



The Millennium Science Complex

The Pennsylvania State University

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Proposal
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Executive Summary

The following proposal provides an overview of the proposed redesigns and analyses that *BIMception*, composed of Stephen Pfund, Christopher Russell, Alexander Stough, and Thomas Villacampa, will research and produce in the spring of 2011 for the Millennium Science Complex. The purpose of this proposal is to outline redesigns for the existing building that are more energy-efficient, cost-effective, and provide the owner with a building that is of a higher value. A highly integrated approach has been taken to determine designs that will be researched for this project. Building information modeling will be heavily used as a tool to facilitate analysis.

Within this proposal, three main areas of focus have been determined for analysis. These interests were chosen as they provide opportunities for input from multiple disciplines, furthering the need for an integrated approach. These areas include the following:

1. Analysis of the building envelope with the intent to design a façade that is more efficient for both the mechanical, lighting, and structural systems.
2. Investigation into the ceiling plenum space with the intent to examine the value of reducing structural depth through a redesign, reducing operational energy consumption and/or reducing floor-to-floor height.
3. Redesign of the structural framing of the cantilever, as well as the exterior lighting system in the plaza below.

While the existing façade of the Millennium Science Complex works for the intents of the existing mechanical and lighting systems, modifying components of the building enclosure can lead to more efficient systems. Based on this, an analysis of the precast panel materials, glass ratio, and light shelf will be conducted to determine the optimal assemblies for both the lighting and mechanical systems. This decision will be used to analyze energy consumption relating to life cycle cost, with the intent to compare to the existing systems. The structural connections of the precast panels will be analyzed and redesigned to accommodate the new panel composition and the connection to the exterior structure.

The driving force behind the investigation of the plenum space is a structural redesign entailing a change from the existing structural framing to “three-building” design. This design is focused on redesigning the structural gravity system by maintaining the steel framing of the cantilever, but using a concrete system for the wings. The purpose of this design is to investigate potential reductions of the structural depth within the plenum space. Based on the space gained through this redesign, the mechanical system will be analyzed to investigate the opportunity to save fan energy by increasing duct size. The benefits of adjusting duct size will be determined through energy consumption and life cycle cost. An analysis of these results will also be conducted to compare to the benefits of reducing floor-to-floor height.

The cantilever of the Millennium Science Complex is the key architectural focal point of the building. An open-air plaza has been designed for the location below the cantilever, which includes an exterior lighting system. This system will be redesigned with the intent to create a more appealing space to walk in the plaza. The structural framing within the cantilever will also be analyzed with the intent of producing a truss system that is equally effective at a reduced cost. An analysis will be conducted to determine if the diagonal braces in the trusses can be changed from compression to tension members in the pursuit of a strength controlled truss design and the benefits of doing so if possible. Changes made to the cantilever layout as well as the concrete redesign of the wings will also prompt a full redesign of the lateral resisting elements.

Cost, schedule and site logistic implications will be assessed for all design decisions, and will be used as additional measures to determine the benefits of the redesigns. It is the responsibility of all team members to maintain an integrated approach to all design decisions. Integration of the disciplines is the most important aspect of this proposal, and will be monitored closely. All decisions will have implications for other disciplines and must be balanced accordingly to determine a product that is most beneficial for the entire building solution.

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Project Background

The Millennium Science Complex is a 275,600 square foot, four-level research facility that will combine both the Huck Institute of Life Sciences and Material Sciences in one location. The project is owned by The Pennsylvania State University, and is located on the University Park campus at the intersection of Pollack and Bigler Roads, as seen in Figure 1. The building's signature feature is a 150-foot cantilever which extends from the connection of the two wings at the main entrance, and extends over an open air public plaza. The project is targeted to achieve a LEED certification upon completion of construction. This project contains several unique features in addition to the cantilever. These include 20,000 square feet of vivarium space, 40,000 square feet of quiet laboratories, and 9,500 square feet of Nano-clean rooms. Fully isolated labs are located below the exterior public plaza, and have extreme sensitivity and vibration requirements that must be adhered to.

There are four occupiable floors, including the basement, with one level of mechanical on the fourth floor. The basement, directly accessed by the loading dock, contains three, fully isolated research labs. The first through third floors have a typical floor plan. Each wing has a central hallway surrounded by laboratories and student offices at the perimeter. Green roofs are located on the floors two, three, and four. The third floor of the Millennium Complex, roughly 45,000 SF, was selected as the focus of the building for this analysis and will be more strictly studied throughout the progression of our research. This floor provides a unique opportunity to study both life and material science laboratories, while incorporating common offices and conference rooms. The third floor is within the scope of a detailed analysis while providing complex interactions between all disciplines. While the whole building will be considered on a holistic level, actual calculations, coordination, and analyses in this report focus solely on the third floor.

Architecture

The intent of the design of this project was to make an architectural statement, and that's exactly what Rafael Viñoly Architects accomplished with this design. The building, which is an "L" shape, incorporates two separate wings combined at the intersection of the two by a 150-foot cantilever protruding towards the Life Sciences Building. In addition to this cantilever, the building contains cantilevered portions at the end of each wing, and was designed to step down from the top mechanical level to the bottom level at the end of each wing. Combine this design with the prominent horizontal lines portrayed by the long strips of windows and brick and precast concrete panels in the enclosure, and the image of a building floating above the landscape is created. Incorporated into the steps of the roof of the building are the five green roofs, which help push this project towards obtaining a LEED certification.



Figure 1: View of Millennium Science Complex from corner of Pollack and Bigler Roads

Building Enclosure

A complex pre-cast panel system comprises the majority of the Complex's building enclosure. Figure 2 shows a mockup of this system. Each of the 338 precast pieces were fabricated in York, PA and trucked to the site. The exterior is clad in "Penn State" brick with bands of recessed dark-fired brick adhered to 6" of concrete. This panel is backed by 4" of rigid insulation and a vapor barrier. Each 22' panel is supported against vertical loads by a bearing connection and lateral loads by a lateral connection. The bearing connection of each panel consists of a steel plate cast in the interior face of the precast panel resting on a steel gusset plate bolted to a steel column. The lateral connection consists of a threaded rod cast in the lower horizontal lip of each precast panel and then bolted to a steel member. Between each precast section, two lites of glass are broken by an exterior shading device, meant to help control solar heat gain and glare, while adding a valuable aesthetic feature. The lower vision lite wraps around the entire building providing views to the exterior, while the upper lite is fritted and meant to improve day lighting. A system of metal panels and storefront glazing encloses the building around the landscaped exterior atrium.



Figure 2: Mockup of building enclosure, including pre-cast panels

The roofing system, once designed to be the largest green roof in the United States, will span 60,000 sq. ft. This extensive sedum green roof will require a shallow depth of soil and drainage, and will be waterproofed from the concrete structure below. The mechanical penthouse will not have a green roof, rather it will be built of rigid insulation covered by a black EPM waterproofing membrane.

The vibration isolated laboratories located under the exterior atrium will be enclosed in a system unique to the building. As these labs are located underground, they will be surrounded by 24" of concrete to mitigate sound and vibration transmittance, while providing moisture protection and thermal resistance.

Construction Management

Preconstruction activities for the Millennium Science Complex began in March 2008, with construction beginning in June 2008. With an expected completion date of June 31, 2011, the project will have a construction duration of just less than three calendar years. The approximate total cost of the project has been reported as \$215 million, with construction costs totaling approximately \$140 million. The project is being produced with a Design-Bid-Build delivery system, but with the Construction Manager, The Whiting-Turner Company, acting as both a CM Agent and a CM-at-risk. This setup is due to the fact that The Pennsylvania State University is receiving Department General Services (DGS) funding for a large percentage of the project. Due to this funding, the owner must hold contracts with all contractors under public funding, which Whiting-Turner then oversees and manages as a CM Agency. The remaining contracts are held by Whiting-Turner, which they oversee as a CM-at-risk.

The construction team has faced many challenges during the construction of the Millennium Science Complex. Due to the location of the project in the heart of The Pennsylvania State University main campus in University Park, PA, student safety and pedestrian traffic was an immediate concern. In addition, the constraints of the site posed concerns for the transportation of materials to the site, as well as storage of materials and placement of such equipment of cranes. The construction of the 150-foot cantilever also provided many challenges to the team as well, including the constructability of a cantilever of that magnitude, deflection concerns, and welding of connections during the winter months.

Existing Structure

The foundation of the Millennium Science Complex utilizes a system of pile caps, micropiles and grade beams. Each column ends at a pile cap on grid lines spaced twenty two feet apart in a square pattern. Groups of micropiles continue from the pile caps and make their descent through the soil allowing friction to carry the load of the building. Each of these pile caps are connected by grade beams which help to prevent differential settlement and help to stiffen the foundation, a crucial design consideration for a laboratory building.

Forming the floor of the basement are four different slabs on grade in the occupiable area of the basement. The basement, extending 20 feet to the first floor of the building, covers only a portion of the entire footprint of the building. From approximately the halfway point of each wing (column lines R and 13) begins a compacted fill extending to the ends of each wing and to the first floor slab on grade. Columns and piers extend from the pile caps at the basement level up through the compacted fill, to the first floor. This was presumably designed in the event that the University would want to expand the basement level under each wing. Further evidence of this assumption can be found in the foundation walls, which enclose the compacted fill, and are in line with the exterior walls of the building. The accessible areas of the basement lie directly under the cantilever and extend to the edge of the compacted fill (column lines R and 13). Four isolation labs were placed at the basement level, designed to be completely disparate of the structural elements that make up the rest of the building. Slabs on grade, foundation walls, footings and piers use 4000 psi concrete; the pile caps are the only concrete items that use 6000 psi concrete. Reinforcement in the foundation and throughout the building is grade 60.

A one way composite steel beam system with typical 22 foot square bays forms the floor system for the Millennium Science Building, as shown in the simplified model of Figure 3. A typical floor layout for the wings contains a centralized corridor surrounded by rooms on either side. Those perimeter spaces are generally divided into either laboratories or offices. The floor loads are handled by three types of composite steel beams and metal decking used throughout the building, the most common of which is a 3 inch 18 gage deck with 3¼ inch light weight concrete topping. The concrete decking is supported by W21 beams and W24 girders which frame into W14 columns, at the intersection of each grid line. Beyond the typical dead and live loads, there are specialty loads from the green roof, mechanical equipment, and the pedestrian traffic at the entrance which call for increased slab strengths. A 3 inch metal deck is used with a 7 inch normal weight concrete



Figure 3: Model of typical steel framing layout

topping immediately below the cantilever where pedestrian traffic is heaviest as people enter and exit the building, and a 4½ inch normal weight topping is used to support each green roof. These hallways call for a slightly higher ceiling so W18 beams are used in the center bay of each frame.

Two moment frames, several bays of braced frames, and two shear walls located at the stairwells make up the dedicated lateral system for the building. The moment frames are located at grid lines Q and 19, which are midway and at the end of their respective wings. The location of these moment frames correspond with shear walls placed in either wing several bays away. Figure 4 shows a layout of these frames and shear walls on the first floor. The objective of these staggered frames and walls is to distribute the lateral forces over the entire floor, preventing excessive localized stresses in the floor diaphragms. State College itself does not suffer from large wind or seismic loads given building height restrictions and geographical location. Along with the large span trusses and C-shaped shear walls that support the cantilever, the dedicated lateral system more than suffices in resisting the maximum lateral loads State College demands.

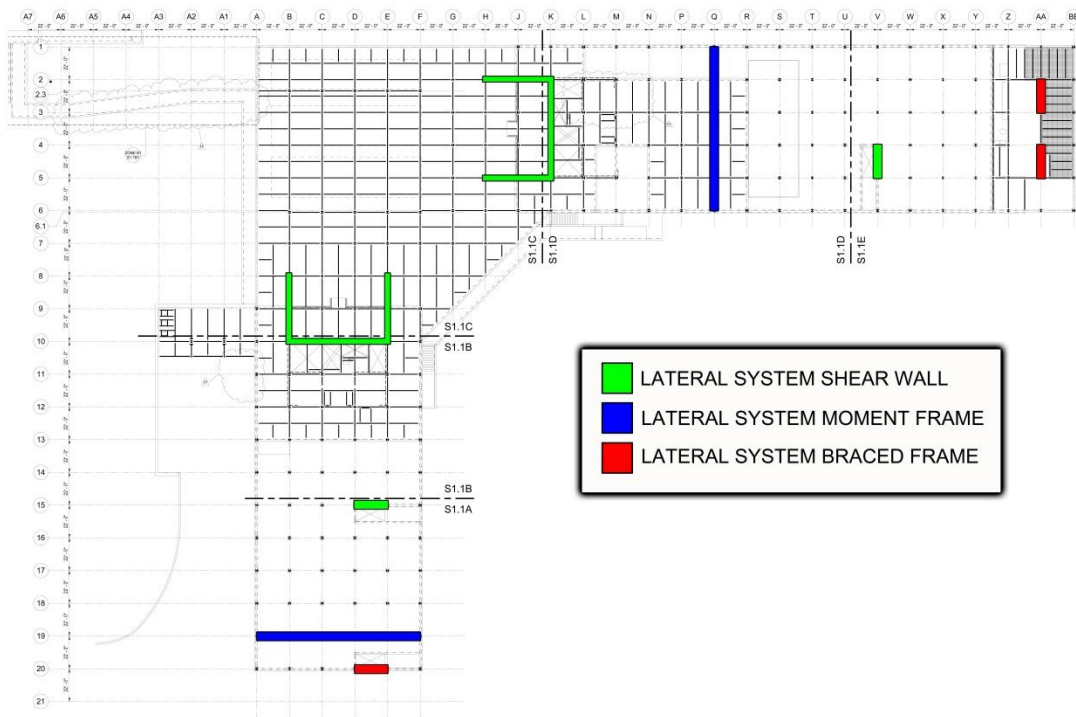


Figure 4: Layout of lateral system elements on first floor

To cope with the massive stresses induced by the 150 foot overhanging cantilever, a truss design was used to handle the gravity forces. Gravity loads start from the tip of the cantilever and are transferred into the diagonal compression members. Continuing on the load path, the truss feeds into a 30" shear wall integral with the truss frame. The loads from the diagonal compression members get carried into the shear wall and transfer into the foundation. The load is handled by 10 points in the foundation. These enlarged pile caps and grade beams act in compression and tension on the soil, using the micropiles as anchors. An image simulating the distribution of these forces is highlighted in Figure 5.

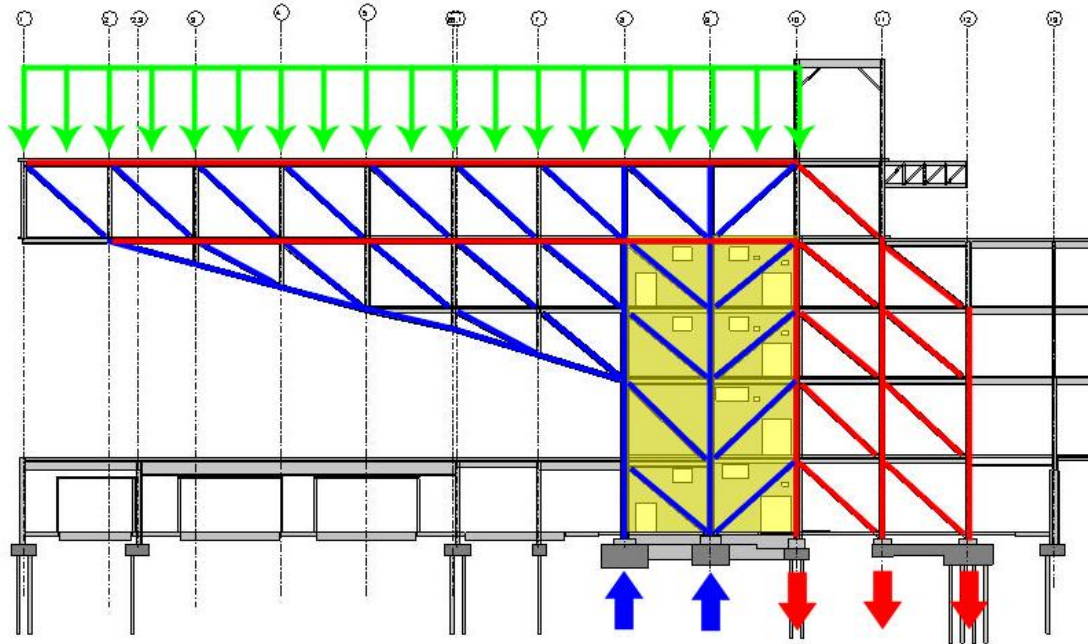


Figure 5: Gravity load simulation in cantilever truss along Frame B. Red and blue denote tension and compression respectively.

Existing Mechanical

The Millennium Science Complex connects into the existing campus steam lines and chilled water lines. Steam enters the building at high pressure, 140 psi, but requires two pressure reducing stations to reduce the steam pressure to medium and low pressures of 60 psi and 15 psi respectively. Medium pressure steam is utilized for sterilization, heat exchangers, and other equipment loads. Low pressure steam is used for the steam coils within the AHUs and in heat exchangers that produce hot water for reheat-coils at terminal devices.

Chilled water is pumped throughout the building using three (3) variable speed split case pumps, with one reserved as a standby. An auxiliary low flow pump is utilized for part load conditions. The AHUs that serve the animal care facility and main lab are connected to standby power to allow for cooling of these spaces during the loss of power.

The laboratory areas of the building are served by five (5) 50,000 CFM VAV AHUs. Each of these AHUs contains a supply fan, cooling coils, heating coils, humidification equipment, and MERV-14 filters. All laboratory AHUs deliver 100% outside air. In an effort to save operating cost and energy in the 100% outside air systems, general laboratory exhaust air enters an enthalpy wheel exchanging energy with the incoming supply air. The laboratory fume hood exhaust is not included in the enthalpy wheel due to the potential contaminants within the exhausted fume hood air.

The office, lobbies, and common areas are served by three (3) 40,000 CFM VAV AHUs. These AHUs do not provide 100% outdoor air and instead contain a mixing box with CO₂ sensors in the outdoor air, return air, and all conference rooms. This ensures that the CO₂ concentrations in these areas are maintained at appropriate levels by supplying enough outdoor air.

The animal care facility is served by two (2) 25,000 CFM 100% outdoor air units. Each unit is sized to handle the full load of the space. Redundancy is needed to allow for continual service to the animal holding rooms and the rest of the animal facility should one unit fail. The clean room also has its own AHU designed to maintain the room's humidity levels at 45% RH. The animal care facility AHUs, quiet lab AHU, and clean room AHU all utilize run around heat recovery coils in an effort to reduce energy usage.

In addition to the main AHUs, cabinet unit heaters, electric heaters, fan coil units, supplemental air conditioning units, and other local equipment are used to address areas of the building where the main HVAC equipment cannot feasibly serve the area. It is necessary to have all of the previously mentioned components in order to effectively keep the building operating under optimum conditions for the various building occupants.

The Millennium Complex will be protected on all floors by an automatic fire alarm notification system. Manual pull stations will not be required where the alarm notification appliances activate upon sprinkler water flow in this fully sprinklered building. The first floor outdoor plaza must also be fully sprinklered as there is potential for combustible materials to be handled under the canopy. The laboratories will be designed to meet Ordinary Hazard Group 1 or 2, while storage rooms with dispensing capabilities must be designed to Extra Hazard Group 2.

An automatic standpipe system will be required throughout the building, and hose connections will be required on each floor at an intermediate landing level in stairways. A minimal residual pressure of 100 psi is required at the outlet of the hydraulically most remote 2 ½ inch hose connection.

Existing Lighting

All lighting is on 277V service. All building perimeter offices and laboratories are controlled by both occupancy and daylighting sensors with appropriate dimming ballasts. Typical internal laboratory and office rooms are controlled by the occupancy sensor. Three general types of ballasts are used. Class B quiet dimming ballasts are used in the quiet labs. Lutron's Hilume dimming ballasts are installed for rooms requiring less than 10% dimming from full power. Advance Mark7 dimming ballast is used in rooms with regular dimming conditions. A system of addressable ballasts is used in accordance with Lutron's GRAKIF Eye system.

Existing Electrical

The electrical system for the Millennium Science Complex is a 12.47kV service feeding a set of dual 4000A, 480Y/277V switchgears (main-tie-main) through two pad mounted transformers. Distribution begins with 480Y/277V for lighting and other systems, then stepped down at further locations to 208Y/120V for receptacle and equipment power. Emergency power is fed from two separate switchgears which feed multiple ATS's with both normal and emergency power. To limit the EMF from interfering with sensitive equipment, electrical closets are encased with aluminum shielding and in certain areas rigid conduit is used in place of standard conduit.

Façade Redesign

Problem Statement

BIMception's redesign of the Millennium Science Complex's façade will retain the integrity and symbology of the architect's, Raphael Vinoly's, vision. This vision is created by the horizontality of the façade's panel and strip window construction, creating the illusion of a building floating in the landscape. To do this, the façade is uniform and consistent in its expression and construction, disregarding solar orientation and building structure. It is BIMception's plan to respect the architect's vision by not altering the cohesiveness of the façade elements.

The Millennium Science Complex's façade does not address the changes in solar orientation, as it retains its uniformity throughout all building faces. This creates unique problems for the selection of components designed to control daylighting and solar heat gain, as they are unable to react to differentiations in varying solar intensity around the building. In keeping with the architect's vision, this uniformity will not be altered, but elements will be redesigned to improve the façade's performance. Reevaluating the wall to glass ratio will allow BIMception to select a ratio that provides opportunities for more comfortable daylighting and for better control of thermal loads. These two opportunities can also be realized by reengineering the overhang length and height of the light shelf. By optimizing the current design, BIMception can respect the architectural features while providing improvements in the façade's performance.

The façade of the Millennium Science Complex is composed of 25,000 lb prefabricated concrete panels used uniformly on all building surfaces. While a defining architectural feature, they can be improved to reduce all forms of building loading. By redesigning the panel's composition to reduce its self-weight exterior structural loads can be reduced. The use of phase change materials will be used to reduce the volume of concrete needed for thermal storage and performance. This savings in weight will decrease the deflections in the cantilever and decrease the bending stresses on exterior connections and columns. The façade will be visually unchanged, but the material and structure behind the veneer will be engineered to increase structural and mechanical performance.

Construction Solution Methods

From a holistic standpoint, the responsibility of the construction manager on a project is to help maintain and manage the construction process, work flow and exchange of information. With this in mind, one of the main goals of the construction manager is to facilitate group exchange of information, and remained involved in design decisions from both a managing perspective and constructability perspective. It is important that work remains on schedule, and adheres to the goals and processes laid out in the BIM Execution Plan created by BIMception. Tables detailing BIMception's BIM goals and uses can be found in Appendix D. In order to accomplish further analysis of designs of the façade, including the precast panels, exterior glass, lighting and mechanical systems, and structural system, information and models for these designs must be exchanged between the engineers and the construction manager. These will be used to analyze cost and schedule implications, used in an analysis of site logistics concerning these changes, and a crane usage analysis. Based on these analyses, information will be passed back to the appropriate parties, and further iterations will occur.

The first analytical focus will be a cost analysis of the proposed redesigns in comparison with the existing conditions. Based on the existing conditions, a cost report will be created for the components of the façade (precast panels, windows, light shelf), lighting and mechanical system components servicing the exterior rooms of the building, the structural components connecting the façade to the building, as well as the crane and labor costs associated with these changes. These numbers will be produced based on cost reports provided by The Whiting-Turner Contracting Company, quantity take-offs created from Autodesk Revit models and 2D drawings in conjunction with RSMeans and other cost references, as well as estimates based on manufacturer-provided numbers. Labor costs, as well as crane costs, will also be investigated based on manufacturer and cost reference data such as RSMeans. Following the production of the redesign of these locations, a similar process will be followed to determine the costs of the proposed designs. Autodesk Revit models, 2D drawings, as well as product reports will be used to produce quantity take-offs. An analysis of the labor required will be performed, as well as an in-depth look at crane costs based on a crane analysis proposed in the Plenum Coordination portion of this report. The existing costs will be placed in a report in comparison to the proposed redesigns, and this information will be provided to the appropriate parties.

In addition to a cost analysis, a schedule analysis will be performed to determine the implications of changing systems. A change in mechanical or lighting systems will have an effect on the lead times for the components of these systems. This must be taken into account as redesigns occur, as it is important to minimize issues with the schedule. This is also true for the precast panels, exterior glass and light shelf, as changing materials can alter the time required to produce and transport them. In addition to lead times, the sequencing of the erection of the precast panels must be analyzed in conjunction with the construction of the redesigned structure (proposed in the Plenum Coordination portion of this report). This will also tie in with the analysis of the cranes used on site, and potential changes to the cranes used based on this analysis. The most current schedule provided by Whiting-Turner will be used as a baseline for comparison with the schedule created based on the redesigns. This schedule will be created in Microsoft project based on data collected from manufacturers as well as reference data books such as RSMeans. In addition to creating a schedule, 4D modeling will be implemented as a comparative tool. One 4D model will be created in Autodesk Navisworks Manage combining both the proposed structural framing, as well as the enclosure of the building. This will be used in an effort to create a sequence of activities that is most efficient for the construction of the project. In addition, this will also be used in comparison with a baseline 4D model of the existing structure and schedule.

Finally, site planning and logistics will be investigated based on the redesigns proposed for the façade. This will primarily tie in with the crane analysis, taking into account the location of cranes, as well as the location of delivery trucks for the precast panels. In order to efficiently construction the precast panels, the coordination of the cranes with the delivery of the panels must be sequenced correctly. In addition to this, safety will also be a primary concern for site planning, and will be focused on throughout the entire analysis of this portion of construction. A combination of 2D drawings created in Autodesk AutoCAD and 3D modeling in Autodesk Revit will be used to produce a report for the investigation of the site.

Mechanical Solution Methods

The mechanical redesign of the façade system will focus on deconstructing elements of the exterior wall and analyzing their performance in isolation. This proposal will have three specific areas of focus evaluated for improvement – Wall to Glass Ratio Analysis, Wall Composition Analysis, and Daylighting Control Analysis.

Reevaluating the wall to glass ratio will select a façade that balances external thermal loads with improved daylighting opportunities. The proper selection of glazing area will reduce the yearly building energy required to heat and cool the Millennium Science Complex. Incremental changes in the wall to glass ratio will be analyzed in Trane Trace 700. This yearly analysis will be able to account for the benefits in both the heating and cooling seasons. A final energy report will be compared to the baseline established in Technical Report 1, found in Appendix C, and used to create criteria in tandem with the L/E’s daylighting report. Figure 6 shows the baseline model used in Technical Report 1 to produce the Trane Trace energy report. Mechanical performance will be evaluated by a reduction in yearly energy consumption. The selection of the final wall to glass ratio will be an interdisciplinary effort synergizing the energy savings and daylighting improvement opportunities.

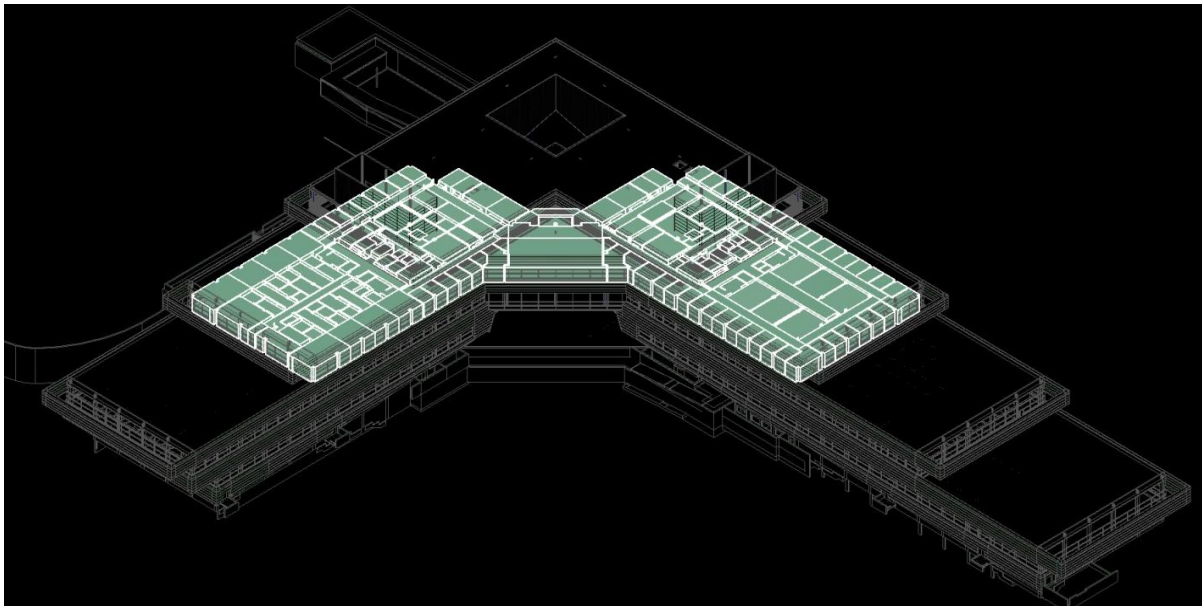


Figure 6: GBXL file exported to Trane Trace for energy analysis

Reconstructing the composition of the exterior wall will select a wall that better controls heat transfer while reducing the structural weight of each panel. Figure 7 shows the existing wall composition. The mass of concrete will be reduced as phase change materials will be impregnated into the new construction to improve its heat capacity. A phase change additive called Micronal PCM by BASF will be utilized for this investigation. The wall will consist of 2" brick, 3.5" concrete, unspecified thickness of airspace, unspecified thickness of insulation, and unspecified thickness of PCM concrete. Analysis of the wall construction in H.A.M. Toolbox will ensure that the PCM concrete remains in the 55-85 degree range where it is most effective. Once airspace and insulation thicknesses are selected, an analysis in the RSTM ASHRAE package will allow the thickness and thermal properties of the PCM concrete to be determined. Improved thermal performance will be evaluated in Trane Trace to track energy savings, and the reduction in panel weight will create structural savings. The final selection of wall composition will produce reduced building conditioning loads, and reduced exterior support sizes.

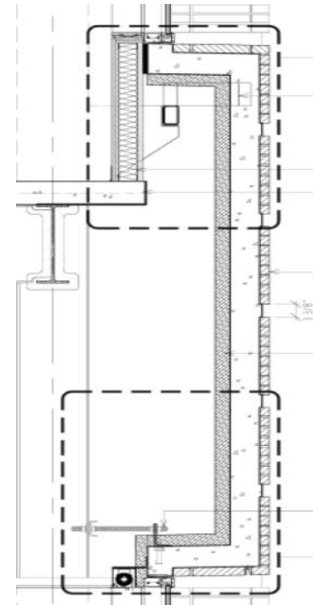


Figure 7: Existing wall panel composition

Resizing the depth of the façade's overhang will select a shading device that enhances daylighting while controlling excessive solar heat gain. An effective overhang depth will reduce the Millennium Science Complex's yearly energy consumption. Varying lengths of shading devices will be modeled in the RSTM ASHRAE package to analyze their effects on the façade's envelope loads. This will produce energy data that can be compared with the L/E's daylighting analysis to select the best length of overhang. The final overhang length will be modeled and compared to the existing conditions energy report to realize reductions in solar loads and yearly energy consumption.

Lighting/Electrical Solution Methods

The lighting/electrical façade redesign will look in the daylight performance. The redesign will strive to find a balance between daylight delivery and increased building solar loads, while maintaining the overall architectural theme of horizontality. This proposal contains three in-depth areas of analysis pertaining to lighting/electrical façade redesign: window to wall ratio analysis, the size, location, and type of the shading devices, and electric and daylight integration control devices.

In order to optimize the façade the Light/Electrical team member will analyze varying window to wall ratios with respect to useful illuminance values and Daylight Autonomy, 100-200lux¹ and 300 lux respectively. The analysis will include 10% increment in window to wall ratio from 20% to 80% using Daysim. This analysis needs to be done for each façade orientation. The new window to wall ratios will then be compared with the existing façade. The selection of the final window to wall ratio will be done in coordination with the Mechanical team member.

The next step in façade optimization will analyze shading devices. This will be done through a profile angle study. Light shelf dimensions will be altered based on the profile angle study; these dimensions include depth and height. Preliminary sizing will be evaluated using AGi32 to see solar penetrations into the space. The Lighting/Electrical team member's light shelf results will be compared with the Mechanical team member's to select the proper one for the building. Once the light shelf size dimensions are set the internal roller shades will be analyzed. A new bottom-up system will be investigated and compared to the existing top-down system.

The final façade redesign will allow the Lighting/Electrical team member to evaluate different lighting strategies for the perimeter spaces. The main lighting redesign area will be the student study area. The branch circuits will be redesigned to reflect the new lighting design. The lighting design will also incorporate different control strategies. The current luminaires are controlled with daylight integrated dimmable ballasts. A daylight integrated switching system will be investigated and assessed using energy savings. The system will be determined based on a life cycle cost by the Construction Manager coupled with occupant comfort.

Structural Solution Methods

The structural contribution to the redesign of the façade system will be to design an innovative solution combining adequate strength of the façade panel, a proper support system, and proper connections to the exterior columns. Specific investigations will include: analysis and design of panels with reduced concrete thickness and reinforcing options, connection options to hold together layers of the precast panel and reduce stress concentrations when hung, as well as a redesign of the steel connections tying the panels to both steel and concrete exterior columns.

The structural engineer will be part of all design coordination meetings concerning the façade redesign. Current façade panels are extremely weighted with up to eight inches of concrete with inlaid brick veneer and interior rigid insulation. This thickness of concrete especially on the exterior is not necessarily needed. Through the introduction of high performance materials it may be possible to reduce the concrete weight used or at least use the concrete in a more efficient way.

The structural issue with the current façade design is that the every panel is hung at a distance from the columns and the floors so as to not encroach on the floor area. The panels, although two feet in thickness is flush with the outside edge of the floor slab. It extends outward from that edge. The connections designed to support this weight are steel seats welded to the columns and because the weight is concentrated outside the edge of the slab edge an eccentricity is created and causes extra moment to be applied to the column. Keeping this eccentricity intact, this moment will not recede. The only tangible goal is to reduce the weight of the façade panels to reduce the applied moment on the exterior columns. This could result in smaller steel sections for the exterior columns and will result in smaller seismic loads due to lower accelerations.

Construction Tasks and Tools

1. *Cost Analysis*

- a. Produce existing conditions cost data based on Whiting-Turner budget, and quantity take-offs of existing conditions 3D Revit models and 2D drawings, all in conjunction with cost reference data (RSMeans)
- b. Organize into single report in Microsoft Excel
- c. Meet with Str, L/E and Mech to discuss designs and obtain information and models for redesigns
- d. Produce quantity take-offs based on information and models presented
- e. Use quantity take-offs in combination with manufacturer information and cost reference data, such as RSMeans, to develop cost estimates
- f. Organize in report in Microsoft Excel for comparison with existing conditions
- g. Meet with Str, L/E and Mech to discuss findings and next step, either proceeding with current proposed redesign or if further iterations are necessary

2. *Schedule Analysis*

- a. Organize existing schedule information from Whiting-Turner schedule for enclosure construction and interior lighting and mechanical systems in rooms on exterior of building
- b. Meet with Str, L/E and Mech to discuss designs and obtain information and models for redesigns
- c. Compile information from manufacturers, reference data, such as RSMeans, for systems proposed by Str, L/E and Mech
- d. Produce new schedule durations for proposed designs in Microsoft Project and compare with existing schedule
- e. Begin production of 4D model in Navisworks for construction of precast panels in conjunction with construction of redesign structural system to create most efficient sequence of activities
- f. Meet with Str, L/E and Mech to discuss results

3. *Site Logistics Analysis*

- a. Obtain current site logistics plans as a baseline comparison
- b. Use information from crane analysis to determine locations of cranes and delivery points, as well as analyze safety concerns
- c. Analyze sequence of construction in combination with site planning
- d. Produce new site plan drawings where necessary, and meet with appropriate parties to discuss results when required

Mechanical Tasks and Tools

1. *Wall to Glass Ratio Analysis*

- a. Establish baseline energy consumption of 3rd floor with existing conditions exterior wall
- b. Select increments of differentiation for analysis – 20,30,40,50,60,70,80% ratios
- c. Perform 3rd floor energy analysis in Trane Trace 700, incorporating differentiations
- d. Graph effects of thermal differentiations
- e. Establish criteria with L/E for optimized daylighting and thermal performances
- f. Graph daylighting and thermal differentiations
- g. Select best ratio solution with L/E
- h. Prove daylighting and thermal performance improvements compared to baseline
- i. Compare lifecycle cost implications with CM
- j. Repeat if new information requires reevaluation
- k. Model best wall solution in Revit Architecture 2011

2. *Wall Composition Analysis*

- a. Perform baseline thermal conduction analysis of existing conditions exterior wall in RSTM ASHRAE Software Package
- b. Draw proposed wall composition, moving insulation to exterior side of concrete, while reducing concrete thickness with impregnated concrete PCMs
- c. Perform wall temperature analysis in H.A.M. Toolbox
- d. Select exterior composition to ensure PCM concrete placed on the interior side of insulation remains in operative temperatures
- e. Perform thermal conduction analysis in RSTM ASHRAE Software Package to reduce thickness of concrete while retaining thermal performance
- f. Share wall composition with STR
- g. Compare lifecycle cost implications with CM
- h. Repeat if new information requires reevaluation
- i. Model new wall composition in Revit Architecture 2011

3. *Daylighting Control Analysis*

- a. Perform baseline shading analysis of existing conditions exterior wall in RSTM ASHRAE Software Package
- b. Select increments of differentiation for analysis – 0,6,12,18,24,30,36” overhang
- c. Perform overhang shading analysis in RSTM ASHRAE Software Package, incorporating differentiations
- d. Graph effects of thermal differentiations
- e. Establish criteria with L/E for optimized daylighting and thermal performances
- f. Graph daylighting and thermal differentiations
- g. Select best overhang solution with L/E
- h. Prove daylighting and thermal performance improvements compared to baseline
- i. Compare life cycle cost implications with CM
- j. Model best overhang solution in Revit Architecture 2011

Lighting/Electrical Tasks and Tools

1. *Window to Wall Ratio Analysis*

- a. Establish baseline daylight analysis for existing window to wall ratio
- b. Select window to wall ratios for analysis – 20,30,40,50,60,70,80%
- c. Analyze each ratio for each façade using Daysim.
- d. Graph results with respect to useful illuminance and Daylight Autonomy.
- e. Establish criteria with Mechanical team member for ratio selection.
- f. Overlay results with mechanical results to select proper ratio
- g. Conduct life cycle cost with Construction Management team member

2. *Shading Devices*

- a. Establish baseline daylight analysis for existing shading devices.
- b. Solar profile angle study.
- c. Select initial light shelf height variations.
- d. AGi32 trellis light shelf shadow study for each façade orientation and height variations.
- e. Select overhang dimensions based on comparison with Mechanical
- f. Model space with light shelf dimensions and final window to wall ratio results.
- g. Analyze light shelf with Daysim
- h. Make adjustments accordingly – reanalyze
- i. Conduct life cycle cost analysis with Construction Management team member.
- j. Model final façade in Revit Architecture 2011.

3. *Electric and Daylight Integration Control*

- a. Establish baseline for existing control – Dimmable fixtures with manual shades
- b. Investigate daylight integrated switching system.
- c. Investigate daylight integrated automatic shades.
- d. Conduct life cycle cost with Construction Management team member.
- e. Select system control based on life cycle cost and occupant comfort.

Structural Tasks and Tools

1. *Design New Typical Connection: Façade to Concrete Column*
 - a. Obtain existing design loads for precast façade panels
 - b. Design innovative connection to include steel plate assembly to be incorporated within formwork
 - c. Investigate anchorage options to transfer design shear and moments from connection into concrete columns
 - d. Present connection options to L/E, ME, and CM in façade design review
 - e. Adjust connections to steel and concrete columns based on new façade redesigns from L/E, ME, and CM
 - f. Repeat steps d and e as necessary
 - g. Finalize façade connections design

2. *Strength Design of New Façade Panel Designs*
 - a. Collaborate with L/E and ME to develop conceptual façade redesign
 - b. Finalize schematic design of façade panel including support conditions
 - c. Design reinforcement for all concrete sections of new panel design using ACI-318-08
 - d. Model Design in SAP 2000 with concrete, reinforcement, and other dead weight
 - e. Include support conditions for connecting façade panels to exterior columns
 - f. Run analysis to determine panel stresses and deflections to evaluate performance
 - g. Propose structural design to L/E and ME for performance evaluation.
 - h. Model new façade structure in Revit Structure as coordination model
 - i. Export ETABS model as Revit Link and import into Revit, if link is available

3. *Reevaluate Exterior Column Sizes*
 - a. Obtain member forces on exterior columns from ETABS analysis
 - b. Obtain perimeter loads on columns due to new façade design
 - c. Model new perimeter loads and moments in ETABS
 - d. Run full analysis and obtain new column member forces
 - e. Compare to existing design and determine if new façade design can result in more efficient column sizes.
 - f. Finalize exterior column sizes
 - g. Check new connection designs to determine adequacy if smaller columns used
 - h. Redesign connections if necessary

Façade Redesign Conclusion

The Millennium Science Complex façade redesign will be analyzed with an interdisciplinary approach. BIMception's Mechanical and Lighting/Electrical team members will analyze the façade's composition, window to wall ratio, and shading devices for optimization with respect to their discipline. These results will then be graphed and overlaid to find an even balance between daylight and mechanical loads. The new façade composition selected will be supplied to the Structural team member for connection design. The Construction Management team member will analyze the life cycle cost and schedule implications for the proposed façade redesign. Through these analyses BIMception will strive for façade optimization.

Façade redesign will result in project deliverables from the BIMception design team. A final façade model will allow the Lighting/Electrical team member to analyze energy usage from different daylight control devices. Interdisciplinary work between Mechanical and Lighting/Electrical team members will provide an energy analysis for the 3rd floor of the Millennium Science Complex. A redesigned façade model showing wall composition, shading devices, and new connections will provide the Construction Management team member with a model for 4-dimensional modeling. The 4-D model will show schedule implications associated with the façade redesign.

Plenum Coordination

Problem Statement

The ceiling plenum is the most critical location in the building with regards to system integration. Every engineered system uses this plenum to service and support the multitude of spaces throughout the building. High levels of congestion result in the constant interaction of each individual system with the others. Without a proportional level of integration between disciplines, a disconnect between the building systems is created to the point vertical space is delegated to each system and then each is designed separately. Instead systems such as the structural floor system and the mechanical duct and piping systems can work together to achieve the most efficient and flexible design possible. The main goal of the ceiling plenum redesign will be to balance the interdisciplinary utilization of vertical space. A large existing structural profile depth intrudes on usable space needed for large runs of supply and return mechanical ductwork while allowing flex space in-between the beams spaced at eleven feet for duct crossover, plumbing, and electrical routing. A reduced structural depth could increase the usable space of long duct runs, which are governed by the lowest structural plane, allowing supply ducts to be increased in size, decrease static pressure losses, potentially leading to energy savings. A similar study will assess the comparison of life cycle energy costs versus the upfront cost reductions due to reductions in floor to floor height. Floor to floor height can have an impact on façade cost and weight given the large perimeter and massiveness of the existing building enclosure. This study will confirm the most effective use of vertical space within the ceiling plenum.

Before the mechanical engineer can gauge the potential energy savings an alternative structural system must be proposed. The current steel framing in the typical gravity system is a one way steel beam and girder system with beams spaced at eleven feet, or half the bay size. This is a very efficient spacing; however, it is resulting in twenty four to thirty inch structural profile depths in most areas. The large section sizes are controlled by vibrational criteria for the laboratories. The 4000 and 2000 micro-inches per second, required as an upper limit in the Life Science and Material Science wings, respectively, have resulted in beam sections that are approximately 100% larger in the life science wing and 200% larger in the material science wing, than would be necessary for strength design. To increase efficiency and reduce the structural depth in the current system it would benefit to either use smaller spacing between beams or use a two way beam system with intersecting beams within bays. However, this increases the amount and design of connections and increases the amount of members to be installed and connected in the field.

Based on previous strength design performed with multiple concrete systems, specifically a flat plate, flat slab, and one-way joist system, it was determined that concrete in general offers a much smaller vertical dimension of structure within the ceiling plenum, as compared to a steel structure.

To produce the most effective plenum design, the compromises, efficiencies and life cycle costs of each discipline must be understood and analyzed. In this following section, each discipline will begin to analyze the implications a plenum redesign could have on their specific design and the interdependencies of the systems involved.

Construction Solution Methods

Similar to the façade redesign, the responsibility of the construction manager on this project will be to help maintain and manage the construction process, work flow and exchange of information. It will be important for the construction manager to aide in facilitating the exchange of information amongst the group, and remained involved in design decisions from both a managing perspective and constructability perspective. This will help ensure that work remains on schedule, and adheres to the goals and processes laid out in the BIM Execution Plan created by BIMception. Tables detailing BIMception's BIM goals and uses can be found in Appendix D. The driving force behind the investigation of the plenum space is the redesign of the structural system, followed by an examination of the mechanical systems within the plenum space. In order to further develop the analysis of these topics, an analysis of the cost and schedule implications must be developed for the new designs, along with a crane analysis and an investigation into site logistics. Based upon these analyses, the information based on the results will be discussed with the appropriate parties, and further iterations will occur until a final conclusion is accepted.

The first focus will be on the cost analysis of the proposed redesigns in comparison with the existing conditions. With the focus for this analysis being the structural framing of the building, as well as the mechanical systems of the third floor, preliminary cost data will be collected based on budgets provided by Whiting-Turner, quantity take-offs produced from 3D Revit models and 2D drawings in conjunction with cost reference data such as RSMeans, and manufacturer data. Specifically, data will be collected for the steel frame, the mechanical systems with a focus on the ductwork, cranes, pump trucks and all labor associated with these topics. This information will be compiled in a single report to be used for comparisons with the redesigns provided by the structural and mechanical engineers. A similar process will be followed for the estimation of the redesigns provided. With the focus of the structural redesign on changing the two building wings outside the braced frames of the cantilever to concrete, full quantity take-offs will be produced based on 3D structural Revit models provided by the structural engineer. Quantity take-offs will be produced through the Autodesk program, QTO, in combination with hand calculations and developed into cost estimates based upon cost data in RSMeans. Quantity take-offs and cost estimates will be developed through a similar process. In addition to these systems, cost estimates will be produced based upon the results of a crane analysis for the project (detailed later in this section). Labor costs will also be examined in conjunction with these proposed changes. Labor will receive a higher focus in this portion of the project because the structural redesign is focused on a concrete frame, where labor will play a larger part in the cost of the building. Information developed in this analysis will be compiled, and presented to the appropriate parties for further analysis.

In addition to this cost analysis, a further analysis will be conducted to compare the benefits of adjusting the mechanical systems to take advantage of the additional spaced gained by redesigning the structural system versus reducing floor-to-floor height. This type of comparison would entail producing cost estimates based upon quantity take-offs for such building components as the concrete structure and the precast panels. In addition, crane costs and labor will need to be accounted for within this estimate as well. Assumptions will need to be made in order to make this type of comparison and estimate feasible, which may include ignoring the cantilever for the purposes of this analysis, and considering only the third floor in the estimate. These estimates would be done based on 2D drawings and 3D Revit models through the use of hand calculated quantity take-offs and Autodesk QTO. RSMeans would be used to produce costs based on the data, and cost estimates would be created to compare to the estimates determined for the changes to the mechanical systems.

A schedule analysis will follow the cost analysis in order to determine the implications of changing to a concrete building and redesigning mechanical systems. A change to any system that requires lead times will have an effect on the schedule of a project. By changing the steel frame to a concrete structure, a reduction in required lead times for steel members in those locations will be found, but a new item will be introduced that will require a lead time: rebar. In addition, lead times for the mechanical systems will have to be examined with the change in components such as the ductwork. A change in the structural system will also completely change how the building is sequenced and scheduled. For the proposed design of a three-building system using concrete wings and a steel cantilever, sequencing will be of the utmost importance to ensure efficiency in construction. There are opportunities for acceleration of the schedule that can be found through proper sequencing of the proposed structure. In addition to sequencing of a concrete structure, both curing time and weather must be considered when developing a schedule. Finally, based upon the crane analysis, cranes and/or pump trucks must be sequenced properly to allow for efficient construction of the building. This information will all be produced in Microsoft Project using a combination of manufacturer data, and reference books such as RSMean. In addition to developing a schedule, a 4D model will be developed in Autodesk Navisworks Manage using the final proposed structural system as well as the enclosure of the building. This will be used to aid in the development of the sequence of activities for the construction of the building, as well as a comparison for the existing building and schedule.

A site logistics investigation will also be conducted for the site in regards to the changes provided in this analysis. Safety is the main concern on a project site, and therefore, will play a heavy role in determining the location of equipment as well as the sequence in which activities occur. The location of equipment such as cranes and pump trucks will be examined, as well as the location of concrete mixing and concrete trucks. Logistical issues will also be examined in the sequencing of concrete pours while steel is erected in the cantilever. This will tie in with the schedule portion of the analysis. This information will be determined based upon reference books, as well as developed on a 2D and 3D scale in Autodesk AutoCAD and Revit.

As reference above, a crane analysis will be performed for the construction of this building. Due to the proposed structural design of concrete, crawler cranes become less of a requirement. While a crawler crane will still be required for the cantilever, it is possible multiple cranes are not needed for the construction of the cantilever. Additionally, a crane must also be considered for the moving and placing of formwork and rebar throughout the construction of the concrete wings of the building. With this in mind, multiple crawler cranes become even less necessary. An investigation into whether it is more feasible to use multiple crawler cranes with pump trucks for the concrete or a single crawler crane with tower cranes for the pouring of concrete and assisting in the moving of materials will be conducted. This will be conducted on the basis of cost, scheduling, practicality, and site logistics. Based on the results of this, the cost, schedule and site planning of all the topics detailed in this report will be adjusted accordingly.

Mechanical Solution Methods

The mechanical redesign of the plenum space will focus on the effects that static pressure losses have on fan energy consumption. The availability and utilization of the vertical height of the plenum will be used to evaluate more efficient duct sizing to produce lifecycle savings.

The existing supply duct for the Materials Science wing, shown in Figure 8, will be modeled in Revit MEP 2011 to produce a baseline static pressure loss, utilizing built in duct sizing capabilities. This will produce a baseline energy model in Trane Trace to analyze the cost of high static pressure. These steps will be repeated, assuming that incremental increases in plenum height are available to be used for increased duct size. As more vertical space is used for duct area, the static pressure will decrease creating potential for energy savings. This incremental energy saving will be compared to the potential savings of reducing floor to floor height and changing structural systems to prove that the plenum can be utilized to produce savings for all disciplines. The final selection of the plenum will allow for an increase in duct size, creating valuable lifecycle energy cost savings.

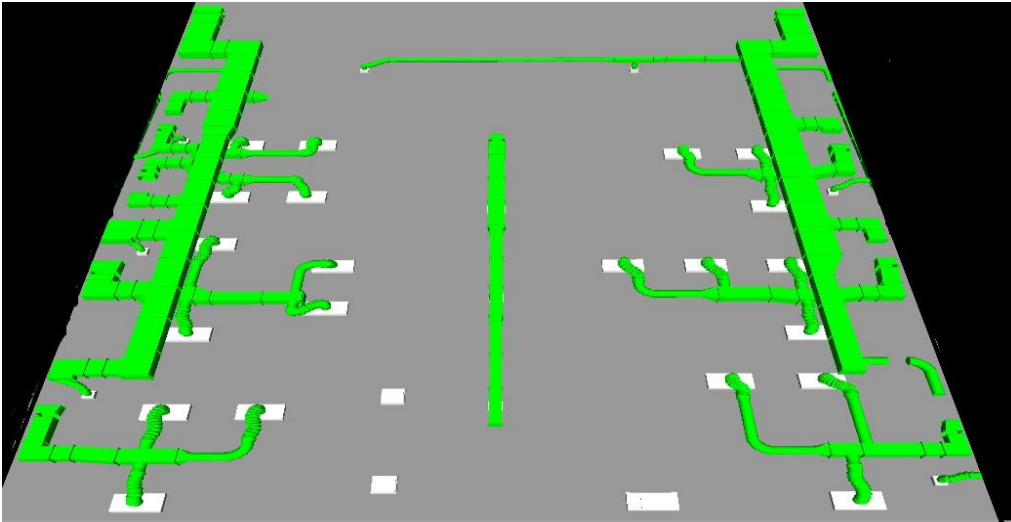


Figure 8: Layout of laboratory supply ducts to be analyzed to fan energy savings

Structural Solution Methods

Structural contribution to the redesign of the ceiling plenum space will focus on a redesign of the gravity system in the north and south wing of the building. The main goal of the ceiling plenum is to balance the interdisciplinary utilization of vertical space. A large existing structural profile depth intrudes on usable space needed for large runs of supply and return mechanical ductwork while allowing flex space in-between the beams spaced at eleven feet for duct crossover, plumbing, and electrical routing. A reduced structural depth could increase the usable space of long duct runs, which are governed by the lowest structural plane, allowing supply ducts to be increased in size potentially leading to energy savings. Before the mechanical engineer can gauge the potential energy savings an alternative structural system must be proposed.

To increase efficiency and reduce the structural depth in the current system it would benefit to either use smaller spacing between beams or use a two way beam system with intersecting beams within bays. However, this increases the amount and design of connections and increases the amount of members to be installed and connected in the field. Therefore an investigation will be done to redesign the gravity system of the north and west wings with a concrete floor system. Due to the complex nature and strict design requirements to be met within the cantilever section of the building the cantilever system will be kept as a steel framed system, with the incorporation of the large c-shaped shear walls.

Thus a full redesign of the structural system is proposed as a three building mixed system solution as shown in Figure 8. This design consists of typical concrete floor system and frame within the North and West wings connected by a steel framed section forming the corner of the L-shape. The steel section includes the cantilever truss system, connecting the corner between the two wings. The three building sections will be connected with a seamless yet abrupt transition from concrete to steel framing, thus no expansion joints will be designed.

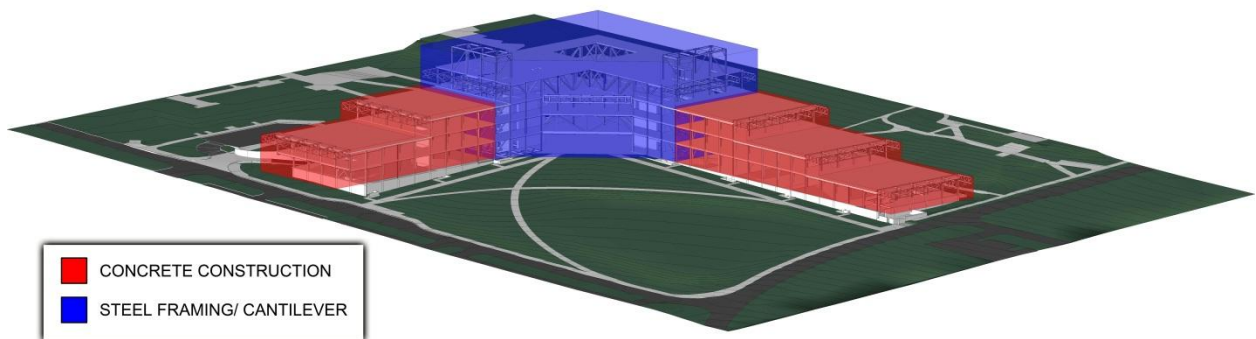


Figure 9: Proposed three building solution

Construction Tasks and Tools

1. *Cost Analysis*

- a. Produce existing conditions cost data based on Whiting-Turner budget, and quantity take-offs of existing conditions 3D Revit models and 2D drawings, all in conjunction with cost reference data (RSMeans)
- b. Organize into single report in Microsoft Excel
- c. Meet with Str and Mech to discuss designs and obtain information and models for redesigns
- d. Produce quantity take-offs based on information and models presented by hand and using Autodesk QTO
- e. Use quantity take-offs in combination with manufacturer information and cost reference data, such as RSMeans, to develop cost estimates
- f. Organize in report in Microsoft Excel for comparison with existing conditions
- g. Meet with Str and Mech to discuss findings and next step, either proceeding with current proposed redesign or if further iterations are necessary

2. *Floor-to-Floor Height Cost Analysis*

- a. Obtain 3D Revit structural model and 2D drawings for final concrete design of building
- b. Use model and drawings in combination with hand calculations and QTO to produce quantity take-offs for structure if floor-to-floor height is reduced
- c. Perform quantity take-offs for enclosure of building based on a reduced floor-to-floor height
- d. Perform quantity take-offs for labor and equipment use, such as cranes
- e. Use quantity take-offs in combination with manufacturer information and cost reference data, such as RSMeans, to develop cost estimates
- f. Organize in report in Microsoft Excel for comparison with cost estimates for redesign of mechanical system taking advantage of additional space in plenum
- g. Meet with Str and Mech to discuss results and determine most effective solution to proceed with for the building

3. *Schedule Analysis*

- a. Organize existing schedule information from Whiting-Turner schedule for steel erection and mechanical systems
- b. Meet with Str and Mech to discuss designs and obtain information and models for redesigns
- c. Compile information from manufacturers, reference data, such as RSMeans, for systems proposed by Str and Mech
- d. Produce new schedule durations for proposed designs in Microsoft Project and compare with existing schedule
- e. Begin production of 4D model in Navisworks for construction of redesigned structure system in conjunction with erection of precast panels to create most efficient sequence of activities
- f. Meet with Str and Mech to discuss results

4. *Site Logistics Analysis*

- a. Obtain current site logistics plans as a baseline comparison
- b. Use information from crane analysis to determine locations of cranes and delivery points, as well as analyze safety concerns
- c. Analyze sequence of construction in combination with site planning
- d. Produce new site plan drawings where necessary, and meet with appropriate parties to discuss results when required

Mechanical Tasks and Tools

1. *Static Pressure Losses in Duct Systems*
 - a. Select duct run for static pressure analysis
 - b. Model duct run in Revit MEP 2011
 - c. Establish baseline static pressure loss in Revit MEP 2011
 - d. Perform baseline energy analysis with baseline static pressure losses in Trane Trace 700
 - e. Select increments of differentiation for analysis –2,4,6,8,10,12” duct height increases
 - f. Perform static pressure loss evaluations with Revit MEP 2011, incorporating differentiations
 - g. Perform energy analysis for each differentiation in Trane Trace 700
 - h. Graph effects of static pressure losses
 - i. Share findings with STR and CM
 - j. Establish criteria with STR and CM for optimized structural performance, energy savings, and construction costs
 - k. Graph effects of height variations
 - l. Select best utilization of vertical plenum space
 - m. Prove energy savings compared to baseline
 - n. Compare life cycle cost implications with CM
 - o. Model best plenum utilization in Revit Architecture 2011

Structural Tasks and Tools

1. *Existing Conditions Modeling*
 - a. Model existing structural components in ETABS as a base for comparison
 - b. Apply all dead, live, snow, wind, and seismic loads as previously determined
 - c. Run Analysis and spot check member forces to confirm excel calculations
 - d. Determine Seismic design criteria to fundamental modes and periods
 - e. Evaluate overall building performance with respect to code limitations
 - f. Prepare model for modification for alternative systems

2. *Explore Two Way Joist/Beam Floor System(waffle slab is the extreme)*
 - a. Design two-way system for strength using Equivalent Frame Method, using ACI 318-08
 - i. Begin with waffle slab; also consider multiple spacing for beams up to two spaces per bay as in existing steel design. Beams will increase in depth.
 - b. Design columns using spColumn
 - c. Calculate vibration characteristics of two-way system
 - d. Adjust design for vibration requirements
 - e. Design proper connections at intersection of concrete and steel systems
 - f. Model two-way system in ETABS
 - g. Refer to lateral system redesign for shear wall design and modeling
 - h. Run analysis to confirm design forces
 - i. Evaluate overall building performance with respect to code limitations, IBC 2006
 - j. Model two-way system in Revit Structure as coordination model
 - i. Export ETABS model as Revit Link and import into Revit, if link is available
 - k. Obtain coordination feedback from ME and cost analysis feedback from CM
 - l. Determine effectiveness of two way system as compared to the existing steel design
 - m. Explore One-Way Slab Floor System(if two way system is excessive)
 - i. Repeat steps a through i in process 2.
 - ii. Use spBeam to obtain design moments, shears and reinforcement for joists and girders

Plenum Redesign Conclusions

BIMception's redesign of the plenum is aimed at utilizing the vertical usable space to create an efficient coordinated design of structural and mechanical systems. By reevaluating the structural system the value of height can be found for a lifecycle comparison. BIMception will analyze whether this height is best used to reduce floor to floor height and save structural construction costs versus increasing duct size and coordination to reduce energy lifecycle costs.

The structural engineer will be expected to create analytical and coordination models of the proposed redesigned system to be used by the construction manager to estimate the cost and feasibility of the system and height changes. The mechanical engineer will be expected to create an analysis that defines the value of using duct height to decrease fan energy consumption. As an integrated team the value and utilization of the vertical plenum space will select the combination of systems to reduce the effective life cycle cost of the plenum design.

Cantilever Redesign

Problem Statement

The cantilever portion of the Millennium Science Complex makes a large architectural statement on the University Park Campus and makes possible the location of the quiet labs below the landscaped plaza beneath the cantilever. Issues have arisen when considering the engineered systems that go into this design. As an entrance the occupants must be guided to the entrance yet due to the quiet labs below and the vibrational criteria set in place even pedestrian walking vibrations can affect the vibrations transferred into the quiet labs. The current landscape has been designed to limit the amount of pedestrian traffic and the lighting design during the night must reflect this design theory. Also innovative to the cantilever is the structural system that supports a building reaching over 150 feet laterally with no additional support. The stiffness required by the trusses supporting this structure results in large member sections and a layout not typical for a truss configuration.

The landscape in the cantilever plaza attempts to reduce pedestrian traffic with winding serpentine paths. The purpose of the serpentine path is to reduce foot traffic above the nanotechnology labs with strict vibration requirements. This provides conflicting viewpoints when it comes to illuminating the space. This space needs to direct people towards the entrances, showcase the cantilever architecturally, and deter people from entering the plaza paths, but at the same time provide adequate and visually appealing illumination for someone who does enter the pathways.

The structural design for a cantilever of this magnitude requires an innovative solution. The existing design consists of two truss systems in each direction intersecting at the tip of the cantilever. In this design the member sizes and orientation of members within the cantilever trusses are based on overall stiffness to control deflections. The current design deflected six inches under its own weight when assembled and individual members were cambered to account for this deflection. Also a maximum limit of two inches of live load deflection was set for the tip of the cantilever and was met. These limits could not be met if tension members were used due to reduced section areas.

Construction Solution Methods

The first responsibility of the construction manager for this portion of project will be to aide in facilitating the exchange of information amongst the group, and remained involved in design decisions from both a managing perspective and constructability perspective. The goal is to ensure that work for this portion of the project remains on schedule, and adheres to the goals and processes laid out in the BIM Execution Plan created by BIMception. Tables detailing BIMception's BIM goals and uses can be found in Appendix D. The redesign of the structure in the cantilever, along with the redesign of the exterior lighting system in the exterior plaza below the cantilever, will be analyzed based on cost and schedule implications, as well as in regards to crane use and site logistics planning.

A cost analysis will be conducted first, with preliminary cost estimates extracted for the existing structure and lighting system for the cantilever and plaza. These estimates will be based upon a budget provided by Whiting-Turner, as well as quantity take-offs produced from 3D Revit models through Autodesk QTO, as well as by hand using 2D drawings. These will be combined with cost data from manufacturers and cost reference material such as RSMeans, and cost estimates will be created as a comparison to the new designs. A similar process will be followed for the designs of the new structural system and lighting systems, developing quantity take-offs and producing cost estimates based on cost data. Labor costs will also be investigated in conjunction with these design changes to further determine the overall cost of these changes. These results will be compiled in a report, and discussed with the appropriate parties.

Schedule implications for these changes will be investigated to determine what effect they will have on the overall schedule. A redesigned truss system can change lead times for the prefabricated steel truss pieces in the cantilever. In addition to this, changing the exterior lighting system to include additional lighting will had time onto the installation of this system. Additional lead times will also come as part of a new lighting system, and will need to be accounted for within the schedule. Information for this will be obtained through methods such as RSMeans and manufacturer data, and compiled into a new schedule with updated durations for the redesigned systems.

Both a crane analysis and site logistics analysis will be conducted in reference to this location of the building. However, it will primarily tie in with the analyses found in the Plenum Coordination section of this report. Investigations for the cantilever will be conducted in conjunction with the structural framing redesign.

Structural Solution Methods

The redesign of the gravity system will prompt the redesign of the lateral system. A full redesign must take place in the wings to replace the existing steel braced frames with concrete walls. A separate investigation of the cantilever system will test the efficiency of truss layouts incorporating varying shear wall layouts and inverted steel brace orientation to limit deflections, increase shear stiffness, and move toward a strength controlled design over stiffness controlled. This will also prompt a reevaluation of the entire lateral system based on changes in the cantilever layout because the cantilever and shear wall system adds stiffness in both directions the lateral resisting system and affects the loads on each walls lateral resistance contribution.

The investigation of the cantilever will attempt to move toward a more strength controlled truss design that will allow the use of more efficient tension members. This will be accomplished by the addition of shear wall panels extending into the cantilever from the existing shear walls. This can reduce the effective length of the cantilever reducing flexural deformations and increase usable shear area within the concrete walls to reduce shear deformations due to racking in the truss. The hope is that this effort can relax the stiffness demand on the diagonal braces so that the orientation of the braces can be changed to be acting in tension and then can be downsized to a level controlled by strength.

Increases in stiffness due to the addition of concrete shear wall panels will directly affect the relative stiffnesses of each lateral resisting element within the building, specifically the concrete shear walls within the wings. A check of the impact of the cantilever design on the overall lateral system must be carried out to determine the adequacy of all shear walls.

Lighting/Electrical Solution Methods

The cantilever plaza lighting redesign will utilize contrast ratios to draw people towards the building entrance and away from the serpentine pathways. The main sidewalks will be illuminated uniformly with a contrast ratio of 5:1 to the serpentine pathways. To showcase the architectural features of the cantilever, and reinforce the floating theme, it will be washed from below with a contrast ratio of 3:1 to the serpentine pathways. The cantilever wash will be brighter near the entrance and fade towards the end of the cantilever, to aid in drawing people into the building. The pathway will be illuminated non-uniformly with low pole mounted fixtures. All lighting branch circuits will be redesigned to reflect new lighting design.

Construction Tasks and Tools

1. *Cost Analysis*

- a. Produce existing conditions cost data based on Whiting-Turner budget, and quantity take-offs of existing conditions 3D Revit models and 2D drawings, all in conjunction with cost reference data (RSMeans)
- b. Organize into single report in Microsoft Excel
- c. Meet with Str and L/E to discuss designs and obtain information and models for redesigns
- d. Produce quantity take-offs based on information and models presented by hand and using Autodesk QTO
- e. Use quantity take-offs in combination with manufacturer information and cost reference data, such as RSMeans, to develop cost estimates
- f. Organize in report in Microsoft Excel for comparison with existing conditions
- g. Meet with Str and L/E to discuss findings and next step, either proceeding with current proposed redesign or if further iterations are necessary

2. *Schedule Analysis*

- a. Organize existing schedule information from Whiting-Turner schedule for erection of cantilever and exterior lighting systems
- b. Meet with Str and L/E to discuss designs and obtain information and models for redesigns
- c. Compile information from manufacturers, reference data, such as RSMeans, for systems proposed by Str and L/E
- d. Produce new schedule durations for proposed designs in Microsoft Project and compare with existing schedule
- e. Continue production of 4D model in Navisworks for construction of redesigned structure system in conjunction with erection of precast panels to create most efficient sequence of activities
- f. Meet with Str and L/E to discuss results

Structural Tasks and Tools

1. *Reduce Effective Length of Steel Cantilever/ Addition of Concrete Shear Wall Panels*
 - a. Obtain all member forces, shear wall forces, and deflections from existing conditions model
 - b. Propose addition of third bay of shear wall into plaza to L/E, ME, and CM
 - i. Consider impact on architectural aspects and landscape of entrance plaza
 - ii. Remove concrete from below existing truss profile if negative feedback from architectural design review with L/E, ME, and CM
 - c. Change orientation of all compression members within truss to tension members
 - d. Run ETABS analysis and gauge impact of additional shear wall on deflections
 - e. Optimize size of tension members to obtain similar cantilever performance if possible
 - f. Rerun analysis until optimal design achieved
 - g. Add one more panel of concrete into the cantilever on each truss
 - h. Repeat steps d through f
 - i. Determine if addition of concrete within the cantilever will achieve a strength controlled truss design
 - j. Run lateral system analysis to determine effect of new cantilever relative stiffnesses with respect to the rest of the system and confirm adequacy of all shear wall designs to resist distributed lateral loads.
 - k. Model two-way system in Revit Structure as coordination model
 - i. Export ETABS model as Revit Link and import into Revit, if link is available
 - l. Obtain coordination feedback from ME and cost analysis feedback from CM
 - m. Determine effectiveness of redesigned cantilever system as compared to the existing steel design

1. *Design Concrete Shear Walls to Replace Existing Braced Frames in Concrete Wings*
 - a. Use existing conditions ETABS model to determine lateral force demands on braced frames and c-shaped shear walls
 - b. Determine stiffness of each braced frame in the wings using ETABS
 - c. Design concrete shear walls with the same dimensions and similar stiffness to the steel braced frames to be used in the concrete wings
 - d. Model shear walls in place of braced frames in ETABS model, within the extents of the concrete wings
 - e. When analysis is run in ETABS check lateral forces on each wall to confirm adequacy of wall design

Lighting/Electrical Tasks and Tools

1. *Cantilever Plaza Lighting Design*
 - a. Establish criteria and considerations
 - b. Schematic Design
 - c. Schematic Design presentation at Lutron.
 - d. Reassess Schematic Design
 - e. Select luminaires
 - f. Build lighting model
 - g. Render space

Cantilever Redesign Conclusions

Bimception's decision to respect the architectural statement made by the monumental 150 foot building cantilever over the large entrance plaza has authored investigations of the effectiveness of the lighting system to highlight the building component as well as the structural system used to accomplish a feat not normally seen in a building design. In all such a unique feature requires a respectively unique design of the incorporated building systems. All changes to the structural truss designs that support the cantilever must then be considered in the entire building design and analyzed as a whole. The CM must keep track of these changes to assess the construction cost and constructability of the structure.

The L/E will deliver perspective images of the redesigned lighting system and the illumination effect on the cantilever plaza landscape and the underside of the cantilever overhangs. A Lighting Design report of all required and proposed lighting requirements as well as results from redesign analysis including foot candle values and lighting power densities in specific areas will be documented. This redesigned lighting system is expected to be more effective at highlighting the monumental nature meant to emanate from the entrance plaza and building cantilever.

The innovative redesign of the cantilever structural system is expected to result in the addition of concrete panels within the truss configurations to add stiffness and improve stiffness efficiency of the trusses. With the redesign of these trusses and the corresponding effect on the lateral loads will result in a full redesign of the lateral system with the replacing and redesign of the lateral elements in the wings with concrete shear walls. Documentation of the design iterations of the cantilever will include detailed elevations showing designed truss layouts, member sizes, and corresponding member stresses. Relative stiffnesses and distribution of loads within the lateral system will be reported to confirm design adequacy of lateral elements. Modeling in Revit architecture will combine these design changes with the gravity system redesigns in a coordination model for use by the CM.

The construction manager must keep track of all design changes for such an important and complex area of the building as the cantilever system. All of the redesigns are focused on the efficiency of building systems involved. Reduced weight from the façade redesigns and a more efficient truss layout is expected to lower the overall material costs of the cantilever without a negative impact on schedule and site logistics planning. Deliverables include a cost report comparing initial and final structural redesigns. These costs will be based on quantity take-offs obtained from the coordination models modeled by the engineers. An updated schedule will report the new durations concerning construction activities. Site logistics plans concerning schedule and site usage will be reported as Auto CAD plans. Also a 4D Navisworks model will act as a summary of the construction process incorporating schedule durations and site usage into a time based movie and additional images.

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APPENDIX B: Proposed Schedule and Timetable


Final Submission *Date*		1/28/2011 Milestone 1	2/18/1011 Milestone 2	3/4/2011 Milestone e 3	Spring Break	3/25/2011 Milestone 4			Stephen Pfund Christopher Russell Alexander Stough Thomas Villacampa										
Team Member	Winter Break	10-Jan-11	17-Jan-11	24-Jan-11	31-Jan-11	7-Feb-11	14-Feb-11	21-Feb-11	28-Feb-11	7-Mar-11	14-Mar-10	21-Mar-11	28-Mar-11	4-Apr-10	11-Apr-11	18-Apr-11	25-Apr-11		
	Existing Conditions Model	Gravity System Redesign/Modeling		Cantilever Redesign/Modeling		Lateral System Redesign/Modeling		Strength Design of Façade		Design Façade Connections to Steel and Concrete Columns		Reevaluate Exterior Structure							
		Vibrational Analysis Research																	
	Existing Façade Strength Analysis																		
	Proposed Thesis Semester Schedule January 2011-April 2011																		
	Final Presentation																		

Figure 10: Structural Schedule and Timetable

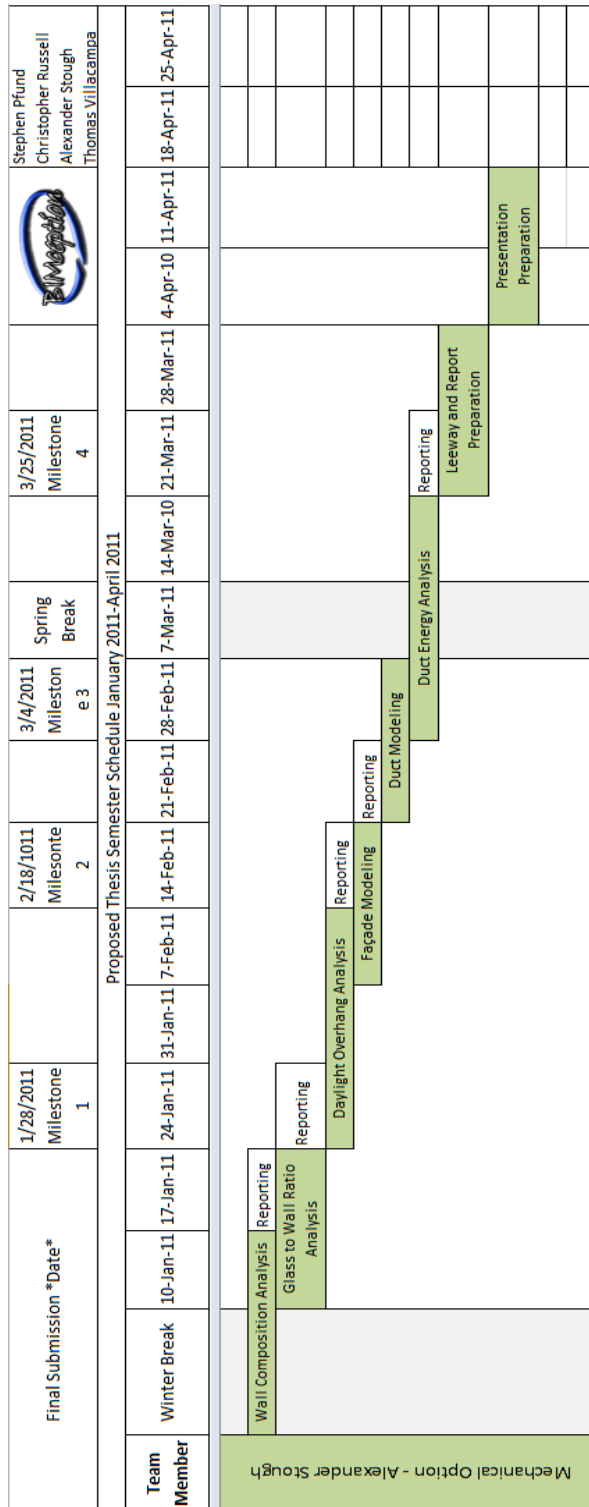


Figure 12: Mechanical Schedule and Timetable

Final Submission *Date*		1/28/2011 Milestone 1	7-Feb-11	14-Feb-11	21-Feb-11	28-Feb-11	7-Mar-11	14-Mar-10	21-Mar-11	28-Mar-11	4-Apr-10	11-Apr-10	18-Apr-11	25-Apr-11				
Proposed Thesis Semester Schedule January 2011-April 2011		1/28/2011 Milestone 1	7-Feb-11	14-Feb-11	21-Feb-11	28-Feb-11	7-Mar-11	14-Mar-10	21-Mar-11	28-Mar-11	4-Apr-10	11-Apr-10	18-Apr-11	25-Apr-11				
Team Member	Winter Break	10-Jan-11	17-Jan-11	24-Jan-11	31-Jan-11	7-Feb-11	14-Feb-11	21-Feb-11	28-Feb-11	7-Mar-11	14-Mar-10	21-Mar-11	28-Mar-11	4-Apr-10	11-Apr-10	18-Apr-11	25-Apr-11	
Construction Management Option - Thomas Villacampa	Schedule Analysis of Existing Building																	
	Cost Analysis of Precast Panels																	
	Cost Analysis of Exterior Glass/Light Sheet																	
	Cost Analysis of Mech/ Lighting System (Façade)																	
	Cost Analysis of Gravity System																	
	Compile Existing Site Plans																	
	Cost Analysis Existing Building Crane Analysis																	
	Schedule Analysis of Structure																	
	4D Modeling																	
	Site Logistics Analysis																	
Schedule Analysis of Lighting/ Mech. Systems (Façade)																		
Schedule Analysis of Mech/ Lighting System (Façade)																		
Schedule and Cost Analysis of Cantilever Structure																		
Schedule and Cost Analysis of Ductwork																		
Cost and Logistics Analysis based on Crane Analysis results for Structure																		
Cost Analysis of Floor-to-Floor																		
Cost and Schedule Analysis of Connections and Exterior Structure																		
Final Presentation																		

Figure 13: Construction Manager Schedule and Timetable

APPENDIX C: Mechanical Existing Conditions

	<i>Electricity (kWh)</i>		<i>Purchased Steam (therms)</i>		<i>Purchased Chilled Water (therms)</i>	
	<i>90.1</i>	<i>Design</i>	<i>90.1</i>	<i>Design</i>	<i>90.1</i>	<i>Design</i>
<i>Jan. Energy</i>	62,633	53,682	3,856	3,720	1,629	351
<i>Jan. Cost</i>	\$4,708	\$4,035	\$3,162	\$3,051	\$2,981	\$642
<i>Feb. Energy</i>	56,759	48,539	3,624	3,487	1,463	288
<i>Feb. Cost</i>	\$4,267	\$3,649	\$2,971	\$2,859	\$2,678	\$526
<i>Mar. Energy</i>	65,874	57,236	3,034	2,715	2,184	747
<i>Mar. Cost</i>	\$4,952	\$4,302	\$2,488	\$2,226	\$3,996	\$1,367
<i>Apr. Energy</i>	61,607	53,705	1,994	1,724	2,507	1,193
<i>Apr. Cost</i>	\$4,631	\$4,037	\$1,635	\$1,414	\$4,588	\$2,182
<i>May Energy</i>	66,840	60,696	959	869	4,187	3,060
<i>May Cost</i>	\$5,024	\$4,562	\$786	\$713	\$7,663	\$5,600
<i>Jun. Energy</i>	66,191	62,053	1,239	989	6,091	4,745
<i>Jun. Cost</i>	\$4,976	\$4,665	\$1,016	\$811	\$11,146	\$8,682
<i>Jul. Energy</i>	65,824	62,375	1,602	1,280	9,260	7,271
<i>Jul. Cost</i>	\$4,948	\$4,689	\$1,318	\$1,050	\$16,946	\$13,305
<i>Aug. Energy</i>	68,852	64,321	1,442	1,164	6,961	5,358
<i>Aug. Cost</i>	\$5,176	\$4,835	\$1,182	\$954	\$12,739	\$9,805
<i>Sep. Energy</i>	63,380	56,988	973	860	4,378	3,135
<i>Sep. Cost</i>	\$4,764	\$4,284	\$798	\$705	\$8,012	\$5,738
<i>Oct. Energy</i>	64,895	57,109	1,870	1,660	2,610	1,313
<i>Oct. Cost</i>	\$4,878	\$4,293	\$1,534	\$1,362	\$4,777	\$2,403
<i>Nov. Energy</i>	61,832	54,547	2,451	2,203	2,122	846
<i>Nov. Cost</i>	\$4,648	\$4,100	\$2,010	\$1,806	\$3,884	\$1,549
<i>Dec. Energy</i>	61,292	53,029	3,645	3,446	1,646	399
<i>Dec. Cost</i>	\$4,607	\$3,986	\$2,989	\$2,826	\$3,013	\$730

Figure 14: Baseline ASHRAE 90.1 & Existing Model Monthly Energy Consumption & Costs

	<i>ASHRAE 90.1</i>	<i>Existing Design</i>	<i>Percent Savings</i>	<i>Cost Savings</i>
<i>Electricity (kWh)</i>	765,979	684,280	11%	\$6,141
<i>Purchased Chilled Water (therms)</i>	45,039	28,705	44%	\$29,891
<i>Purchased Steam (therms)</i>	26,694	24,119	9%	\$2,111
<i>Total Costs and Savings</i>	\$161,889	\$123,745	23%	\$38,144

Figure 15: Summarized Annual Energy Results

	<i>Cooling (tons)</i>	<i>Heating (MBTUh)</i>	<i>Supply Airflow (cfm)</i>	<i>Outside Air Percentage</i>	<i>cfm/ft²</i>
<i>Baseline 90.1</i>	113.3	779.6	39,814	16.3	1.39
<i>Existing Design</i>	97.2	513.9	28,974	22.5	1.01

Figure 16: Office Zone Load Summary

	<i>Cooling (tons)</i>	<i>Heating (MBTUh)</i>	<i>Supply Airflow (cfm)</i>	<i>Outside Air Percentage</i>	<i>cfm/ft²</i>
<i>Baseline 90.1</i>	295.8	3,151.4	34,078	100.0	2.19
<i>Existing Design</i>	217.7	2,409.2	25,588	100.0	1.64

Figure 17: Office Zone Load Summary

APPENDIX D: BIM Execution Planning

BIM Goals

Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	Value added objectives	
1	Life Cycle Cost / Value Engineer all design decisions	Cost Estimation, Engineering Analysis, Building System Analysis, Design Reviews, Existing Conditions Modeling
1	Optimize Building Performance	Engineering Analysis, Building System Analysis, Design Reviews, Existing Conditions Modeling, Site Analysis
1	Eliminate Field Conflicts	3D Coordination, Design Reviews, Existing Conditions, Modeling, Design Authoring
1	Improve Energy Efficiency	Engineering Analysis, Building System Analysis, Design Reviews, Site Analysis, Existing Conditions Modeling, Design Authoring
1	Improve Daylighting	Engineering Analysis, Building System Analysis, Design Reviews, Site Analysis, Existing Conditions Modeling, Design Authoring
1	Optimize Sequence and Schedule	4D Modeling

BIM Uses

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resour	Notes	Proceed with Use
				Scale 1-3 (1 = Low)					
	High / Med / Low		High / Med / Low	Resources	Competency	Experience			YES / NO / MAYBE
Maintenance Scheduling	Low								NO
Building Systems Analysis	High	MEP	High	3	3	2			YES
		STR	Med	3	3	2			
		L/E	High	3	3	2			
Record Modeling	Low								NO
Cost Estimation	High	CM	High	3	3	2			YES
4D Modeling	High	CM	Med	3	3	2			YES
Site Utilization Planning	Low								NO
Layout Control & Planning	Low								NO
3D Coordination (Construction)	Low								NO
Engineering Analysis	High	MEP	High	3	3	2			YES
		STR	High	3	3	2			
		L/E	High	3	3	2			
Site Analysis	Med	MEP	Med	3	3	2			YES
		L/E	Med	3	3	2			
Design Reviews	High	MEP	High	3	3	2			YES
		STR	High	3	2	2			
		CM	High	3	2	1			
		L/E	High	3	2	1			
3D Coordination (Design)	High	MEP	High	3	3	2			YES
		STR	High	3	2	2			
		CM	Med	3	2	1			
		L/E	Low	3	2	1			
Existing Conditions Modeling	Low	MEP	Low	3	3	2			YES
		STR	Med	3	3	3			
		CM	Low	3	3	2			
		L/E	High	3	3	3			
Design Authoring	Med	MEP	Low	3	3	2			YES
		STR	High	2	2	2			
		L/E	Med	2	3	3			
Programming	Low								NO
Energy Analysis	High	MEP	High	3	3	2			YES
		L/E	Med	3	3	2			

APPENDIX E: Additional Thesis Requirements

Mechanical MAE

In order to fulfill the requirements established for the MAE program, I will investigate the exterior façade with material taught in AE542 – Building Enclosure Design and Science. This class analyzes the effects the enclosure can have on the control of thermal transfer and structural loading. In addition, AE558 – Centralized Heating Production and Distribution Systems will be used for economic modeling and system lifecycle costing.

Structural MAE

The structural MAE requirements will be fulfilled through the incorporation of knowledge gained from the three MAE electives completed so far. Advanced 3d computer modeling, based on lessons in AE 597A-Advanced Computer Modeling of Building Structures, will be used to model the gravity and lateral systems to achieve proper simulation of building performance. The model will use proper assumptions and modeling techniques including connection rigidities, boundary conditions, shear wall meshing, and rigid and semi-rigid diaphragm assignments. In combination with methods of analysis and design for seismic and wind loads obtained from both AE 597A and AE538-Earthquake Resistant Design of Buildings, The Lateral System can be modeled analyzed and redesigned. The use of the knowledge gained from AE534-Steel Connections Design will additionally be used to reevaluate and design proper connections of the façade to the exterior columns and to design adequate connections for steel to concrete members.

APPENDIX F: Citations

^[1] IESNA Lighting Handbook 10th Edition. (2010).