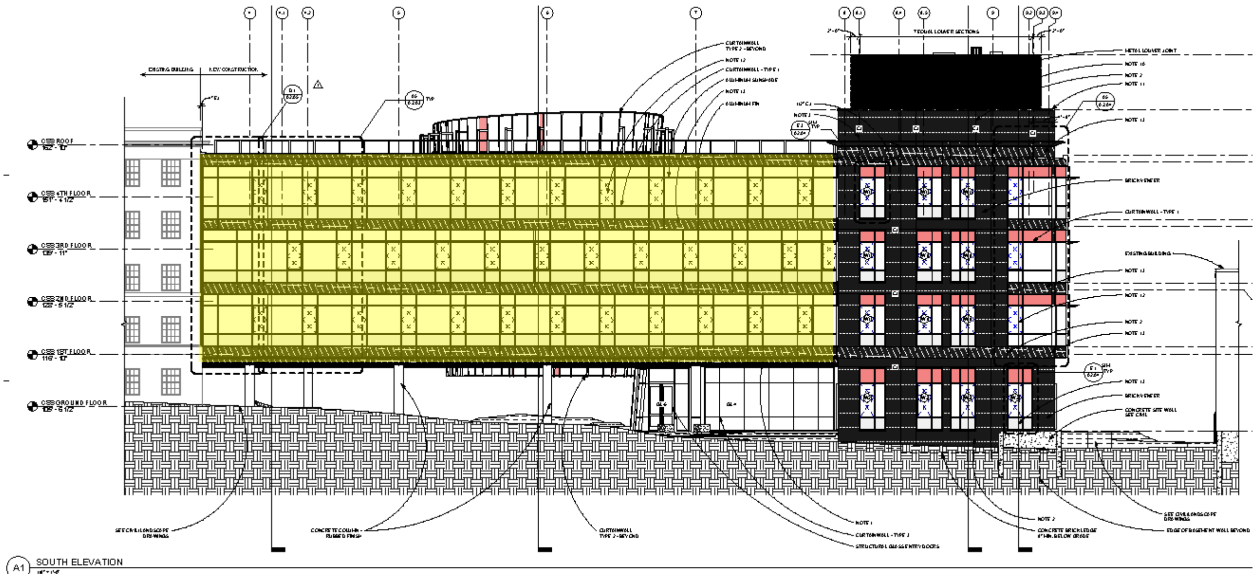


Figure.20: Area of HCPV interest on south facing façade

The figure below shows what a typical large scale façade HCPV system may look like.

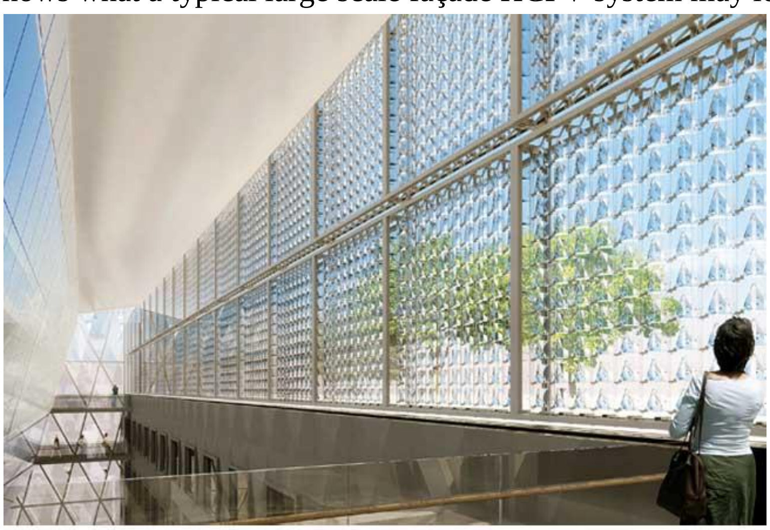


Figure.21: Conceptual mock-up of typical HCPV façade assembly (courtesy of Helioptix)

Appendix D shows a detailed breakdown of the cost estimate of the currently planned façade system. Zone 1 and 2, in appendix D, are the North and South facades, which are identical in material and design. The associated cost for the South Façade is approximately $1,105,120. This is a cost difference of approximately $189,030 between the proposed HCPV system and the original system.

Scheduling Impacts

Just like any other façade system, the plans and elevations must be created, scrutinized, and value engineered from the inception of the building construction documents. Given identical conditions for the proposed system and the original, no significant scheduling changes should occur. The system, although part of a growing future of photovoltaic technology, is no more complex than what is currently installed on the building.

Mechanical Breadth

A system this large will require changes to be made to the mechanical systems. In addition to DC to AC inverters, a large hot water storage tank will be required to receive the heat coming from the cells contained in the HCPV modules.

Sizing the inverter

In order to ascertain the size of the inverter required for this HCPV array, the specifications of an existing typical modern HCPV module can be used. In this instance a module by a company called Envoltek has a HCPV module that closely resembles the module that will be used in the façade. The system model is an S5K 5KW HCPV.(7) It has a power generating surface area of 23m^2 and an output of 4.37kW under an irradiance of 850w/m^2. This equates to wattage per square meter of 190 watts. This is extremely similar to the theoretical output of modules in question for the Science Complex.

Normally, systems like these have inverters built into the module its self. Under the circumstances for the Science Complex, this would be impossible due to the limited space available on the façade. The façade is 370m^2 and this module is rated at 190W/m^2. This equates to 70kW of power. Adding 15% for exceptionally sunny days, the power input to an inverter on the DC end must be rated for at least 80,500 watts.

A 100,000 watt, 480 V DC to AC inverter is approximately $50,000 to $65,000.(8)

Sizing the Heat Exchanger

The HCPV façade will require a cooling system to cool the photovoltaic cell. Enough heat is generated during peak performance that the heat can be exchanged with cool water to ease the load on other HVAC systems such as a water heater, or water heated air system. According to Helioptix, of the 60% energy that is not converted to electricity, up to 80% of that energy can be captured using a cooling system in conjunction with a frame and plate heat exchanger.

60% of the irradiance of the sun in this instance is 850watts/m^2 * .60 = 510watts/m^2. Of this, only 80% of it can be used with a heat exchanger while the remaining 20% is lost to the ambient air convection and radiation off of the photovoltaic cell. So 510watts/m^2 * .80 = 408watt/m^2.

A total of 408w/m^2 * 370m^2 = 150,960 watts must be cooled. Since heat exchangers are typically rated in BTUs, 150,960 watts * 3.412 BTU/hr/watt = 515,096 BTU/hr.

Because of the long leads on the tubes that carry the water, much of the heat will be lost during circulation. In this instance, two 240,000 BTU water to water heat exchangers can be utilized.

Two 240,000 BTU frame and plate heat exchangers is approximately $14,000 to $20,000.(9)

Under the right circumstances, the heat exchanger can alleviate the heating loads of other systems, on average, by up to 150kW * .57 solar hour factor * 24 hours/day * 365 days/year = 749,000 kWh per year, which equates to a theoretical cost savings of $101,100 per year. However, the theoretical savings via heat exchanging is limited to the actual demand of the building, and without having the proper experimentation on a full scale building, could also yield little to no benefits over the alternative which is passive water cooling using water from the city grid and expelling it back into the sewer system. For this reason the benefit yielded from the heat exchange of the system will be left out of the final payback time period calculation.

Conclusion/Summary

Original Façade Costs:		$1,105,120.00
Proposed HCPV System Costs:	Curtain wall	$1,294,150.00
	Inverter	$65,000.00
	Heat Exchanger	$20,000.00
HCPV System additional costs:		+$273,030.00
Electrical Savings with HCPV:		$84,778.00
Heating Savings with Heat Exchanging:		$0.00

The payback period for implementing a HCPV system is 3 years and 3 months under typical loads and usage for the Physical Sciences Complex. A HCPV array is recommended for this project for long run cost savings.

Analysis Topic #4: Multi-shift Work Schedule Reduction

Problem:

The Physical Sciences Complex is a building on a University campus. Therefore, is must abide by the yearly academic schedule. When research first began into this building, the building was set for a substantial completion date of September 2013. The substantial completion date actually occurred on January 6, 2014. The building gets zero use from the faculty of the school or its students prior to the substantial completion date. The original substantial completion of September in 2013 did not give fully operational use of the building for the fall semester. It would be much more advantageous for the University of Maryland to get the building occupied and set up for the busy fall semester during the summer prior. In order to accomplish this, the building must be completed during the summer of 2013.

Research/Investigation:

The concept of using two crews to schedule around a 14 hour day became apparent during discussions with industry personnel. While using two crews cannot work on all aspects of the project, it can help condense the schedule to allow for the university to get more usage out of the building at an earlier date. Occasionally an owner can incentivize the GC/CM to complete a project earlier by offering a higher pay for early project completion. There was no such stipulation or clause on this project (although given the information in the next few pages, it should have been heavily urged by Gilbane to have such a clause be applied).

Mr. Robert M. Specter, the VP for Administrative Affairs at University of Maryland was able to offer information on the statistics regarding school revenue. Mr. Specter was able to assist in calculating the theoretical revenue generated by the UMPSC per semester based off of the volume of students who attend the school and the theoretical increase in student volume due to new buildings, like the PSC.

According to information freely collected and released by the school, and Mr. Specter's personal information, the school has approximately 27,000 undergraduates enrolled, and 4,000 graduate students enrolled, as well as 2,000 faculty and staff.[11] Of the 31,000 combined undergraduate and graduate students, the average yearly tuition is $23,500. [12] According to Mr. Specter, the PSC will be responsible for generating an additional 3% of all students and tuition fees. This comes to approximately 22 million dollars yearly. Because the PSC will not be fully operational during the fall semester of 2013, it cannot generate this revenue.

Solution:
The solution to getting the PSC completed earlier is to first negotiate a clause that indicates if the building is finished sooner, that more monies will be collected by Gilbane. Once this can be established, a plan for having two crews on various construction activities must be created.

Appendix C shows a detailed breakdown of the project schedule for the PSC. Much of the work can have two crews working back to back to complete the work. In an ideal situation, certain activities such as millwork would have one crew begin at one location and focus on only that one location, while the other crew focuses on an entirely different location or floor. With this in mind, activities that can accommodate this type of sequencing have had the days tallied up and accounted for overlapping activities.

Taking into account all activities, the total construction time from breaking ground to substantial completion is two years and 3 months. Activities such as steel erection, caisson drilling, and concrete pouring cannot be done using two crews. These activities would violate the local sound ordinance during off hours.[13] As such, they have been removed from the final tally of days involved in activities that can be compressed.

This leaves 1 year and 8 months' worth of activities for multi-shift work schedule compression. The morning crew will begin at 4am and cease at 2pm, and the evening crew will commence at 2pm and cease at 9pm. Although there is 75% more hours' worth of work on a typical day being performed, the ratio of schedule compression is not 75% more. It is instead less because of issues surrounding the coordination between crews, material delivery, and crane usage. A more accurate representation of the efficiency increase by a percentage with days in mind is 50%. This efficiency ratio was calculated using the collective aggregate of various industry personnel who were polled (see credits and acknowledgements at the beginning of this report).

If the two shift crew method is 50% more efficient, then it means the project will compress the 1 year and 8 months into 1 year and 3 months (because a crew that is theoretically 100% more efficient would cut the time in half, therefore a crew that is 50% more efficient cuts the work days down to 75% of the original). This is a savings of 5 months' work time. Factoring this into the total completion schedule for the project that includes the non-workshifted hours' activities, the total start to finish time for this project comes to 1 year and 10 months. This now brings forward the substantial completion of the project from September of 2013 to April of 2013.

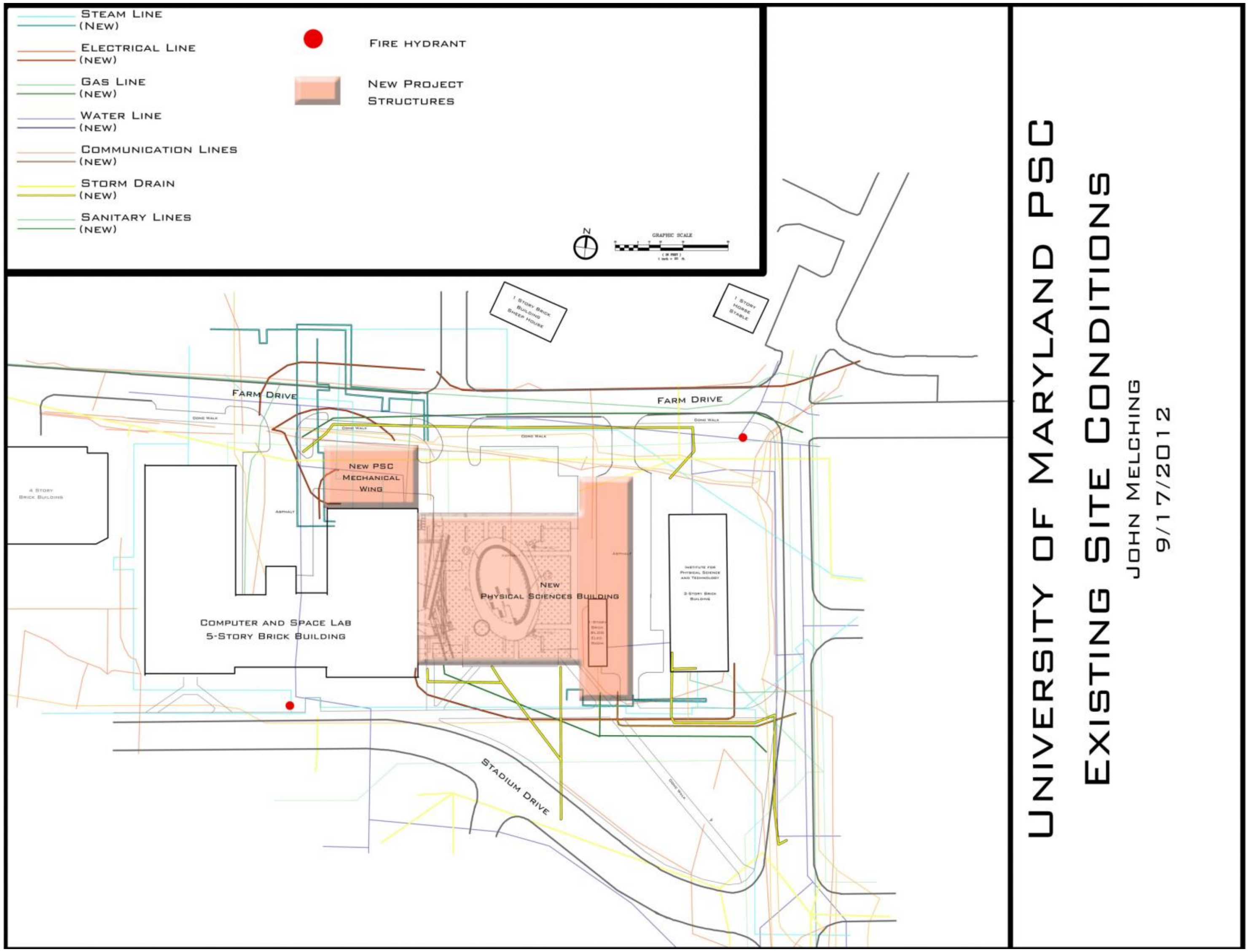
Using the information from Mr. Specter, this is a theoretical revenue increase to the university of approximately 9 million dollars.

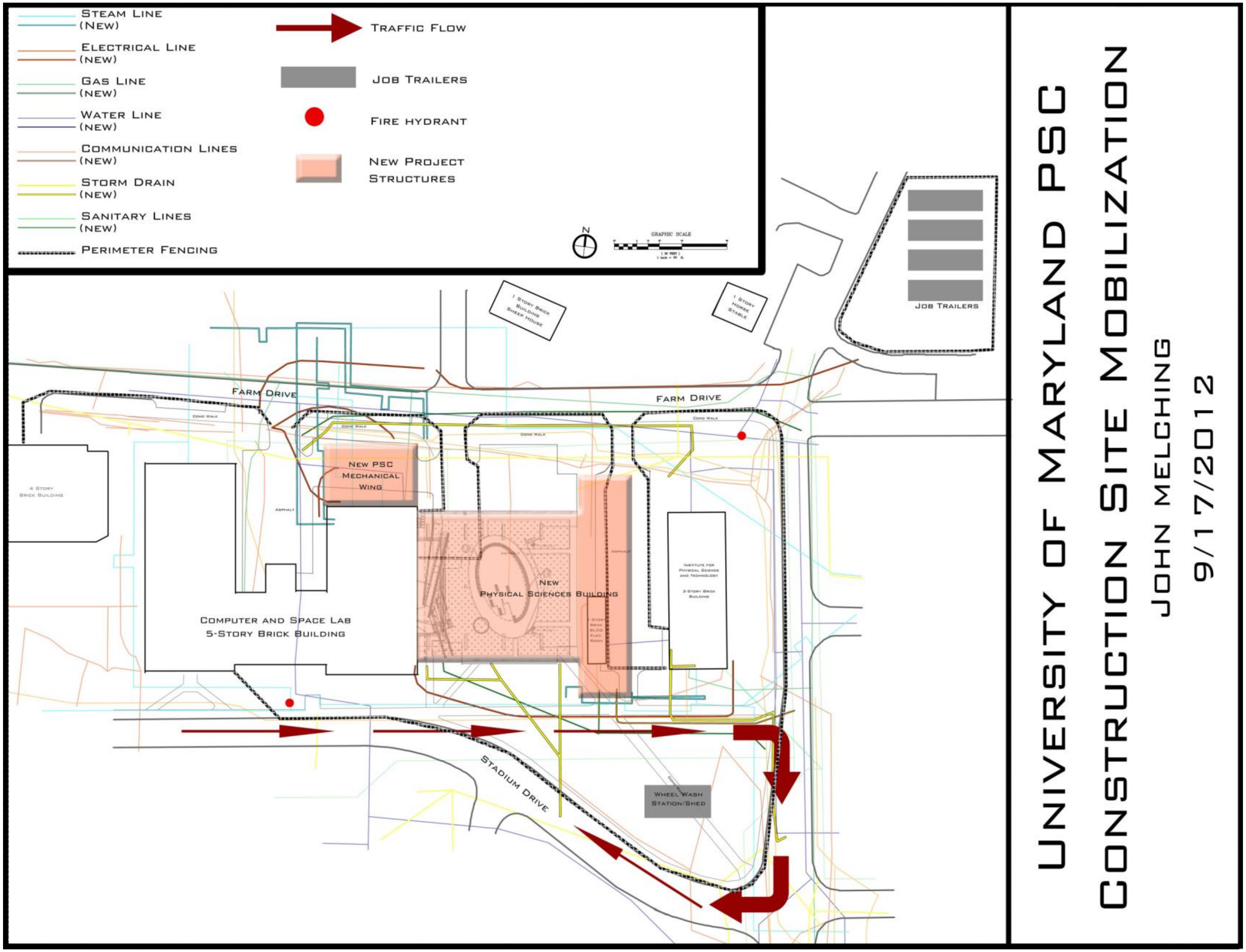
There are obvious costs associated with using multiple crews on a project. However, because different workers will be used between shifts, overtime will not be paid, but partial off hours work time will. This contributes to an increase in approximately 12.5% of installation costs for Gilbane. Installations accounts for approximately 50% of the total construction costs of the project. Of the 67 million dollars for construction, 33.5 of it is installations. Therefore, an increase in 4.2 million dollars would be required by Gilbane to finish installations. Given the fact that the school can see a potential early revenue stream of an additional 9 million dollars, it is extremely advantageous for Gilbane to negotiate an early finish deal for an amount over and above the additional costs incurred by using multi shift crews.

Conclusion/Summary

Although it may be a slight risk to Gilbane to move forward with a multi-shift work schedule, the additional income to be made is significant. Also, given the recent changing climate of worker rates for prevailing wages in the United States regarding unions and benefits, it will be easier for sub-contractors to negotiate worker pay for off-hours, and therefore, issue better quotes to Gilbane, reducing the risk taken on.

Appendix A: Site/Phasing Plans

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Gas Line
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Water Line
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Communication Lines
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Storm Drain
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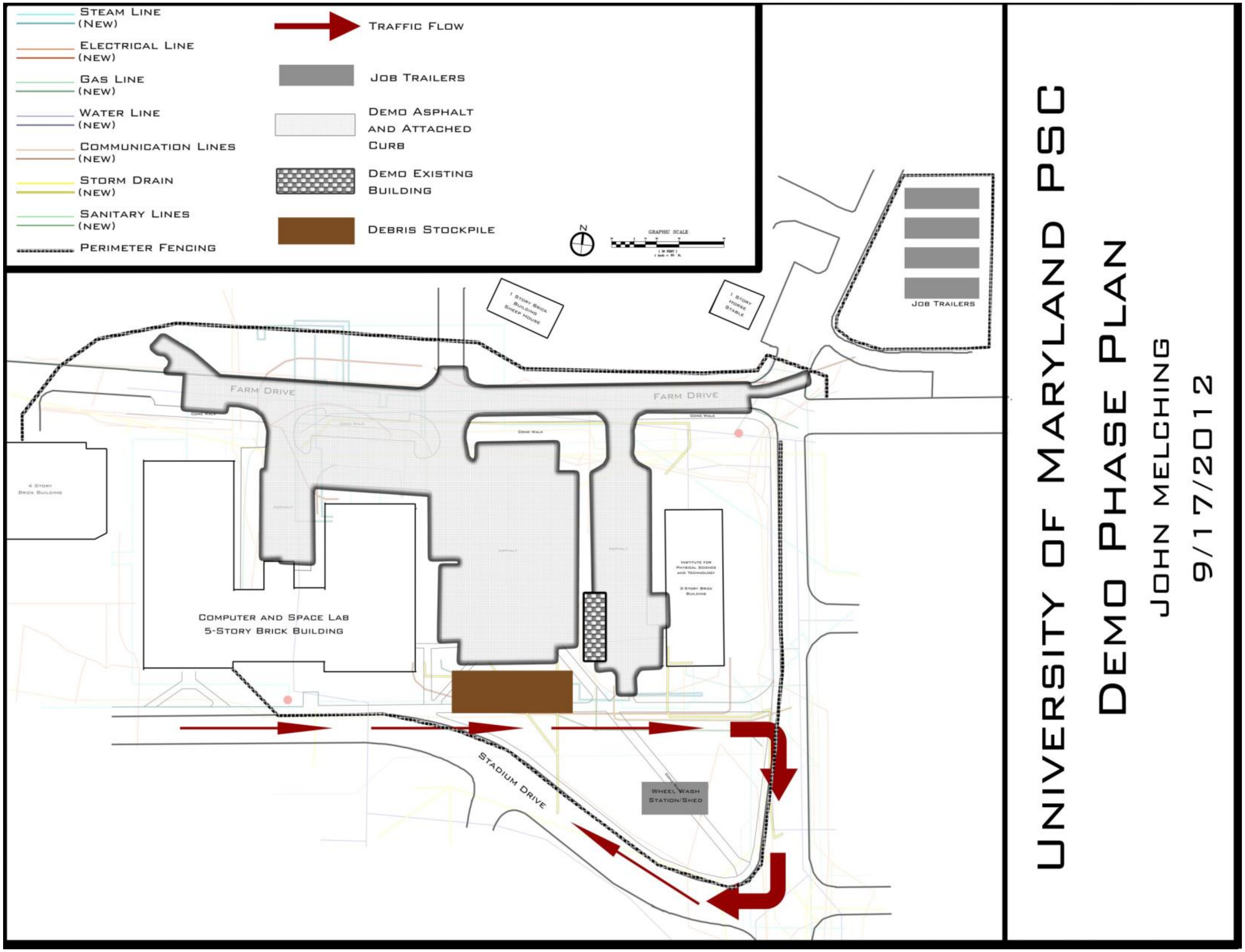
(New)
Perimeter Fencing
Traffic Flow
Job Trailers
Fire Hydrant
New Project
Structures
Job Trailers
Farm Drive
Farm Drive
New PSC
Mechanical
Wing
New
Physical Sciences Building
Computer and Space Lab
5-Story Brick Building
Stadium Drive
Wheel Wash
Station/Shed
University of Maryland PSC
Construction Site Mobilization
John Melching
9/17/2012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COMMUNICATION LINES
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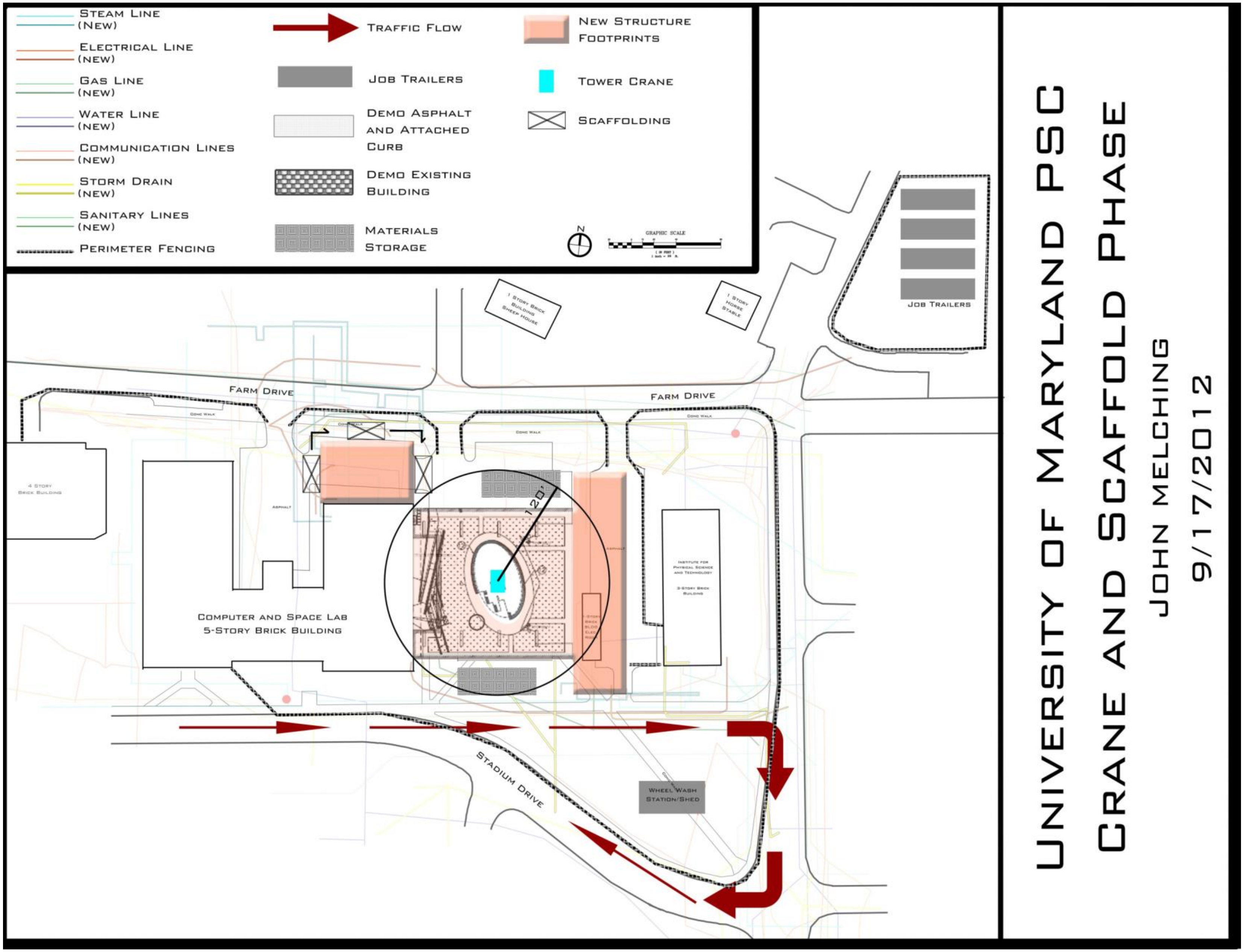
STORM DRAIN
(NEW)
SANITARY LINES
(NEW)
PERIMETER FENCING
TRAFFIC FLOW
JOB TRAILERS
DEMO ASPHALT
AND ATTACHED
CURB
DEMO EXISTING
BUILDING
DEBRIS STOCKPILE
N
JOB TRAILERS
FARM DRIVE
FARM DRIVE
COMPUTER AND SPACE LAB
5-STORY BRICK BUILDING
STADIUM DRIVE
WHEEL WASH
STATION/SHED
UNIVERSITY OF MARYLAND PSC
DEMO PHASE PLAN
JOHN MELCHING
9/17/2012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Water Line
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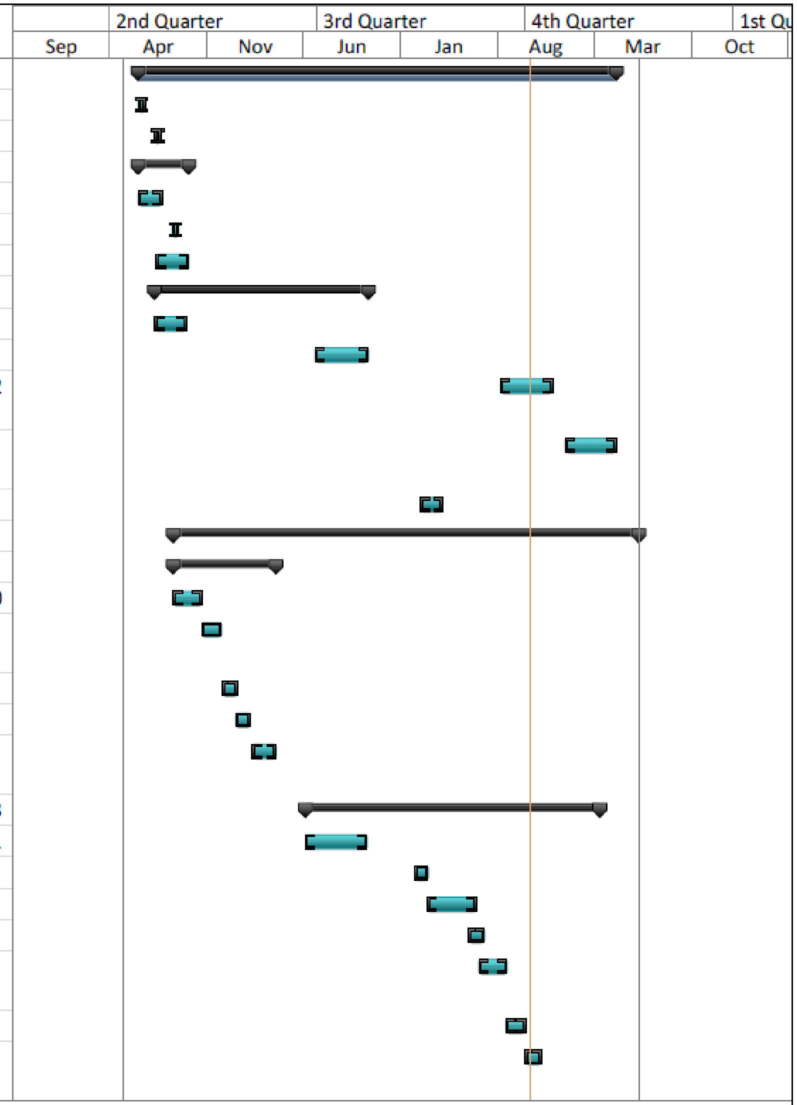
Communication Lines
(New)
Storm Drain
(New)
Sanitary Lines
(New)
Perimeter Fencing
Traffic Flow
Job Trailers
Demo Asphalt and Attached Curb
Demo Existing Building
Materials Storage
New Structure Footprints
Tower Crane
Scaffolding
Farm Drive
Farm Drive
Job Trailers
Computer and Space Lab
5-Story Brick Building
120'
Stadium Drive
Wheel Wash Station/Shed
University of Maryland PSC
Crane and Scaffold Phase
John Melching
9/17/2012

Appendix B: General Conditions Estimate

General Conditions Estimate					
Line Number	Description	Quantity	Unit	Total Incl. O&P	Ext. Total Incl. O&P
13113200120	Field engineer, average	145	Week	$1,875.00	$271,875.00
13113200120	Field engineer, average	145	Week	$1,875.00	$271,875.00
13113200120	Field engineer, average	145	Week	$1,875.00	$271,875.00
13113200200	Field Personnel, project manager, average	145	Week	$3,075.00	$445,875.00
13113200200	Field Personnel, project manager, average	145	Week	$3,075.00	$445,875.00
13113200200	Field Personnel, project manager, average	145	Week	$3,075.00	$445,875.00
13113200220	Field Personnel, project manager, maximum	145	Week	$3,500.00	$507,500.00
13113200260	Field Personnel, superintendent, average	145	Week	$2,850.00	$413,250.00
13113200260	Field Personnel, superintendent, average	145	Week	$2,850.00	$413,250.00
14523500020	Field Testing, for concrete building, costing $1,000,000, maximum	1	Project	$39,166.60	$39,166.60
14523500082	Testing and Inspecting, quality control of earthwork	240	Day	$350.96	$84,230.40
15113800450	Temporary Power, for temp lighting only, 23.6 KWH/month, max	158000	CSF Flr	$3.40	$537,200.00
15213200350	Office Trailer, furnished, rent per month, 32' x 8', excl. hookups	74	Ea.	$213.21	$15,777.54
15419600100	Crane crew, tower crane, static, 130' high, 106' jib, 6200 lb. capacity, monthly use, excludes concrete footing	15	Month	$36,812.20	$552,183.00
15426500030	Hand Operated steel cable hoist, 500lbs capacity	18	Month	$445.45	$8,018.10
15626500250	Temporary Fencing, chain link, rented up to 12 months, 6' high, 11 ga, over 1000'	1800	L.F.	$6.71	$12,078.00
24119230725	Selective demolition, rubbish handling, dumpster, 20 C.Y., 8 ton capacity, weekly rental, includes one dump per week, cost to be added to demolition cost.	155	Week	$770.00	$119,350.00
24119230725	Selective demolition, rubbish handling, dumpster, 20 C.Y., 8 ton capacity, weekly rental, includes one dump per week, cost to be added to demolition cost.	155	Week	$770.00	$119,350.00
	Webcam Services by OxBlue	36	Month	$550.00	$19,800.00
13113300010	Insurance				$936,000.00
13113900010	CM Bonding				$757,000.00
12116000000	CM Contingency				$323,000.00
				Total	**$7,010,403.64**

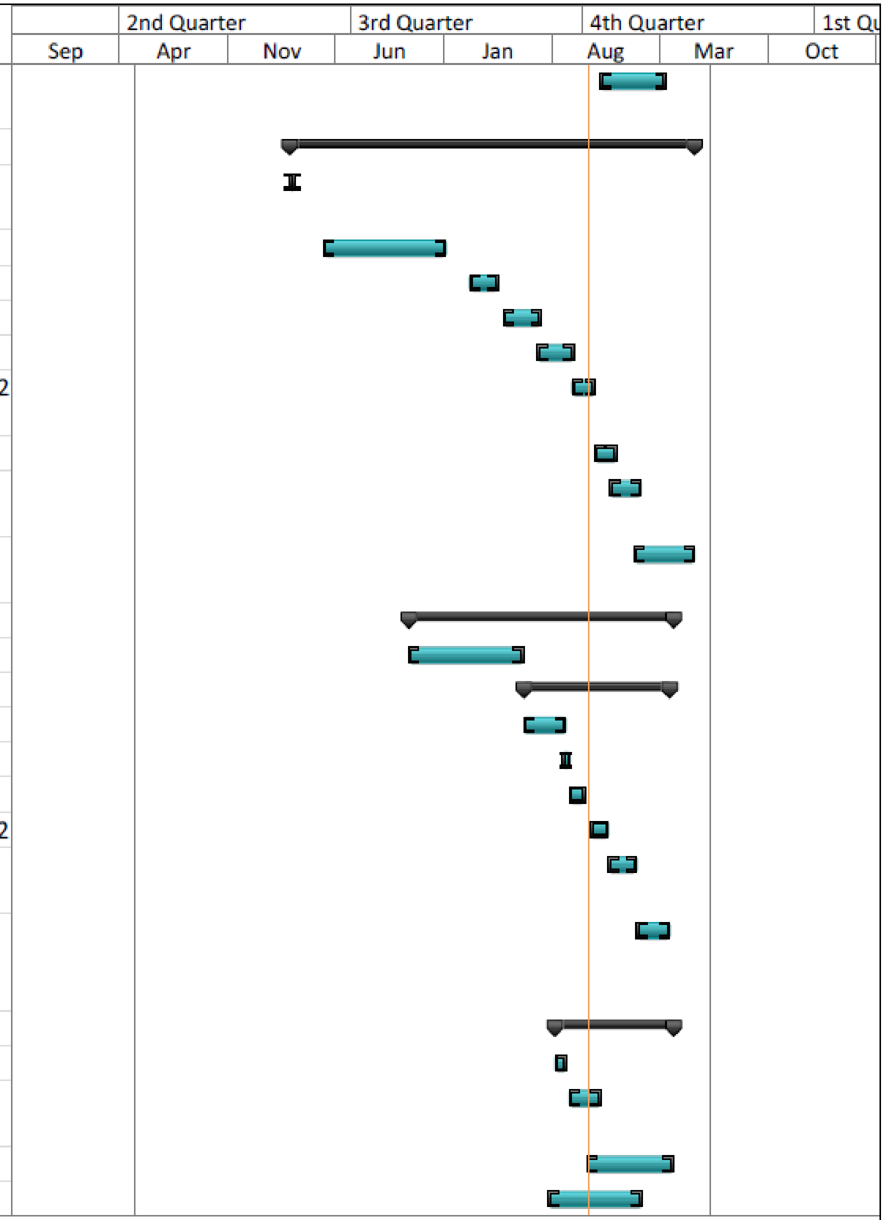
Appendix C: Detailed Schedule

Task Name	Duration	Start	Finish
Sitework	**751 days**	**Thu 6/3/10**	**Thu 4/18/13**
Sediment and Erosion Control	12 days	Thu 6/3/10	Fri 6/18/10
Demo Existing Improvements	10 days	Fri 7/9/10	Thu 7/22/10
North	**79 days**	**Thu 6/3/10**	**Tue 9/21/10**
Install Duct Banks	38 days	Thu 6/3/10	Sun 7/25/10
Temporary Steam	10 days	Tue 8/17/10	Mon 8/30/10
New Utility Lines	51 days	Tue 7/13/10	Tue 9/21/10
South	**336 days**	**Fri 7/9/10**	**Fri 10/21/11**
Install Duct Banks	50 days	Fri 7/9/10	Thu 9/16/10
Excavate & Install New Steam	85 days	Mon 6/27/11	Fri 10/21/11
Plaza East - Retaining wall, Paving, and finishings	82 days	Wed 8/8/12	Thu 11/29/12
Plaza West - Seat wall, paving, drains, furnishings	80 days	Fri 12/28/12	Thu 4/18/13
Permanent site lighting	35 days	Tue 2/14/12	Mon 4/2/12
PSC Main Building	**732 days**	**Thu 8/19/10**	**Fri 6/7/13**
Excavation	**162 days**	**Thu 8/19/10**	**Fri 4/1/11**
Equip. set-up & Delivery	46 days	Thu 8/19/10	Thu 10/21/10
Exc. For Piles, caissons, steam lines	30 days	Fri 10/22/10	Thu 12/2/10
Install Dewatering wells	24 days	Mon 12/6/10	Thu 1/6/11
Install Lagging & guardrail	23 days	Tue 1/4/11	Thu 2/3/11
Drill for Caissons/remove spoils	38 days	Wed 2/9/11	Fri 4/1/11
Sub Basement	**463 days**	**Mon 6/6/11**	**Wed 3/13/13**
Structure	97 days	Mon 6/6/11	Tue 10/18/11
Wall Framing	20 days	Thu 2/2/12	Wed 2/29/12
Duct and Pipe	78 days	Wed 2/29/12	Fri 6/15/12
Insulation and set Equip.	24 days	Wed 5/30/12	Mon 7/2/12
Electrical (Panel Boxes, conduit, in wall)	44 days	Thu 6/21/12	Tue 8/21/12
Finish Walls & Paint	31 days	Mon 8/20/12	Mon 10/1/12
Pull Wire and Set lighting Fixtures	26 days	Mon 10/1/12	Mon 11/5/12

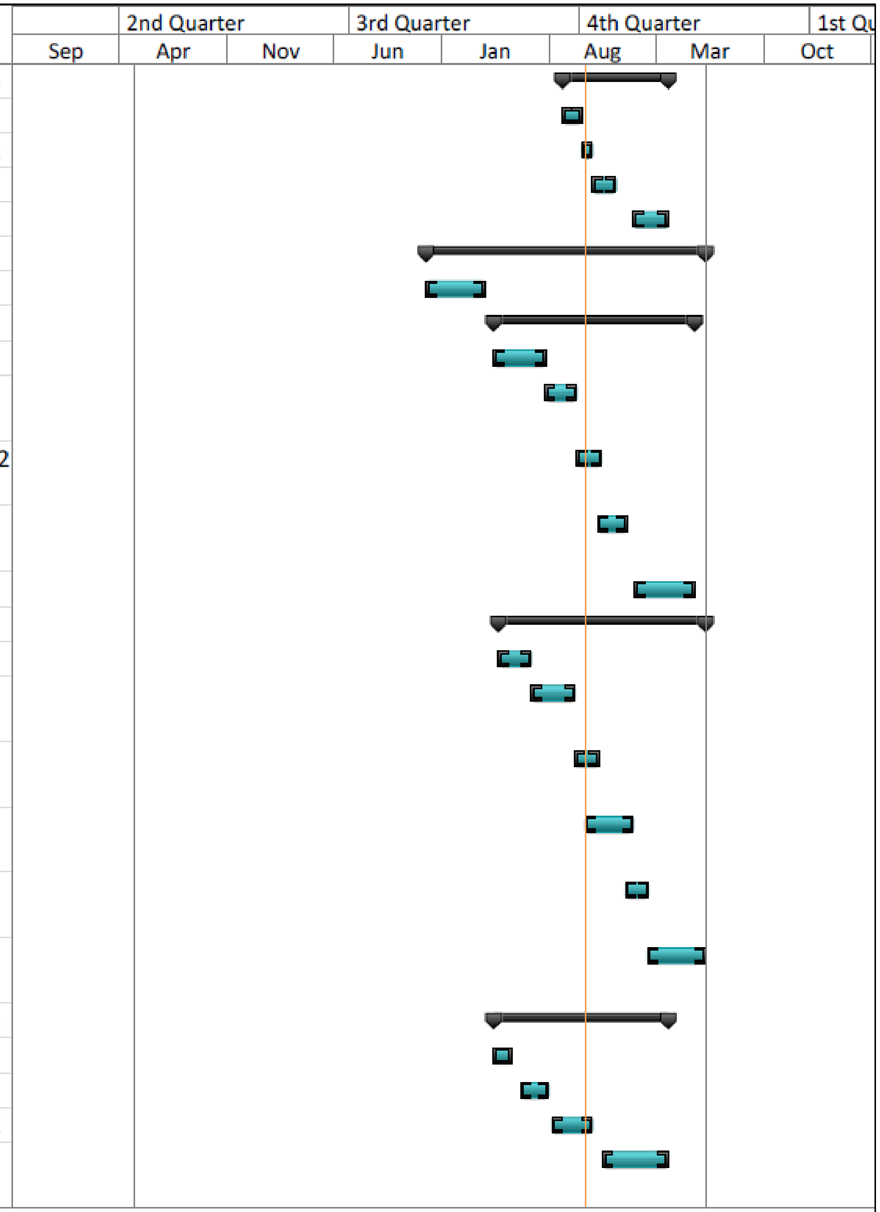


Page 1

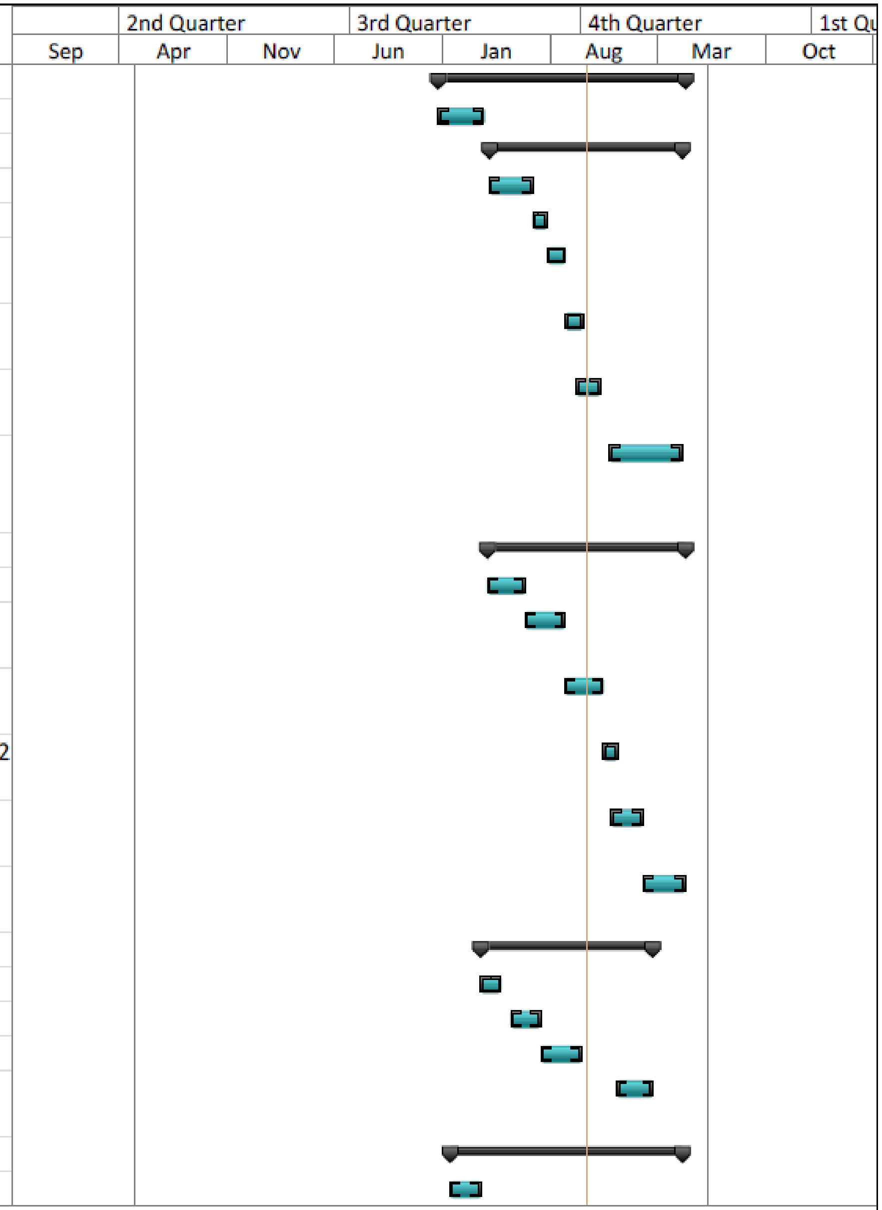
Task Name	Duration	Start	Finish
Install Doors, Casework, and electrical finishes	94 days	Sun 11/4/12	Wed 3/13/13
Basement	**570 days**	**Thu 3/3/11**	**Wed 5/8/13**
Tower Crane Foundation/Build	8 days	Thu 3/3/11	Sat 3/12/11
Structure	173 days	Mon 5/9/11	Wed 1/4/12
Wall Framing	40 days	Tue 2/21/12	Mon 4/16/12
Duct and Pipe	53 days	Fri 4/27/12	Tue 7/10/12
Insulation and set Equip.	52 days	Tue 7/3/12	Wed 9/12/12
Electrical (Panel Boxes, conduit, in wall)	33 days	Mon 9/10/12	Wed 10/24/12
Finish Walls & Paint	31 days	Thu 10/25/12	Thu 12/6/12
Pull Wire and Set lighting Fixtures	44 days	Fri 11/23/12	Wed 1/23/13
Install Doors, Casework, and electrical finishes	85 days	Thu 1/10/13	Wed 5/8/13
Ground Floor	**374 days**	**Mon 10/24/11**	**Thu 3/28/13**
Structure	162 days	Mon 10/24/11	Tue 6/5/12
Office & Collab Space	**205 days**	**Thu 6/7/12**	**Wed 3/20/13**
Install Duct and Plumbing	58 days	Thu 6/7/12	Mon 8/27/12
Wall Framing	12 days	Tue 8/21/12	Wed 9/5/12
In-wall electrical	22 days	Wed 9/5/12	Thu 10/4/12
Finish Walls & Paint	25 days	Tue 10/16/12	Mon 11/19/12
Pull Wire and Set lighting Fixtures	40 days	Tue 11/20/12	Mon 1/14/13
Install Finishes (grills, diffusers, electrical, covers)	47 days	Tue 1/15/13	Wed 3/20/13
Lobby	**168 days**	**Tue 8/7/12**	**Thu 3/28/13**
Install Duct and Plumbing	17 days	Tue 8/7/12	Wed 8/29/12
Field measure and Fab for steel	45 days	Tue 9/4/12	Mon 11/5/12
Flooring and Finishes	123 days	Tue 10/9/12	Thu 3/28/13
Plaza Storefront & fixtures	133 days	Wed 7/25/12	Fri 1/25/13



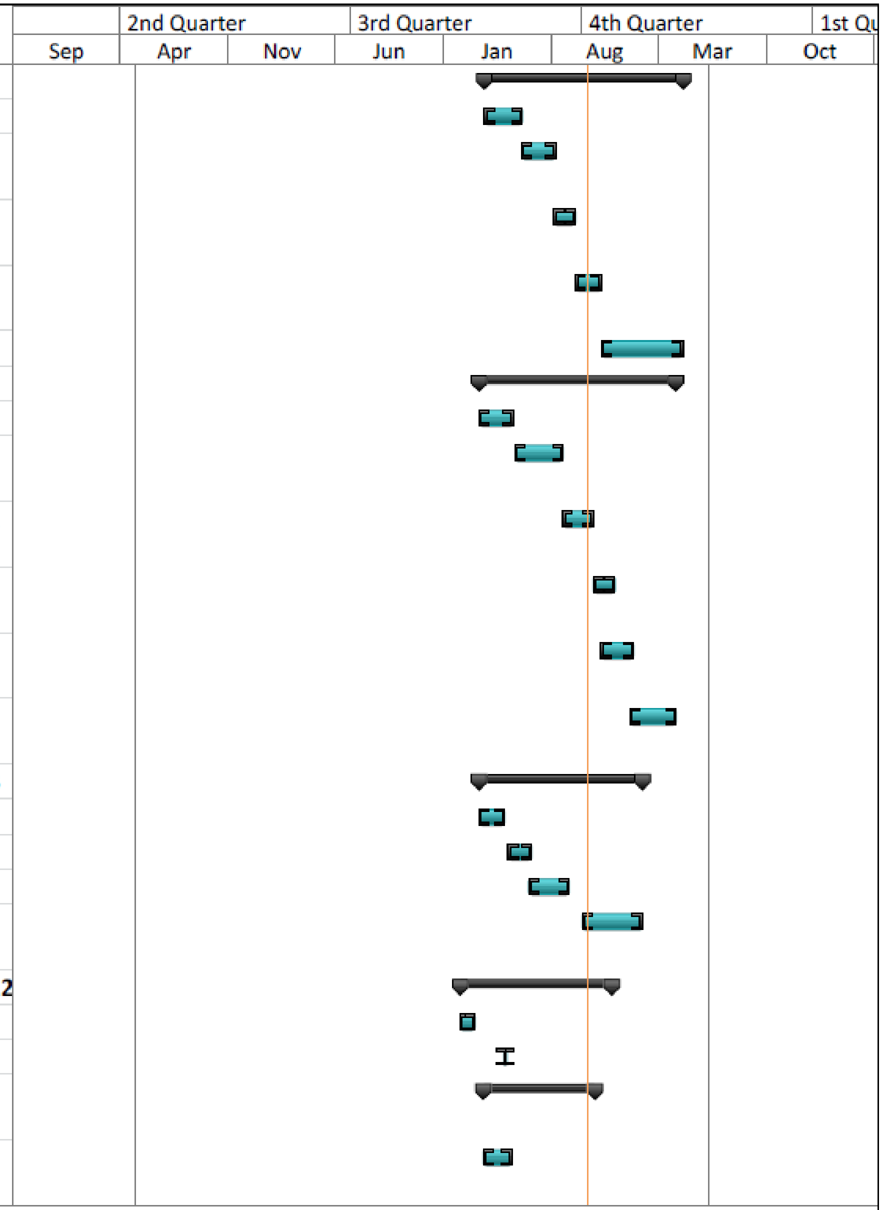
Task Name	Duration	Start	Finish
Bathroom & Kitchen	**150 days**	**Tue 8/28/12**	**Mon 3/25/13**
Install Duct and Plumbing	28 days	Tue 8/28/12	Thu 10/4/12
Wall Framing	15 days	Fri 10/5/12	Thu 10/25/12
In-wall Electrical	33 days	Fri 10/26/12	Tue 12/11/12
Finishes	50 days	Tue 1/15/13	Mon 3/25/13
1st Floor	**397 days**	**Thu 12/1/11**	**Fri 6/7/13**
Structure	83 days	Thu 12/1/11	Mon 3/26/12
Lab Space	**285 days**	**Fri 4/13/12**	**Thu 5/16/13**
Install Duct and Plumbing	74 days	Fri 4/13/12	Wed 7/25/12
Electrical conduit/ Misc HVAC	45 days	Tue 7/24/12	Mon 9/24/12
Hang & finish walls/ finish flooring	35 days	Tue 9/25/12	Mon 11/12/12
Pull electrical and install lighting	43 days	Tue 11/6/12	Thu 1/3/13
Finishes and final Paint	85 days	Fri 1/18/13	Thu 5/16/13
Office Collab Space	**295 days**	**Mon 4/23/12**	**Fri 6/7/13**
Install Duct and Plumbing	47 days	Mon 4/23/12	Tue 6/26/12
Underfloor electrical/ Misc. HVAC	62 days	Wed 6/27/12	Thu 9/20/12
Frame walls & access flooring	35 days	Fri 9/21/12	Thu 11/8/12
Hang & Finish doors and partitions	67 days	Fri 10/12/12	Mon 1/14/13
Pull Electrical and set lighting fixtures	33 days	Mon 12/31/12	Wed 2/13/13
Finishes(ceiling tile, diffusers, coverings)	83 days	Wed 2/13/13	Fri 6/7/13
Bathrooms & MEP closets	**247 days**	**Fri 4/13/12**	**Mon 3/25/13**
Layout and Frame walls	25 days	Fri 4/13/12	Thu 5/17/12
Install Duct & Plumbing	38 days	Thu 6/7/12	Mon 7/30/12
Electrical rough-in	58 days	Tue 8/7/12	Thu 10/25/12
Finishes (grilles, fixtures, devices)	92 days	Fri 11/16/12	Mon 3/25/13



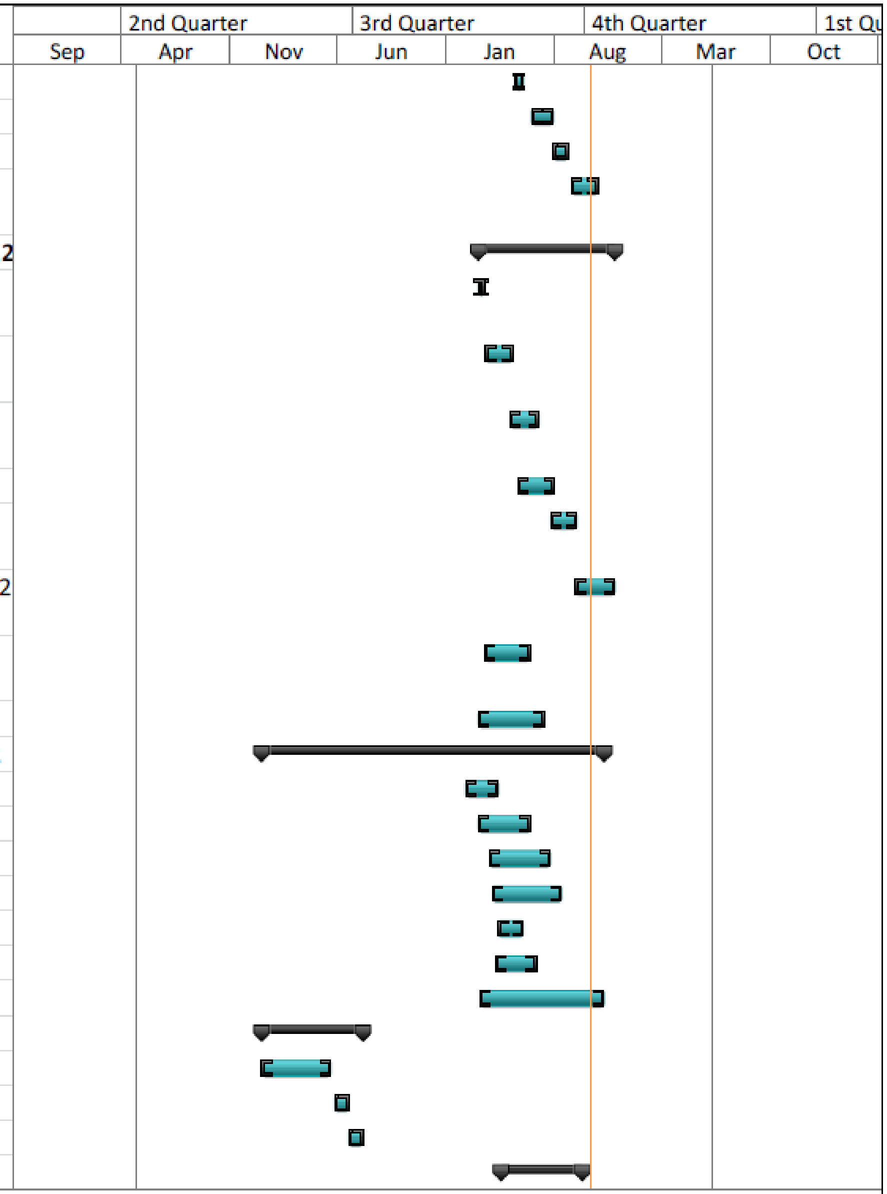
Task Name	Duration	Start	Finish
2nd Floor	**350 days**	**Fri 12/23/11**	**Thu 4/25/13**
Structure	65 days	Fri 12/23/11	Thu 3/22/12
Lab Space	**274 days**	**Tue 4/3/12**	**Fri 4/19/13**
Install Duct and Plumbing	62 days	Tue 4/3/12	Wed 6/27/12
Framing walls & Bulkheads	21 days	Thu 6/28/12	Thu 7/26/12
In-wall electrical & Plumbing	25 days	Fri 7/27/12	Thu 8/30/12
Hang & Finish walls/ finish floor	25 days	Fri 8/31/12	Thu 10/4/12
Pull Electrical wire and install lighting	35 days	Fri 9/21/12	Thu 11/8/12
Finishes (diffusers, coverings, panels, devices)	105 days	Mon 11/26/12	Fri 4/19/13
Office and Collab Space	**280 days**	**Fri 3/30/12**	**Thu 4/25/13**
Install Duct and Plumbing	53 days	Fri 3/30/12	Tue 6/12/12
Underfloor electrical/ Misc. HVAC	56 days	Wed 6/13/12	Wed 8/29/12
Frame walls & access flooring	54 days	Thu 8/30/12	Tue 11/13/12
Hang & Finish doors and partitions	21 days	Wed 11/14/12	Wed 12/12/12
Pull Electrical and set lighting fixtures	46 days	Thu 11/29/12	Thu 1/31/13
Finishes(ceiling tile, diffusers, coverings)	60 days	Fri 2/1/13	Thu 4/25/13
Bathrooms & MEP closets	**243 days**	**Fri 3/16/12**	**Tue 2/19/13**
Layout and Frame walls	28 days	Fri 3/16/12	Tue 4/24/12
Install Duct & Plumbing	44 days	Tue 5/15/12	Fri 7/13/12
Electrical rough-in	58 days	Sat 7/14/12	Tue 10/2/12
Finishes (grilles, fixtures, devices)	51 days	Tue 12/11/12	Tue 2/19/13
3rd Floor	**330 days**	**Mon 1/16/12**	**Fri 4/19/13**
Structure	45 days	Mon 1/16/12	Fri 3/16/12



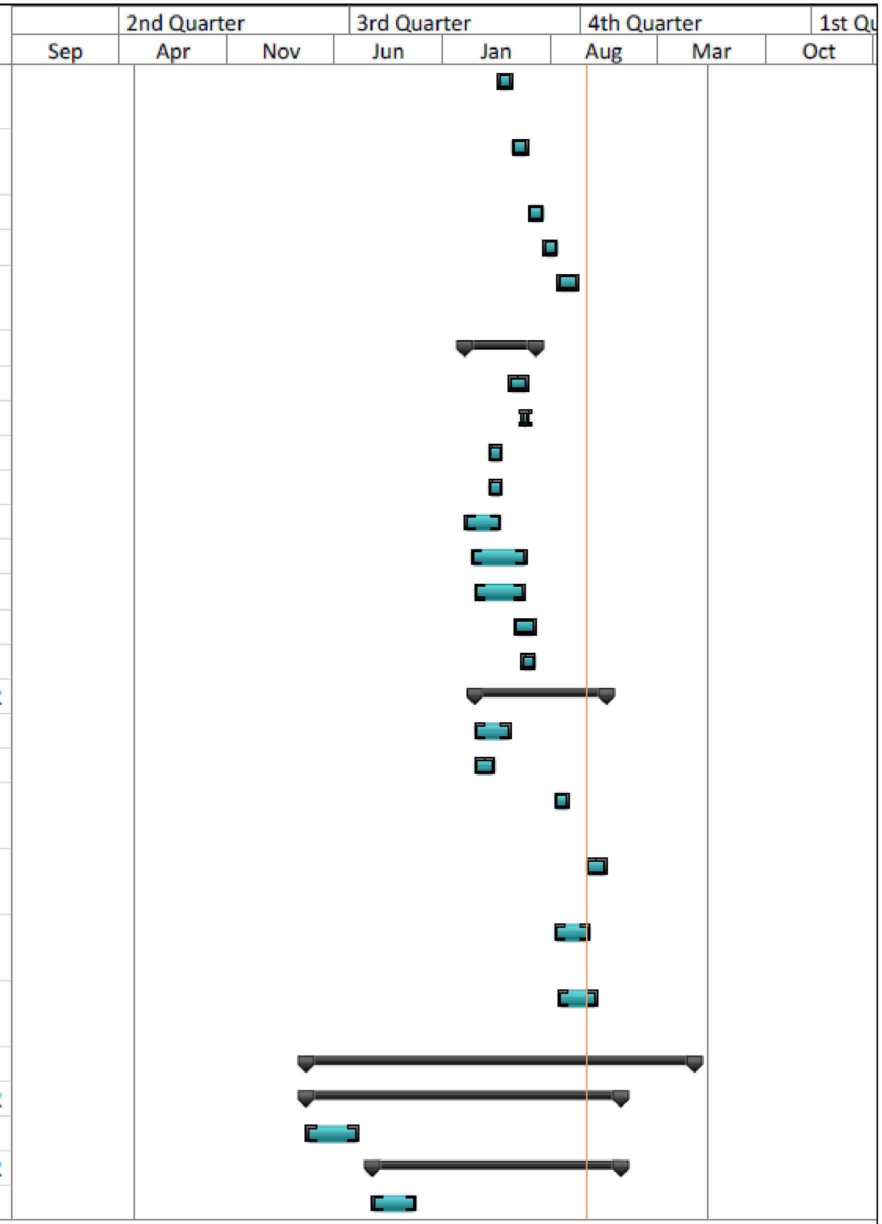
Task Name	Duration	Start	Finish
Lab Space	**282 days**	**Thu 3/22/12**	**Fri 4/19/13**
Install Duct and Plumbing	53 days	Thu 3/22/12	Mon 6/4/12
Electrical conduit/ Misc HVAC	49 days	Mon 6/4/12	Thu 8/9/12
Hang & finish walls/ finish flooring	31 days	Mon 8/6/12	Mon 9/17/12
Pull electrical and install lighting	38 days	Tue 9/18/12	Thu 11/8/12
Finishes and final Paint	116 days	Fri 11/9/12	Fri 4/19/13
Office Collab Space	**279 days**	**Mon 3/12/12**	**Thu 4/4/13**
Install Duct and Plumbing	50 days	Mon 3/12/12	Fri 5/18/12
Underfloor electrical/ Misc. HVAC	68 days	Tue 5/22/12	Thu 8/23/12
Frame walls & access flooring	43 days	Fri 8/24/12	Tue 10/23/12
Hang & Finish doors and partitions	31 days	Wed 10/24/12	Wed 12/5/12
Pull Electrical and set lighting fixtures	47 days	Wed 11/7/12	Thu 1/10/13
Finishes(ceiling tile, diffusers, coverings)	65 days	Fri 1/4/13	Thu 4/4/13
Bathrooms & MEP closets	**231 days**	**Mon 3/12/12**	**Mon 1/28/13**
Layout and Frame walls	36 days	Mon 3/12/12	Mon 4/30/12
Install Duct & Plumbing	34 days	Tue 5/8/12	Fri 6/22/12
Electrical rough-in	58 days	Mon 6/18/12	Wed 9/5/12
Finishes (grilles, fixtures, devices)	85 days	Tue 10/2/12	Mon 1/28/13
Roof Level	**214 days**	**Fri 2/3/12**	**Wed 11/28/12**
Structure	21 days	Fri 2/3/12	Fri 3/2/12
Remove Tower Crane	5 days	Mon 4/30/12	Fri 5/4/12
Elevator Machine/ Control Room	**159 days**	**Tue 3/20/12**	**Fri 10/26/12**
Framing & Sheathing, Concrete	40 days	Tue 3/20/12	Mon 5/14/12



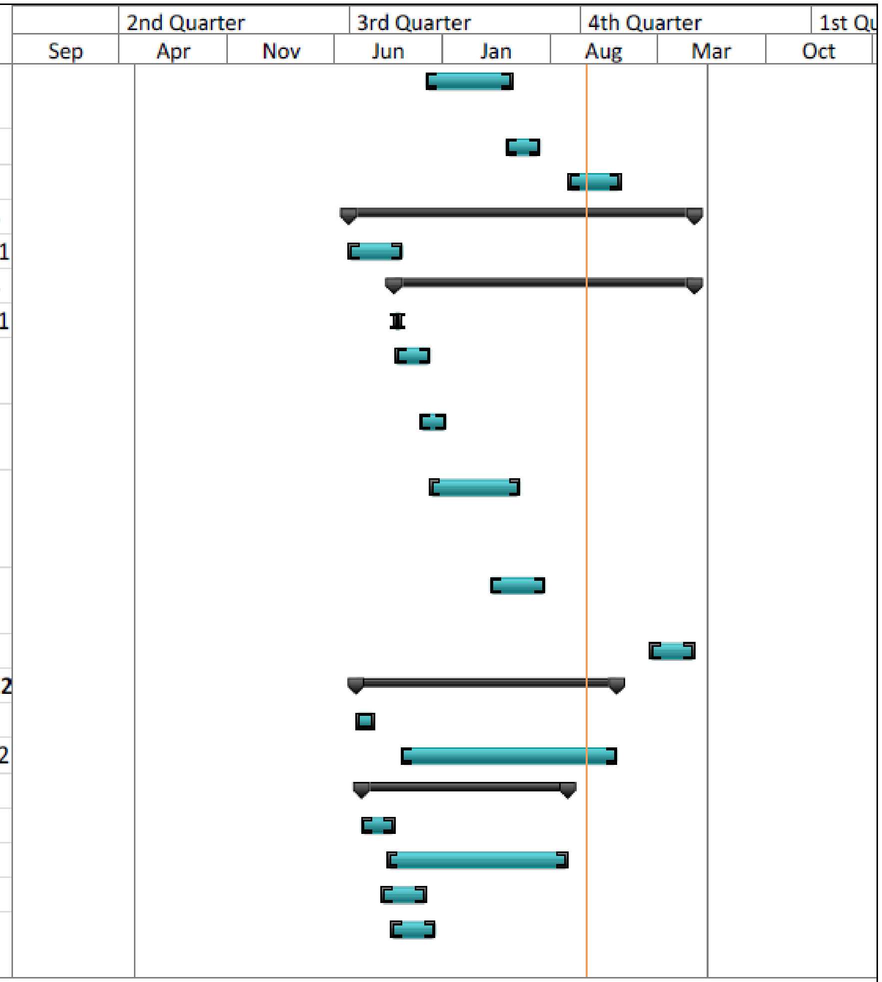
Task Name	Duration	Start	Finish
Insulation & Metal Panels	13 days	Wed 5/16/12	Fri 6/1/12
Electrical Conduit	31 days	Mon 6/18/12	Mon 7/30/12
Pull Wire	21 days	Tue 7/31/12	Tue 8/28/12
Terminate Panels & Final Paint	38 days	Wed 9/5/12	Fri 10/26/12
Lab Roof	**193 days**	**Mon 3/5/12**	**Wed 11/28/12**
Set AHU's and other Equip.	10 days	Mon 3/5/12	Fri 3/16/12
Install Tubesteel and Roofing	40 days	Mon 3/19/12	Fri 5/11/12
Install Metal Panels & Roof Hatch	41 days	Mon 5/7/12	Sun 7/1/12
Roof Ductwork & Insulation	52 days	Tue 5/22/12	Wed 8/1/12
HVAC Connections & termination	37 days	Thu 7/26/12	Fri 9/14/12
Electrical Connections & Testing	56 days	Wed 9/12/12	Wed 11/28/12
Equipment Start-up for Construction	65 days	Sun 3/18/12	Thu 6/14/12
Office Roof	94 days	Mon 3/5/12	Thu 7/12/12
Façade	**483 days**	**Mon 1/3/11**	**Wed 11/7/12**
Structure	46 days	Thu 2/9/12	Thu 4/12/12
Column Line 8 & North El.	75 days	Mon 3/5/12	Fri 6/15/12
East El.	86 days	Tue 3/27/12	Tue 7/24/12
Column Line 8 & South El.	97 days	Tue 4/3/12	Wed 8/15/12
West El.	35 days	Fri 4/13/12	Thu 5/31/12
Ellipse/Light Shaft	58 days	Mon 4/9/12	Wed 6/27/12
Install & operate Hoist	174 days	Fri 3/9/12	Wed 11/7/12
Mock-up	**144 days**	**Mon 1/3/11**	**Thu 7/21/11**
Submittals	98 days	Mon 1/3/11	Wed 5/18/11
Construct	20 days	Fri 5/27/11	Thu 6/23/11
Review & Approve	20 days	Fri 6/24/11	Thu 7/21/11
Elevators	**114 days**	**Thu 4/19/12**	**Tue 9/25/12**



Task Name	Duration	Start	Finish
Install EMI Shielding (shaft 1)	21 days	Thu 4/19/12	Thu 5/17/12
Install EMI Shielding (shaft 2)	22 days	Fri 5/18/12	Mon 6/18/12
Install Rails and Belts	22 days	Tue 6/19/12	Wed 7/18/12
Finish Rails & Counterweight	20 days	Thu 7/19/12	Wed 8/15/12
Build Cab & Wire (Fire Alarms etc)	29 days	Thu 8/16/12	Tue 9/25/12
MEP Risers	**101 days**	**Tue 2/14/12**	**Tue 7/3/12**
Electrical	27 days	Fri 5/11/12	Mon 6/18/12
Fire Alarm	11 days	Tue 6/5/12	Tue 6/19/12
Office Mechanical Duct	20 days	Mon 4/2/12	Fri 4/27/12
Men's Room Duct	20 days	Mon 4/2/12	Fri 4/27/12
Plumbing	51 days	Tue 2/14/12	Tue 4/24/12
Stair 1 Risers	79 days	Tue 2/28/12	Fri 6/15/12
Stair 2 Risers	71 days	Mon 3/5/12	Mon 6/11/12
Sprinkler	31 days	Tue 5/22/12	Tue 7/3/12
Security/Telecom	20 days	Tue 6/5/12	Mon 7/2/12
Stairs	**187 days**	**Mon 3/5/12**	**Tue 11/20/12**
Stair 1 Measure/Fab/Install	51 days	Mon 3/5/12	Mon 5/14/12
Stair 2 Measure/Fab/Install	29 days	Mon 3/5/12	Thu 4/12/12
Stair 3 Metal and Glass railings/treads	21 days	Fri 8/10/12	Fri 9/7/12
Stair 4 Metal and Glass railings/treads	28 days	Fri 10/12/12	Tue 11/20/12
Stair 5 Construct/Hang & Finish	50 days	Fri 8/10/12	Thu 10/18/12
Stair 6 Construct/Hang & Finish	55 days	Fri 8/17/12	Thu 11/1/12
Mechanical Building	**549 days**	**Wed 4/6/11**	**Mon 5/13/13**
Basement	**445 days**	**Wed 4/6/11**	**Tue 12/18/12**
Structure	74 days	Wed 4/6/11	Mon 7/18/11
MEP Equipment	**352 days**	**Mon 8/15/11**	**Tue 12/18/12**
Pad and Set equipment	62 days	Mon 8/15/11	Tue 11/8/11



Task Name	Duration	Start	Finish
Connect/Conduit/pull wire	124 days	Tue 11/29/11	Fri 5/18/12
Equipment testing	49 days	Sun 5/6/12	Wed 7/11/12
Flush/Start-up/Sign-off	74 days	Thu 9/6/12	Tue 12/18/12
Upper Basement	**489 days**	**Wed 6/29/11**	**Mon 5/13/13**
Structure	76 days	Wed 6/29/11	Wed 10/12/11
MEP Equipment	**425 days**	**Tue 9/27/11**	**Mon 5/13/13**
CMU Walls	10 days	Tue 9/27/11	Mon 10/10/11
Pad and Set equipment	48 days	Fri 9/30/11	Tue 12/6/11
Conduit & Rough-in	36 days	Fri 11/18/11	Fri 1/6/12
Ductwork, Plumbing, and Insulation	127 days	Wed 12/7/11	Thu 5/31/12
Pull Wire & Terminate	77 days	Thu 4/5/12	Fri 7/20/12
Start-up/Testing/Sign-off	62 days	Fri 2/15/13	Mon 5/13/13
Ground Floor	**368 days**	**Thu 7/14/11**	**Mon 12/10/12**
Structure	26 days	Thu 7/14/11	Thu 8/18/11
MEP Equipment	305 days	Tue 10/11/11	Mon 12/10/12
2nd Floor	**292 days**	**Mon 7/25/11**	**Tue 9/4/12**
Structure	47 days	Mon 7/25/11	Tue 9/27/11
MEP Equipment	255 days	Wed 9/14/11	Tue 9/4/12
Roofing & roof Hatch	63 days	Fri 9/2/11	Tue 11/29/11
CMU/Brick Façade & waterproofing	63 days	Wed 9/21/11	Fri 12/16/11



Appendix D: Detailed Façade Cost Estimate

SQFT Quantities														
		Framing					Installation		Glass (Insulated)					
Zone	Influence SQFT	Straight	Segmented	Gasket/Seal	Unitize	Delivery	Interior	Exterior	1" Clear/Vision	1" Color	Alum. Metal Panel	Alum. Sunshade	Operable Windows	Final Seal/ Inspection
1	6500	6500	0	6500	6500	6500	0	6500	3600	1200	1600	630	700	6500
2	6500	6500	0	6500	6500	6500	0	6500	3600	1200	1600	0	700	6500
3	2400	0	2300	2300	2300	2300	2400	0	1035	1265	0	0	0	2400
4	2400	0	2300	2300	2300	2300	2400	0	1080	1320	0	0	0	2400
5	2600	0	2600	2600	2600	2600	2600	0	1508	1092	0	0	0	2600
6	2600	0	2600	2600	2600	2600	2600	0	1690	910	0	0	0	2600
7	6030	6030	0	6030	6030	6030	0	6030	2715	2109	1206	585	120	6030

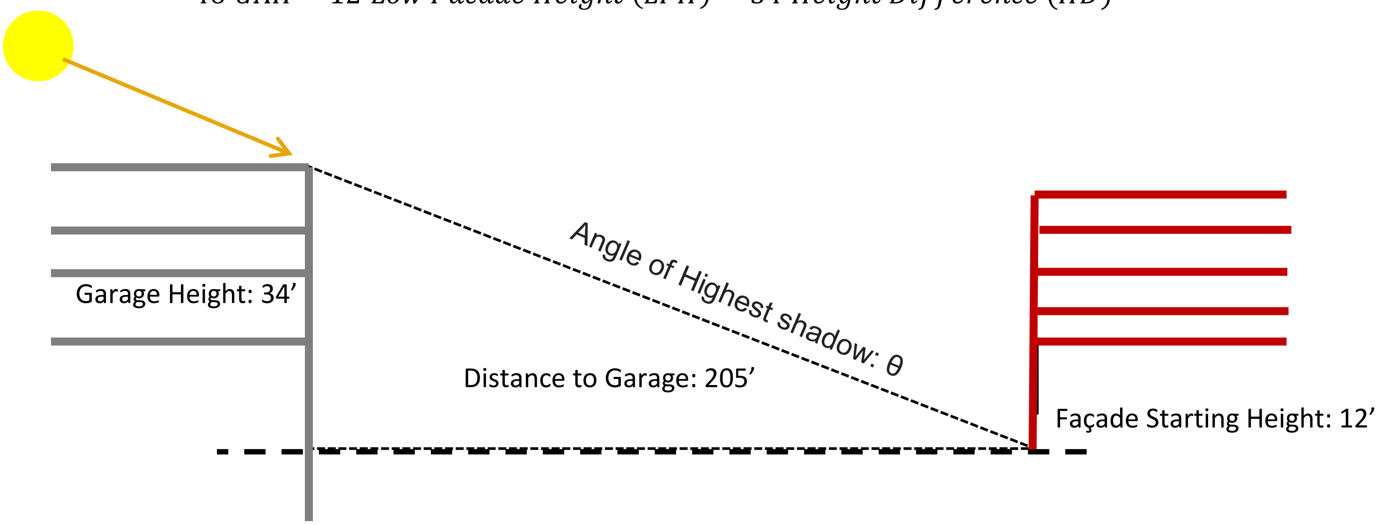
Zone	Influence SQFT	Cost/SQFT of Component													Subtotal Cost	Subtotal Cost/SQFT
		$36	$58	$9	$45	$6	$59	$36	$18	$31	$27	$108	$32	$7		
1,2	13000	$468,000	$0	$117,000	$585,000	$78,000	$0	$468,000	$129,600	$74,400	$86,400	$68,040	$44,800	$91,000	$2,210,240	$170
3,4,5,6	10000	$0	$568,400	$88,200	$441,000	$58,800	$590,000	$0	$95,634	$142,197	$0	$0	$0	$70,000	$2,054,231	$205
7	6030	$217,080	$0	$54,270	$271,350	$36,180	$0	$217,080	$48,870	$65,379	$32,562	$63,180	$3,840	$42,210	$1,052,001	$174
Punch-in Windows	3653														$401,830	$110
Total Cost	**32683**	**$468,000**	**$568,400**	**$205,200**	**$1,026,000**	**$136,800**	**$590,000**	**$468,000**	**$225,234**	**$216,597**	**$86,400**	**$68,040**	**$44,800**	**$161,000**	**$5,718,302**	**$175**

Zone	Description
1	South elevation, metal and glass curtainwall
2	North elevation, metal and glass curtainwall
3	Interior, elliptical curtain wall. Quadrant 1 on sheet A5.23
4	Interior, elliptical curtain wall. Quadrant 4 on sheet A5.23
5	Interior, elliptical curtain wall. Quadrant 2 on sheet A5.23
6	Interior, elliptical curtain wall. Quadrant 3 on sheet A5.23
7	East Elevation, metal and glass curtainwall (includes wrap around)

Punch-in window type	Count	SQFT/Window	Subtotal SQFT
W1	27	63	1701
W2	23	74	1702
W4	2	125	250
		Total SQFT	3653
		Cost/SQFT	$110
		Total Cost	**$401,830**

Appendix E: Solar Angle Design Calculations

$$40' \, Garage\ Height + 6' \, Topo\ difference = 46' \, Garage\ Absolute\ Height (GAH)$$
$$46' \, GAH - 12' \, Low\ Facade\ Height\ (LFH) = 34' \, Height\ Difference\ (HD)$$



$$Tan\theta = \frac{34'}{205'}$$
$$\theta = 16.5°$$

Appendix F: HCPV Energy Calculations

$$850\frac{W}{m^2}\ Avg.Irradiance\ *\ .40\ efficiency * .57\ sun\ exposure = 193.8\frac{W}{m^2}\ Actual\ Irr.$$

$$193.8\frac{W}{m^2}\ Actual\ Irr.\ * 24\ \frac{Hours}{Day} =\ 4651\,Wh/m^2/Day$$

$$\frac{4651\,Wh/m^2/Day}{1000\ \frac{W}{kW}} = \mathbf{4.65\ \boldsymbol{kWh/m^2/Day}}$$

$$4.65\ kWh/m^2/Day * 370m^2\ Facade\ Size\ * 365\ \frac{Days}{Year} = \mathbf{627,982}\frac{\boldsymbol{kWh}}{\boldsymbol{Year}}$$

$$627{,}982\frac{kWh}{Year} * .135\frac{\$}{kWh} = \$\mathbf{84,778}\ \boldsymbol{Theoretical\ Energy\ Savings}$$

Appendix G: References

1) U.S. Naval Observatory, *Astronomical Information Center and Applications Department* http://aa.usno.navy.mil/data/docs/AltAz.php
2) Current Results Research News & Science Facts, *Amount of Sunshine Maryland Gets Each Month* http://www.currentresults.com/Weather/Maryland/sunshine-by-month.php
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4) Light Farm, *Façade Light Harvesting System* http://www.mohsen-saleh.com/2011/10/light-farm.html
5) Hi-Globe, Sustainable New Technology, http://hi-globe.com/
6) Suntrix HCPV Vendor http://www.suntrix.cn/
7) CETC International, *Envoltek S5K 5KW HCPV* http://www.cetci.com.cn/article_product.aspx?id=482
8) Ecodirect, *PV Power Inverters* *http://www.ecodirect.com/PV-Powered-PVP100kW-480-100kW-480-VAC-p/pv-powered-pvp100kw-480.htm*
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12) University of Maryland, Costs http://www.admissions.umd.edu/costs/
13) Noise in Our Community, College Park Public Service Center http://www.collegeparkmd.gov/document_center/PublicServices/Other/2012_Noise_with_new_County_code.pdf