

# UNIT 1: IPD/BIM DISCUSSIONS



## BIM/IPD TEAM #3

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## EXECUTIVE SUMMARY

KGB Maser is pleased to present the team's year-long senior capstone thesis project for AE482. Over the course of the year, the team has collaboratively assessed the current Millennium Science Complex building design and targeted areas where the team could explore design enhancements through integrated project deliver and building information modeling platforms. The KGB Maser team consists of a student from each discipline within Architectural Engineering at Penn State. Each discipline came into the IPD/BIM thesis with sufficient background in building information modeling programs. Together, KGB Maser has analyzed engineering systems of the Millennium Science Complex using BIM software in an IPD environment. Specifically, the team made efforts to analyze the façade, optimize energy performance, and redesign the structure to attempt to save cost of the building.

The existing façade consists of a pre-cast panel system sized to span each 22'-0" bay. The brick veneer wraps around the approximately 27-inch deep reveal to eight feet of window wall. The windows are separated vertically by a louvered overhang that reaches out to the plane of the pre-cast panels. Team members dissected daylight delivery, structural integrity, indoor environment, and constructability to achieve a cost-effective alternative to the existing façade composition. Through substituting a triple-pane glazing for the existing double-pane glazing, reducing the depth of the panel flanges, and optimizing the overhangs for daylight and indoor environment, the team is able to reduce mechanical operating costs by 1.5%. Additionally, the dimming system in public perimeter zones saves 6.97% in automated areas. The flange thickness reduced to 15.75" resulting in \$243,932 savings in estimated construction costs.

The next phase of KGB Maser's analysis aims to reduce energy consumption through optimizing the mechanical distribution system. Research in ASHRAE Journal articles and Labs21 design guides has shown that chilled beam application in a laboratory facility can produce substantial savings in operating costs. The chilled beam redesign was applied to the whole building with the use of single enthalpy wheel and enthalpy-sensible wheel air handling units. The system was sized in response to façade design changes and the resulting electrical system implications were assessed. Annually operating costs are 14.1% less than the existing VAV design. Life cycle cost analyses demonstrated that the high initial cost will be suppressed over a thirty year span. A separate study was performed to quantify energy savings for reducing fume hood face velocity. Through analysis with a computational fluid dynamics model, similar containment effectiveness was found to warrant energy savings with lower face velocities.

The expensive cantilever structure was investigated for redesign possibilities that could reduce materials and therefore structural cost. The 154 foot cantilever is supported by four main trusses whose members are controlled by stiffness rather than strength. By placing two columns underneath the intersections of these four trusses, stresses are reduced and truss members can be downsized. Bays of bracing that once resisted the cantilever's inherent overturning moment can now be removed due to different end conditions. A sculpture was added underneath the overhang to enhance the support of the cantilever and prohibit pedestrian traffic over the nano-technology labs relieve the space visually.

Through each of KGB Maser's phases of analysis, communications between team members and model sharing software needed continuous input. KGB Maser chose to continue use of Revit analytical models provided by the design team and share information across a spectrum of BIM software.

## FOREWORD: INTENT AND USE OF THIS DOCUMENT

Being part of the IPD/BIM Thesis pilot program has its inherent challenges. Teamwork is a major theme throughout the duration of projects. Groups do their best to perform as a single, full-service design firm – a well-oiled machine. The challenge for IPD/BIM groups is hinged on two goals – working as a team and presenting a cohesive product that embodies the team dynamic used during the 2010-2011 academic year. Not only must each student be part of the team, but must also display knowledge and proficiency in engineering studies. The structure of this document tries to accommodate both team and individual requirements for the Architectural Engineering senior capstone thesis project.

The reader will be introduced to two binders collectively form one final report – the body and the appendices. Using two books will allow readers to consult tables, figures, drawings, and manufacturer information while concurrently examining the analysis portion of the report.

The body of the report has been divided into 5 units: IPD/BIM, Construction Management, Lighting/Electrical, Mechanical, and Structural. In no way is this document structure intended to imply disconnects in teamwork throughout the academic year. Rather, the document separates information based on topic. The reader can easily maneuver to the portion of the document they are most interested in. Supporting engineering calculations and explanations are grouped together in option-specific units to highlight discussions of teamwork and integration.

The appendices section of the final report is structured in the same fashion as the body. Each unit of the body has its associated set of appendices to support design discussions, also named and numbered by unit. Again, this format is designed to keep readers on the same naming and numbering convention between analysis and appendices so as not to become disoriented within the document.

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## IPD INTERACTIONS: FULL SERVICE DESIGN

KGB Maser maintained three objectives throughout the entire redesign process. Reducing the cost of the façade, creating more energy efficient lighting, electrical and mechanical systems, and reducing the cost of the structure were the collaborative goals. Through negotiation and communication, BIM goals were attained. The process included consistent negotiations and compromises, which replicate engineering as it is practiced in the field.

## ENERGY CONSUMPTION REDUCTION

### CHILLED BEAMS ELECTRICAL SYSTEM IMPACT

KGB Maser's team goal to reduce energy consumption by applying chilled beams instead of a VAV system also impacts the electrical distribution system. The proposed active chilled beam necessitated some equipment changes. The existing air handling units will be resized or deleted while the pumps will be consolidated into a motor control center. The redesign air handling units have a single electrical connection for the entire assembly. Since this is the case, the air handling units will be excluded from the motor control center and simply replace the existing air handling units on their associated distribution panelboards. The air handling unit changes can be reviewed in the "Revised Panelboard Schedules" and "Revised Panelboard Feeder Sizing" section of Unit 3. A summary of the total equipment changes is as follows:

| Existing Equipment |                        |                      |                   |                    | Redesign Equipment   |                                      |                      |                   |                    |
|--------------------|------------------------|----------------------|-------------------|--------------------|--|--------------------------------------|----------------------|-------------------|--------------------|
| Tag                | Service                | Location             | Supply Motor (hp) | Exhaust Motor (hp) | Tag  | Service                              | Location             | Supply Motor (hp) | Exhaust Motor (hp) |
| AHU-1              | Lab                    | Mechanical Penthouse | 100               | (2) 50             | AHU-EXT-1  | Lab/Office                           | Mechanical Penthouse | 50                | 50                 |
| AHU-2              | Lab                    | Mechanical Penthouse | 100               | (2) 50             | AHU-EXT-2  | Lab/Office                           | Mechanical Penthouse | 50                | 50                 |
| AHU-3              | Lab                    | Mechanical Penthouse | 100               | (2) 50             | AHU-INT-LS1  | Interior Labs Life Science           | Mechanical Penthouse | 75                | 75                 |
| AHU-4              | Lab                    | Mechanical Penthouse | 100               | (2) 50             | AHU-INT-LS-2   | Interior Labs Life Science           | Mechanical Penthouse | 75                | 75                 |
| AHU-5              | Lab                    | Mechanical Penthouse | 100               | (2) 50             | AHU-INT-MS1  | Interior Labs Material Science       | Mechanical Penthouse | 75                | 75                 |
| AHU-6              | Offices                | Mechanical Penthouse | 60                | N/A                | AHU-INT-MS2  | Interior Labs Material Science       | Mechanical Penthouse | 75                | 75                 |
| AHU-7              | Offices                | Mechanical Penthouse | 60                | N/A                | CWP-1  | Active Chilled Beams CLG             | Basement Mezzanine   | 150               | N/A                |
| AHU-8              | Offices                | Mechanical Penthouse | 60                | N/A                | CWP-2  | Active Chilled Beams CLG Standby     | Basement Mezzanine   | 150               | N/A                |
| CWP-1              | Chilled Water          | Basement Mezzanine   | 150               | N/A                | CWP-3  | AHUs + Process Chilled Water         | Basement Mezzanine   | 100               | N/A                |
| CWP-2              | Chilled Water          | Basement Mezzanine   | 150               | N/A                | CWP-4  | AHUs + Process Chilled Water Standby | Basement Mezzanine   | 100               | N/A                |
| CWP-3              | Chilled Water Standby  | Basement Mezzanine   | 150               | N/A                | CWP-5  | Chilled Water Low Flow               | Basement Mezzanine   | 60                | N/A                |
| CWP-4              | Chilled Water Low Flow | Basement Mezzanine   | 60                | N/A                | HWP-5  | Active Chilled Beams HTG             | First Floor          | 50                | N/A                |
| HWP-5              | Ventilation Heating    | First Floor          | 40                | N/A                | HWP-6  | Active Chilled Beams HTG Standby     | First Floor          | 50                | N/A                |
| HWP-6              | Ventilation Heating    | First Floor          | 40                | N/A                | Will be consolidated to a motor control center in the basement Mezzanine |                                      |                      |                   |                    |

A detailed discussion of the motor control center design can be viewed in Depth Topic 2 of Unit 3 in this document. In summary, the six pumps that are consolidated to the motor control center yield a 15'-0" long structure that must be located within the basement of the building. The basement has been chosen due to the location of the pumps served by the center. An isometric view of the unit can be seen in Figure 1.1 below:

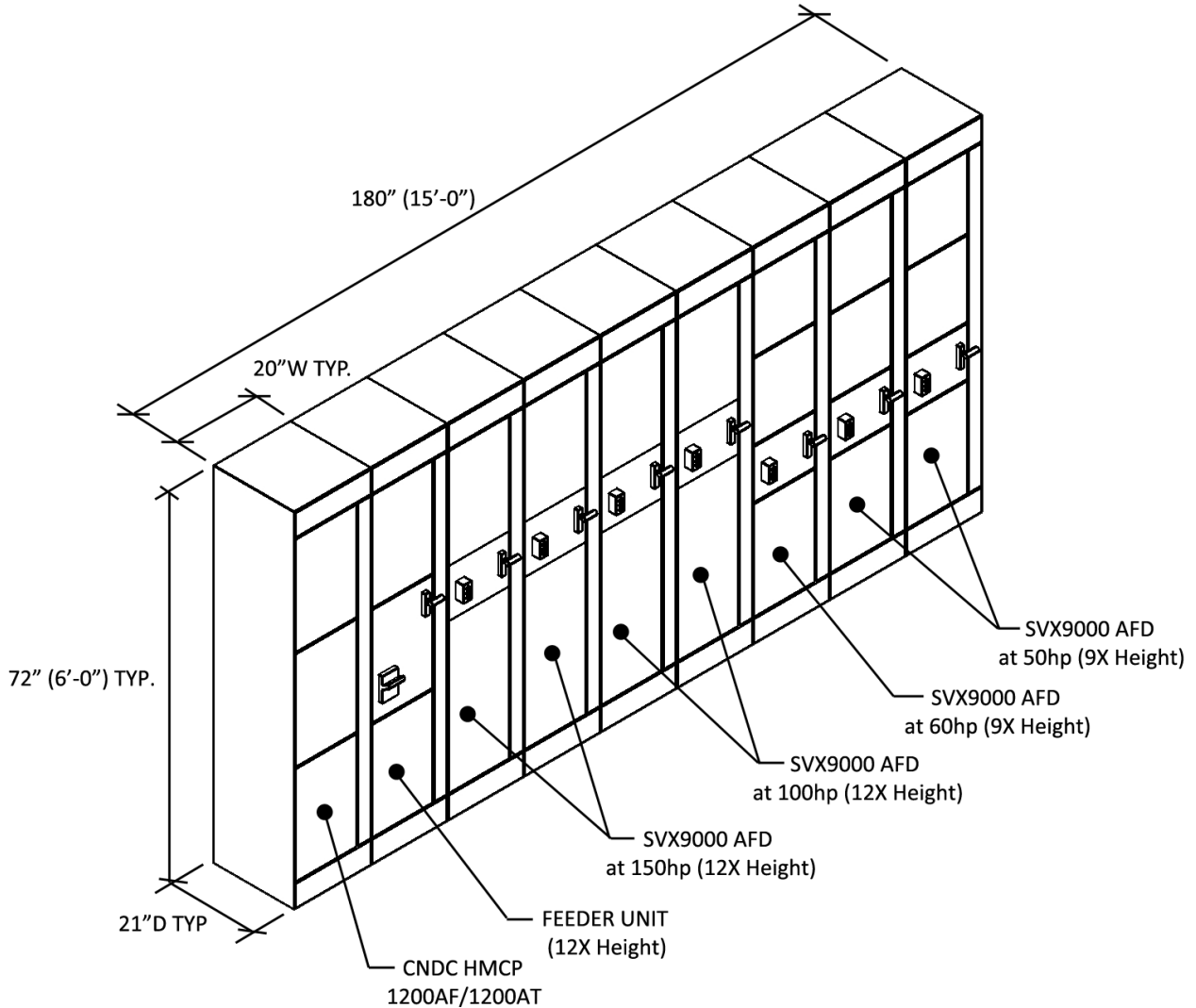


Figure 1.1: Motor Control Center Design Isometric View

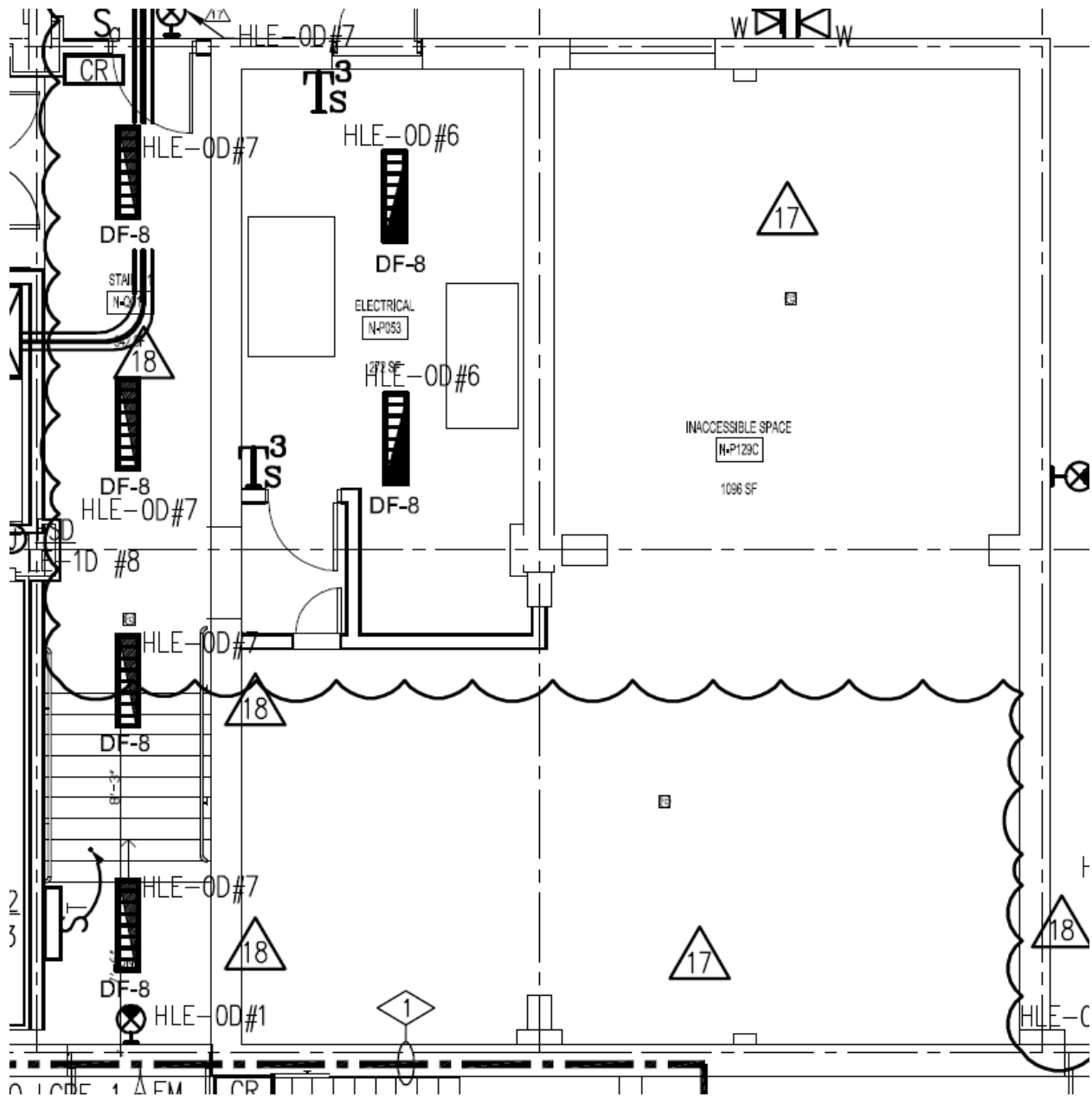


Figure 1.2: Available Space for Motor Control Center, NTS

The dimensions from the aforementioned data result in a motor control center that is 15'-0" in length. With the space now available, the motor control center can be located in the newly formed room using Revit Architecture. The plan for locating the MCC can be seen in Figure 1.3 below:



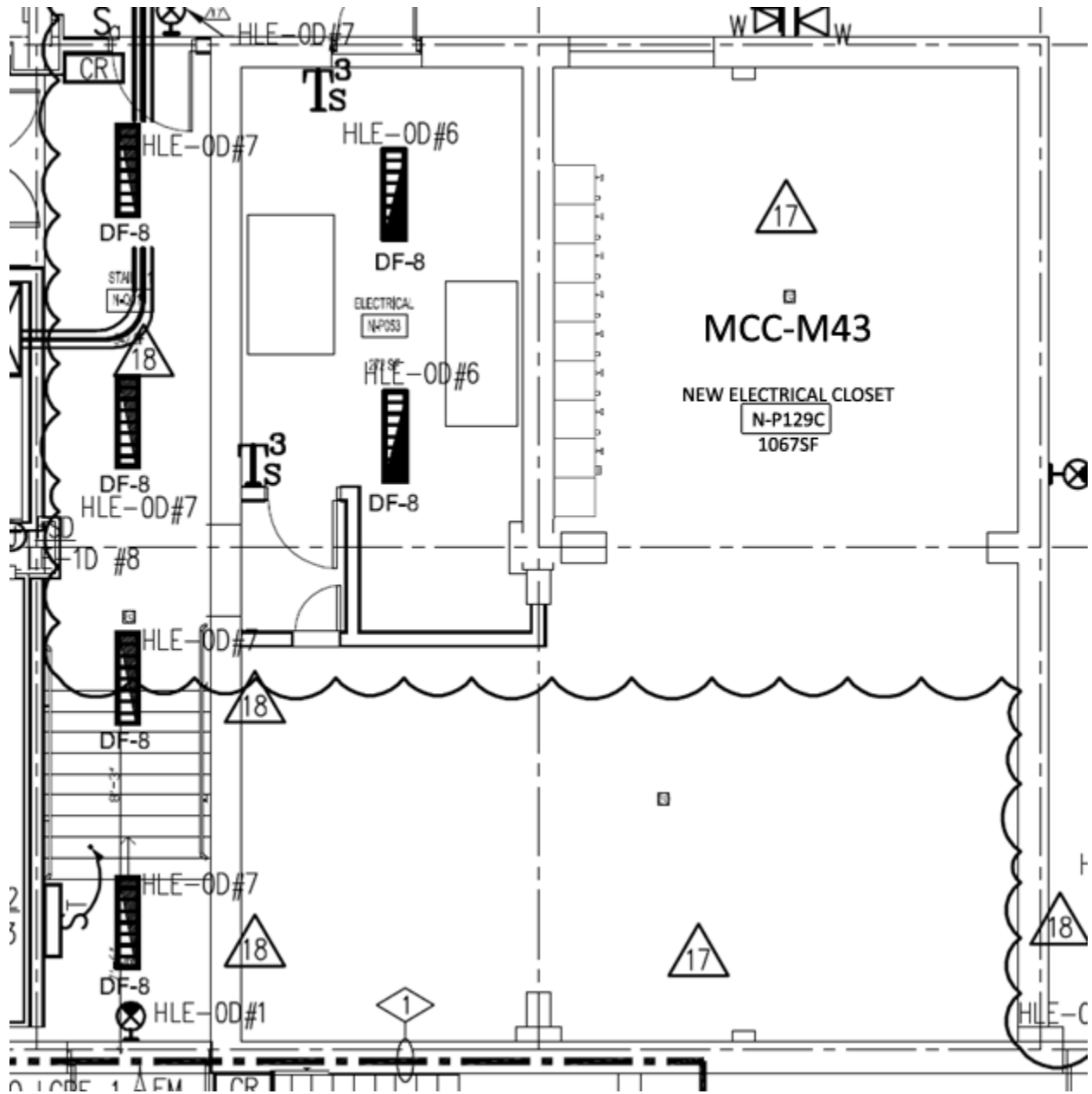


Figure 1.3: Motor Control Center Location Plan, NTS

The feeders running to the pumps will need to be resized according to voltage drop regulations according to the National Electrical Code. In the figure above, they are sized at 125% of the full load current of each motor.

The mechanical engineer used a Trane TRACE model to track the operating costs associated with the existing VAV design and the proposed active chilled beam redesign. The model compares the effectiveness of the two distribution systems. However, to analyze the energy use of each system, the adjusted pump and fan demands needed to be included in the model.

| Comparison of Fan and Pump Energy |                     |                      |
|-----------------------------------|---------------------|----------------------|
|                                   | Fan Energy (kWh/yr) | Pump Energy (kWh/yr) |
| Existing VAV                      | 309,022             | 390,077              |
| Proposed Active Chilled Beam      | 257,607             | 438,177              |

The results in the table above correlate to what would be expected for the systems compared. The next step in system comparison was to assign economic costs to each of the utilities. The rates for purchased chilled water, purchased district steam, and electricity consumption/demand were obtained from Penn State's Office of Physical Plant. The following table compares the results of the final energy model simulated. The detailed energy model was completed for the 3<sup>rd</sup> floor only to gain accurate results. The results were extrapolated by area to provide an estimate of the building's energy use.

| 3 <sup>rd</sup> Floor and Estimated Building Operating Costs |                         |                        |             |
|--|-------------------------|------------------------|-------------|
|  |                         | 3 <sup>rd</sup> Floor  | Building    |
| Existing VAV   | Building Energy kBtu/yr | 16,478,534             | 98,871,204  |
|  | Source Energy kBtu/yr   | 26,688,590             | 160,131,540 |
|  | Operating Costs         | \$250,288              | \$1,501,728 |
|  | Cost/SF                 | \$5.84/ft <sup>2</sup> |             |
| Proposed ACB + Triple Pane Glazing                           | Building Energy kBtu/yr | 13,912,786             | 83,476,716  |
|  | Source Energy kBtu/yr   | 24,018,516             | 144,111,096 |
|  | Operating Costs         | \$214,983              | \$1,289,898 |
|  | Cost/SF                 | \$5.02/ft <sup>2</sup> |             |
|  | Percent Savings         | 14.1%                  |             |

Additionally the mechanical engineer studied the effect of downsizing the face velocity of fume hoods from 100 fpm to 80 fpm. The results of the energy study showed a savings of 30% when operating fume hoods at 80 feet per minute. The lowered face velocity was also modeled in a computational fluid dynamics program to compare the leakage rate of a tracer gas. The simulation of the tracer gas test showed slight increases of contaminant levels at the face of the fume hood. Overall, the concentrations observed in all conditions were less than 0.015% of the tracer gas inlet. For more information on CFD results, please refer to Unit 4. If the lowered face velocity fume hoods were approved by Penn State and the Industrial Hygiene & Safety Officer for the project, additional operating cost savings and equipment changes could be attained. The potential changes are summarized in the following table.

| Summary of Fume Hood Makeup Air Costs and Savings |              |              |
|---|--------------|--------------|
| Metric  | 100 fpm VAV  | 80 fpm ACBs  |
| Cooling/Dehumidification                          | \$233,356.06 | \$122,597.17 |
| Heating   | \$6,479.29   | \$13,447.52  |
| Fan   | \$110,512.71 | \$81,042.65  |
| Humidification                                    | \$17,610.24  | \$33,343.69  |
| CAV Operation Costs                               | \$367,958.30 | \$250,431.03 |
| VAV Multiplier for Operation                      | 0.32         | 0.32         |
| Adjusted Operation Costs                          | \$116,704.95 | \$79,428.95  |
| Percent Savings                                   |              | 31.94%       |

| Fume Hood Exhaust Fan Comparison |                            |        |                 |    |
|----------------------------------|----------------------------|--------|-----------------|----|
| Design                           | Fan Type                   | CFM    | Static Pressure | HP |
| Existing<br>100 fpm              | (3) Greenheck Vektor MD-33 | 21,400 | 5"              | 50 |
|                                  | (3) Greenheck Vektor MD-33 | 11,600 | 5"              | 25 |
| Proposed<br>80 fpm               | (3) Greenheck Vektor MD-33 | 17,200 | 5"              | 40 |
|                                  | (3) Greenheck Vektor MD-33 | 9,280  | 5"              | 15 |

## FLOOR SYSTEM AND MECHANICAL DISTRIBUTION

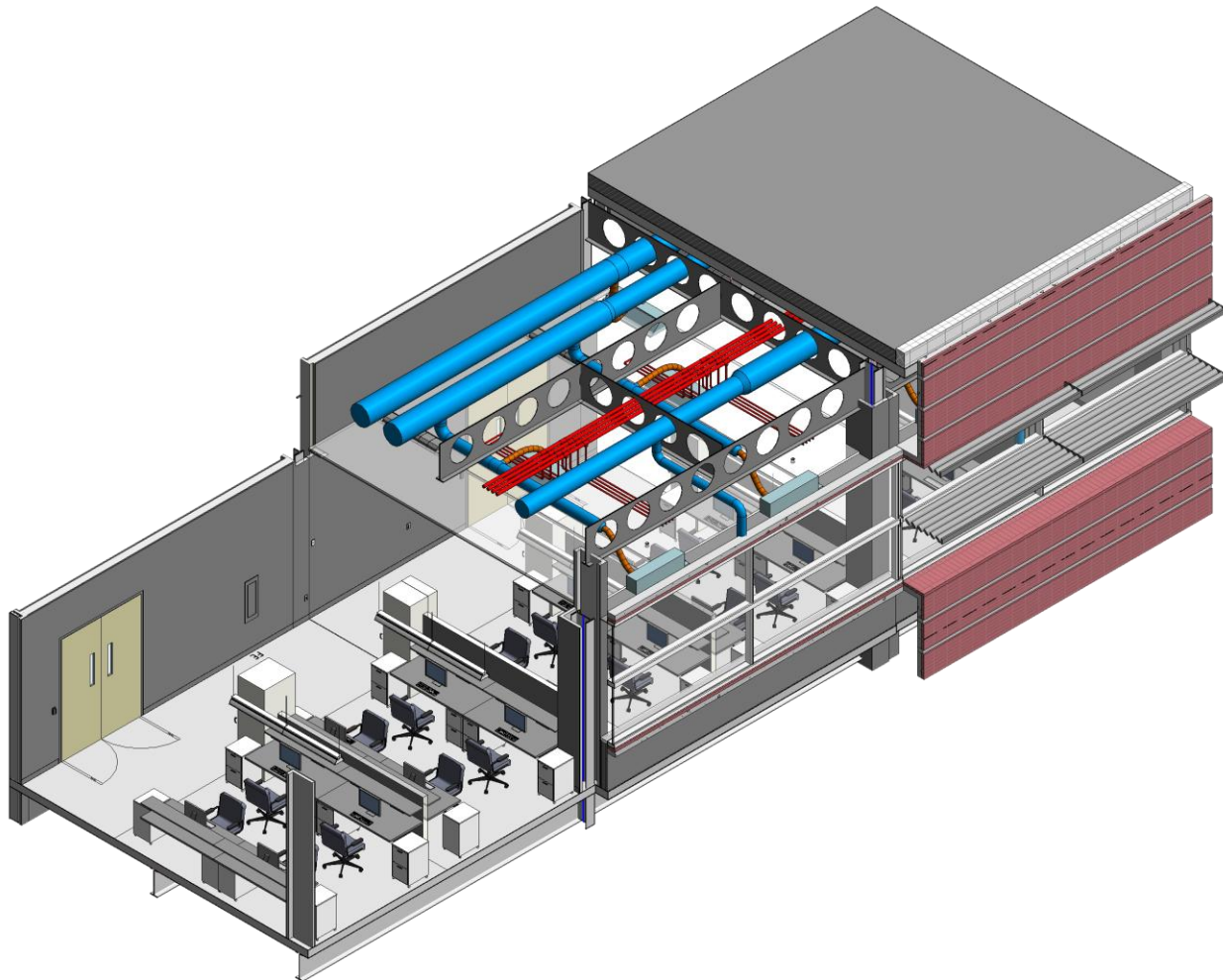


Figure 1.4: 3D Section of Student Area

The smaller mains were sized to fit in the cellular members and had a maximum diameter of 17". One main served the first half of the wing while the second main continued to serve the further half. Within other cellular members, mechanical hot and chilled water piping was easily distributed.

The existing floor system utilizes steel beams and girders to support a composite deck in square, 22' x 22' bays. Wide Flange, 21 inch deep beams frame into 24 inch deep girders in typical fashion. Strict vibrational criterion necessitates the use of heavier beams and lightweight concrete in areas where labs and offices are located. It is this limit on vibrational velocity that controls the design of the current floor system. Velocities were limited to 2000 micro inches per second in the material sciences wing and 4000 micro inches in the life sciences wing. To minimize weight while maintaining stiffness, the engineers used lightweight concrete. Beams and girders had to be sized two to three times larger than required by gravity.

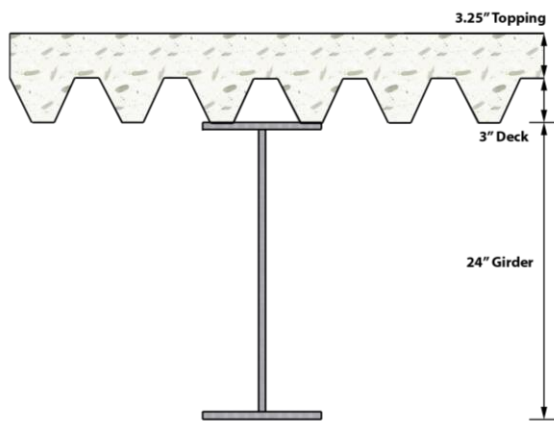


Figure 1.5: Existing Floor Profile

The combination of lightweight concrete and oversized beams allowed the velocities to be limited to around 3900 micro inches per second in both wings; this was discovered after an investigation of vibrations of the existing conditions. Unfortunately this stiffness was acquired by a deep floor profile, 30 inches from top of slab to the bottom of each girder. Plenum space was limited to 7 feet in the third floor and with two and a half being devoted solely to structure, it leads to congestion with the rest of the MEP equipment. In the existing design, holes are cut into the girders and beams at locations of maximum congestion, which also decreases the stiffness of these beams. A proposal was drawn up to maintain the vibrational criteria required of the building while alleviating congestion in the plenum space.

This would be accomplished two ways. The mechanical equipment would use more energy efficient methods to downsize the ducts running through the current plenum, and the existing wide flange beams and girders would be replaced with cellular beams, whose voids would provide an inherent alleyway through which the mechanical ducts could snake.

Using cellular beams has two distinct advantages. The first was mentioned above, as it contains manufactured voids through which mechanical equipment can flow. The second advantage comes in the form of weight and stiffness. Since cellular beams are made from normal wide flanges, their weights are relatively the same as shallower, w-shapes but with a large increase in inertia. The components of these cellular beams are really just the two halves of a typical wide flange cut in a way such that they can be put back together, forming a deeper, stiffer beam.

The biggest issue with this concept is that cellular beams are typically used in longer spans, in buildings whose loads are far less than those seen in the millennium science complex. It is also untraditional for it to be used in a laboratory requiring large exhaust and delivery ducts which cannot be fit through the small voids in a cellular beam. The process of redesign was nonetheless begun with a vibrational study of the existing conditions. Based on this analysis, a baseline was formed to which the redesign was desired to meet.



Figure 1.6: Cellular Beam Fabrication

Because of the large ducts, the cellular beams were sized deeper than would have been normally considered under a purely structural premise. 30-inch deep beams were chosen with 20.75-inch diameter voids in order to accommodate the larger ducts. But even with the larger voids, the existing mechanical equipment was far too large to fit through them.

The mechanical engineer was able to downsize the ducts run to the proposed chilled beams. It was initially decided that while the branch ducts would be able to utilize these voids, the mains could not be fit through such a limited space. The mains would be run underneath the structure. This option would still relieve congestion as it

would not require every duct to be run in the same 4-foot space. The mechanical design altered the distribution of the mains to utilize multiple runs of smaller supply and return ductwork runs that can be integrated within the cellular voids and allowed only the branch ductwork to run beneath the structure. One main served the first half of the wing while the second main continued to serve the further half. Within other cellular members, mechanical hot and chilled water piping was easily distributed. This redesign allowed much of the plenum to be freed of large ductwork allowing space for other distribution systems to be designed without congestion.

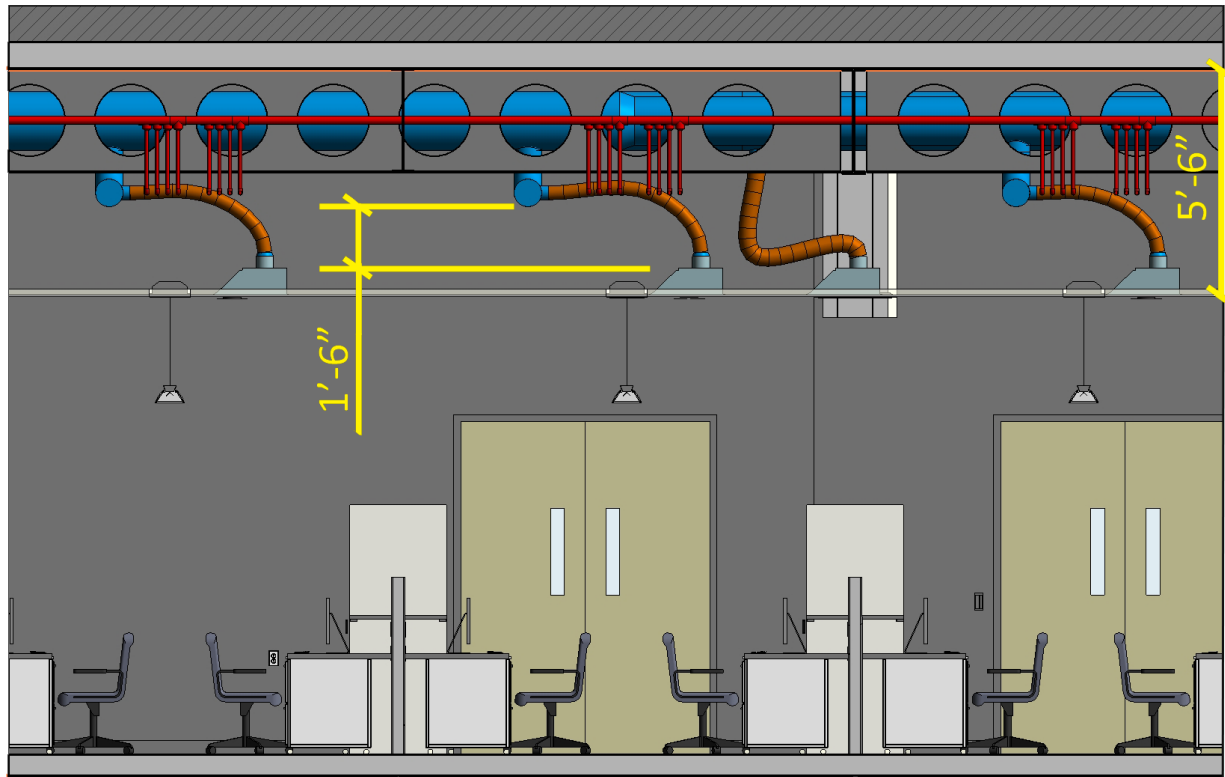


Figure 1.7: Available Plenum Space

## ENERGY EFFICIENCY AND COST MANAGEMENT

The cost management aspect of working toward energy efficiency required close interaction with KGB Maser's mechanical engineer and construction manager. In terms of upfront cost, it was important to the construction manager to limit the amount of excess piping that would be needed for the chilled beams. In terms of construction, the chilled beams have a high upfront cost and are very labor intensive. The cost of each of the mechanical engineers designs was easily estimated for a defined area to quickly assess what the upfront costs would be. The chilled beams were also expected to have a negative effect on the schedule duration for the mechanical system.



FAÇADE REDESIGN

As part of KGB Maser’s objective for energy efficiency, the team performed analyses of overhang depths for both daylighting and envelope load. The end goal is to pick a façade shading system that will be a compromise between mechanical energy usage and daylight dimming energy savings. In aesthetics, the new design is intended to not break up horizontal lines and the overall “length” of the building. The analyses presented take into account overhang depth with and without redesign, energy usage, and operating costs. An overhang depth will be chosen after each analysis is “overlaid” with the other.

MECHANICAL ANALYSIS

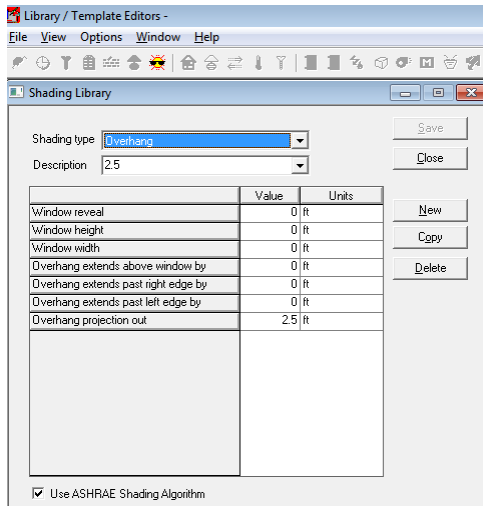


Figure 1.8 Trace Overhang Imports

Modeling the effect of different overhang depths and adding triple pane glazing was done using two different computer modeling platforms. Trane TRACE was used to model the change in overhang depth by adding external overhangs of varying depths within the shading libraries. The existing precast panels created a roughly 2.5 foot overhang. With material costs, and effect on daylighting in consideration, energy models were ran with existing glazing and overhang depths of 2.5 feet, 3.0 feet, and 3.5 feet. Similarly, the existing glazing was changed to triple pane glazing in the Trane TRACE construction templates within the models with the same overhang depths and rerun. The overhangs had to be manually changed for each opening in the third floor. There was no option found that enabled mass changes of overhang to the whole model.

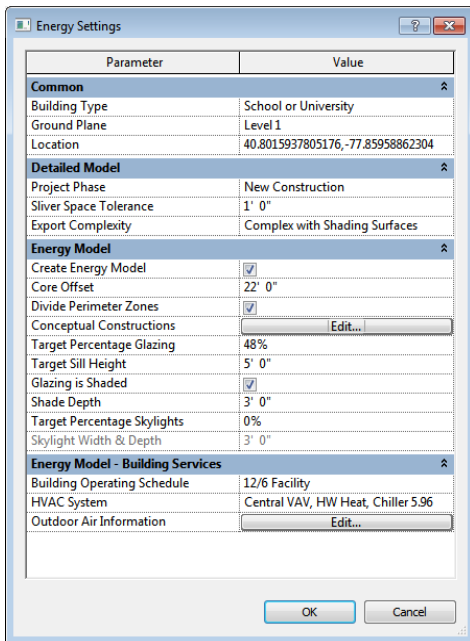


Figure 1.9: Project Vasari Energy Settings

To compare the results of changes in overhang depths and glazing, a mass model was created in Project Vasari. Project Vasari, a technology lab from Autodesk, is meant to provide quick calculations during the conceptual phase of a project. In Project Vasari, The shading depth and window construction was changed as shown in Figure 1.9 and Figure 1.10.

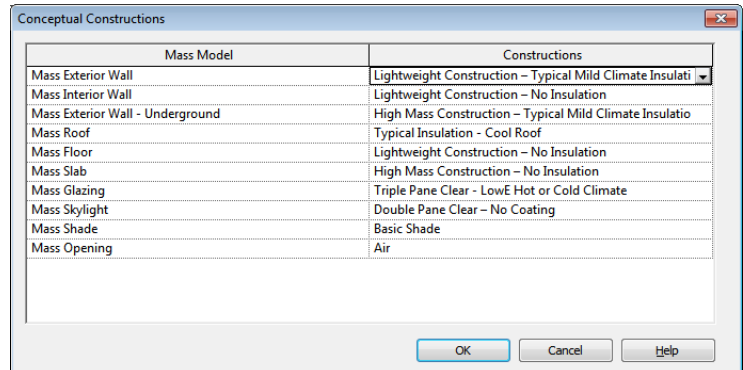


Figure 1.10: Project Vasari Construction Template

| Overhang and Glazing Analysis: Summary of Effect on HVAC Operating Cost |                  |             |             |                  |             |             |             |
|---|------------------|-------------|-------------|------------------|-------------|-------------|-------------|
| Overhang Depth  | Existing Glazing |             |             | Proposed Glazing |             |             |             |
|   | 2.5              | 3           | 3.5         | 0                | 2.5         | 3           | 3.5         |
| TRACE Building Costs  | \$1,501,728      | \$1,494,852 | \$1,490,400 | \$1,512,576      | \$1,481,418 | \$1,478,640 | \$1,478,268 |
| % Decrease from Existing  | -                | 0.45%       | 0.75%       | -0.7%            | 1.35%       | 1.53%       | 1.56%       |
| Vasari Building Costs   | \$953,470        | \$952,430   | \$951,956   | \$888,241        | \$884,272   | \$883,823   | \$883,286   |
| % Decrease from Existing  | -                | 0.11%       | 0.16%       | 6.84%            | 7.26%       | 7.30%       | 7.36%       |

Due to the more detailed load related data input into the TRACE model, it is believed that the numbers from Trane TRACE reports are more accurate than those from Project Vasari. As shown by the case modeled in TRACE without overhangs, the building benefits from shading devices. However, increasing the shading depth after 2.5 proved to have little additional benefit on the operating cost of the Millennium Science Complex. With daylighting and material costs of longer shading considered as well, the best option for the 2.5 feet overhang and triple pane window should be used to maximize efficiency of the façade.

## DAYLIGHTING AND ENERGY

Overhangs are a two-fold advantage in daylight delivery. First, they limit the direct gains on occupants of the space. Secondly, they allow for occupants to use shades less often, depending on overhang depth. This increases the visual interaction between the occupant and the exterior environment. Both of these advantages coexist with the application of a dimming system within the Millennium Science Complex in both the existing design and the redesign of the space. The following study models the existing and redesign student study area for energy usage and utility cost for four of the facades of the Millennium Science Complex – Life Science East and West; and Material Science North and South.

The daylight energy analysis was performed using Daysim – a Penn State Beta release of radiance with a graphical user interface. When using Daysim, a building model can be created in AutoCAD, 3D Studio Max, or Ecotect Analysis. For this study, the model had to be created from scratch in AutoCAD. It is possible to use BIM technologies to arrive at a model for Daysim; however, the process from Revit to AutoCAD does not produce a model that is entirely 3D faces. For more information on lighting analysis processes, see the “BIM Processes for Lighting Design” section of this document. One major advantage to using Daysim over other energy modeling programs is the ability to install and estimate energy usage of shades and dimming systems. Due to the variable nature of shading within the perimeter spaces, shading was left out of this analysis.

The analysis is able to be examined by a “grand total” savings or a “zone savings” from Daysim. In order to estimate savings for the entire perimeter area, the “zone savings” of the redesign space will be applied to the perimeter of the building on a per square foot basis. The initial results are shown in the table below. This initial result is for the Material Science South façade and perimeter area.



| Energy Savings (kWh) |        |        |        |        |        |        |        |        |        |        |        |        |         |           |
|----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|-----------|
| Design Overhang      | Jan    | Feb    | Mar    | Apr    | May    | Jun    | Jul    | Aug    | Sept   | Oct    | Nov    | Dec    | Total   | % Savings |
| Actual Grand         | 135.01 | 112.46 | 118.70 | 107.26 | 123.12 | 117.71 | 117.71 | 123.17 | 113.72 | 127.98 | 128.93 | 125.25 | 1451.08 | 0.00%     |
| New Grand            | 100.58 | 78.23  | 73.52  | 61.91  | 70.60  | 63.21  | 63.13  | 69.44  | 70.10  | 83.76  | 93.91  | 99.26  | 927.72  | 36.07%    |
| 3' Grand             | 97.35  | 75.36  | 70.71  | 60.18  | 68.73  | 62.67  | 62.82  | 67.96  | 67.78  | 81.56  | 91.47  | 96.10  | 902.75  | 37.79%    |
| 3.5' Grand           | 100.16 | 77.80  | 73.03  | 61.65  | 70.54  | 63.10  | 63.02  | 69.23  | 69.73  | 83.36  | 93.51  | 98.95  | 924.12  | 36.32%    |
| 4' Grand             | 96.29  | 74.55  | 70.08  | 59.68  | 68.31  | 62.60  | 62.78  | 67.51  | 67.09  | 80.87  | 90.47  | 95.06  | 895.33  | 38.30%    |
|                      |        |        |        |        |        |        |        |        |        |        |        |        |         |           |
| Actual Zone          | 49.61  | 38.20  | 37.02  | 33.01  | 37.73  | 36.03  | 36.03  | 37.78  | 35.75  | 42.59  | 47.24  | 47.28  | 478.33  | 0.00%     |
| New Zone             | 60.40  | 43.29  | 35.08  | 26.96  | 30.42  | 24.77  | 24.69  | 29.25  | 33.41  | 43.58  | 55.47  | 62.57  | 469.95  | 1.75%     |
| 3' Zone              | 57.17  | 40.42  | 32.27  | 25.24  | 28.55  | 24.23  | 24.38  | 27.77  | 31.09  | 41.38  | 53.04  | 59.41  | 444.99  | 6.97%     |
| 3.5' Zone            | 59.97  | 42.86  | 34.59  | 26.70  | 30.35  | 24.66  | 24.58  | 29.05  | 33.04  | 43.17  | 55.07  | 62.26  | 466.36  | 2.50%     |
| 4' Zone              | 56.11  | 39.61  | 31.64  | 24.74  | 28.12  | 24.16  | 24.34  | 27.32  | 30.40  | 40.68  | 52.03  | 58.36  | 437.57  | 8.52%     |

Each façade interacts with daylight differently. The original Daysim model was edited and rotated to account for the other three facades of the Millennium Science Complex. The results of the new models are shown in the table below:

| Orientation Change Summary |                           |                    |               |                   |               |                   |               |
|----------------------------|---------------------------|--------------------|---------------|-------------------|---------------|-------------------|---------------|
| Design Overhang            | MS South kWh from Table X | Mat. Science North |               | Life Science East |               | Life Science West |               |
|                            |                           | Total kWh          | % of MS South | Total kWh         | % of MS South | Total kWh         | % of MS South |
| Actual Grand Total         | 1451.08                   | 1446.46            | 99.68%        | 1457.40           | 100.44%       | 1447.28           | 99.74%        |
| Actual Zone Total          | 478.33                    | 473.70             | 99.03%        | 484.65            | 101.32%       | 474.53            | 99.21%        |

Since the results from changing orientation varied on average of +/- 1%, the Material Science South model was used to calculate energy usage for the entire perimeter. This 1% difference will only add up to a few pennies of savings for the operation of the whole system. Figure 1.11 below shows the results of the analysis in chart-form.

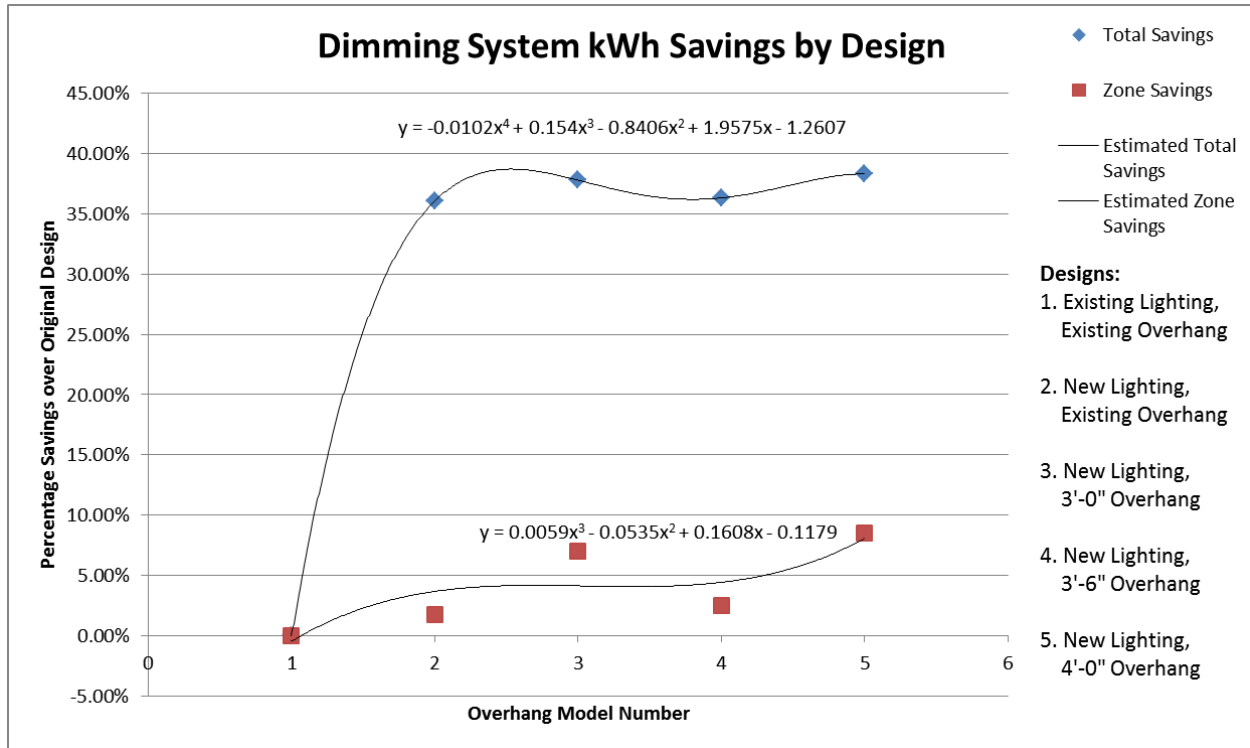


Figure 1.11: Daysim energy analysis results

The maximum savings for daylighting are as follows:

|                            |                           |            |        |
|----------------------------|---------------------------|------------|--------|
| Total Optimum Overhang:    | 2.756 ft, 40.26 % savings | 867.17 kWh |        |
| Zone Optimum Overhang:     | 2.796 ft, 4.24 % savings  | 458.05 kWh | 810 SF |
| Existing Overhang and Ltg: | n/a 0% savings            | 478.33 kWh | 810 SF |

At the maximum zone savings of the overhang (approximated to 2.8 ft), the savings density is as follows:

|                 |   |
|-----------------|---|
| Existing System | 0.5905 kWh/SF applied to 14115 SF of perimeter area |
| 2.8' Overhang   | 0.5655 kWh/SF applied to 14115 SF of perimeter area |

|                 |                          |
|-----------------|--------------------------|
| Existing System | 8335.34 kWh energy usage |
| 2.8' Overhang   | 7981.95 kWh energy usage |
| Net Difference  | 353.40 kWh energy usage  |

Total operating cost savings at \$0.08/kWh is \$28.27

This total energy cost savings is minimal once analysis is performed, but it does not tell the entire story of the design. The existing dimming system utilizes three two-lamp fixtures connected to the Lutron Ecosystem dimming controls. The redesign consists of two two-lamp fixtures connected to the same Lutron Ecosystem. For an in-depth description of the lighting redesign, see Unit 3. The redesign will save on up-front costs by having one less luminaire per dimming row. However, this initial cost savings is balanced out by the operating characteristics of the system. The initial design dimmed three fixtures, which is essentially 50% more light output than the redesign. More light output will be dimmed to a lower level more often than the redesign. For this reason, the two systems

are essentially the same operating cost. The major difference in light delivery is in the aesthetics and goals of the design. For more discussion on the aesthetic goals of the study area lighting design, see Unit 3.

In choosing the 3'-0" overhang, a new analysis of operating cost for the electrical system was performed. The analysis assumptions were the same as discussed in the "Daylight Analysis" section previous to this section. At 3'-0", the zonal savings was at a measurable peak. This resulted in more savings than the mathematical optimal overhang depth.

At 3'-0" the zone savings density is as follows:

|                 |   |
|-----------------|---|
| Existing System | 0.5905 kWh/SF applied to 14115 SF of perimeter area |
| 3'-0" Overhang  | 0.5494 kWh/SF applied to 14115 SF of perimeter area |

|                 |                          |
|-----------------|--------------------------|
| Existing System | 8335.34 kWh energy usage |
| 3'-0" Overhang  | 7754.36 kWh energy usage |
| Net Difference  | 580.98 kWh energy usage  |

Total operating cost savings at \$0.08/kWh is \$46.48 for the third floor perimeter spaces of the Millennium Science Complex.

A side note must be addressed – these models do not take shading into consideration. At the time of the analysis, programs were not cooperating with shading inputs. Without the use of analysis programs, such as Daysim and Trane Trace, some shading analysis may be performed with appropriate graphs from the IES handbook. Figure 1.12 below illustrates profile angles seen by each façade of the Millennium Science Complex. Each colored line in the graph represents the maximum profile angle that is cut-off by the decided upon overhang construction. Profile angles that lie below these colored lines will penetrate the windows.

### 1'-0" Panel, 3'-0" Tot Overhang Profiles

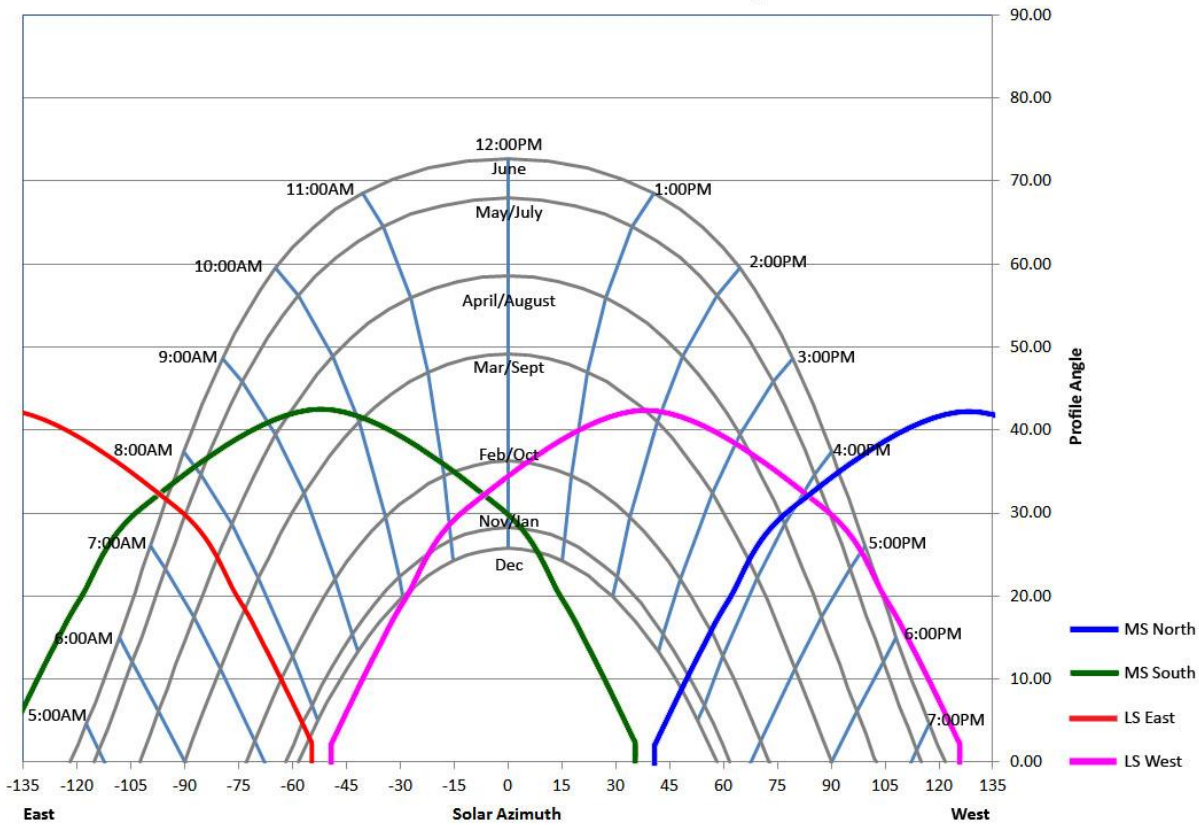
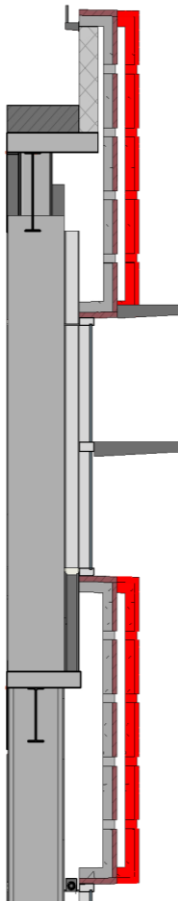


Figure 1.12: Profile angles with redesign of 3'-0" overhang in solar time

In summary of the figure above, the largest sunlight penetration will be on the Material Science South and Life Science West Façades. These two façades will utilize the MechoShade Solar Trac system to provide automatic shade adjustment in public spaces and labs. The offices will utilize user-controlled shades. For a more in-depth discussion on shading delivery, see Unit 3. The perimeter spaces on the Life Science East and Material Science North façades interact with daylight in the early morning and late afternoon hours. The shading delivery along their façades will be user-controlled only.



From an energy cost perspective only, the best condition for maximum operating cost savings is to install a 3.5' foot overhang. However, the 3.5' overhang provided only a small margin of savings when compared to the 3.0' overhang. A larger first cost will likely be incurred if a 3.5' overhang was used. Also, in both models, more significant savings are seen with the installation of triple pane glazing. For this reasoning, coupled with daylight and initial cost considerations, 3.0' overhang shading devices placed at the top and middle of the glazing as well as a triple pane glazing assembly will be recommended for the Millennium Science Complex. Figure 1.13 shows the addition of the 3' overhangs and the reduction of the panel depth versus existing conditions (shown in red). For more information concerning the panel reduction reference Unit 5.

Figure 1.13: Proposed Facade Changes

CONSTRUCTABILITY AND STRUCTURAL IMPACT

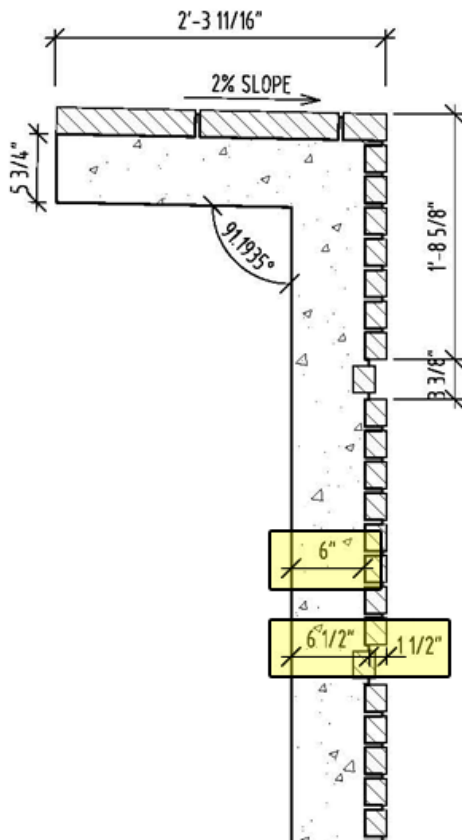


Figure 1.14: Existing Panel Design Detail

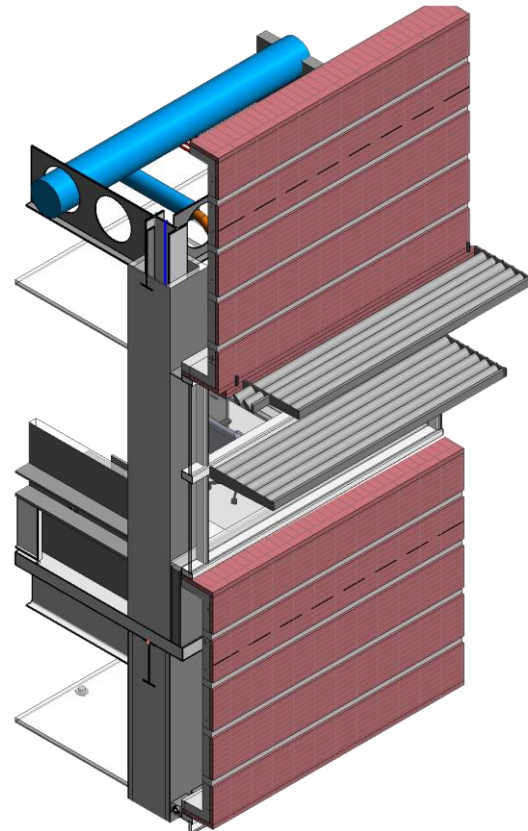


Figure 1.15: 3D Representation of Proposed Façade

From the outset of the redesign process, it was thought that the existing panels were larger than need be. The existing precast panels weigh 36 thousand pounds each. Due to the architect's desire to avoid interfering with the interior space, the panels have a C-shape section in order to avoid the cantilevered slab edge and to retain as much interior area as possible. They span 22 feet across each bay from column to column. Two bearing connections at either end of each panel were placed near its bottom, with lateral connections being placed at its top. The simplicity of connections made panel erection easy, despite their heavy weight. This weight comes by way of sheer volume. The panels were designed 6 inches thick at the face, with flanges recess back towards the building adding nearly 2 feet of depth to the profile. Panels were designed to fit multiple instances across the entire exterior of the building.

Initially, KGB Maser had hoped to reduce the weight of the façade by simply making the panels thinner. Several strength calculations were carried out on the existing panels with dimensions being taken from the provided construction documents. These calculations revealed a few facts about each panel. The "larger than need be" thickness was warranted, as it prevents cracking under the panel's own self-weight. When lain on its back, the panel face is subjected to bending from the combined weight of the concrete and masonry brick on its exterior. Although the panel face could be made thinner and still remain uncracked under its own self weight, the risk of cracking under poor quality control when being transported led to the engineers to size the panels conservatively. Unfortunately, this also means that the panels gain a large amount of weight.

Assuming the architect wanted to maintain the aesthetic of a real brick façade, the face of each panel was covered in 2-inch face brick. These masonry units appear to be normal bricks split in two and laid into the face of the panel. This amount of brick adds a large amount of mass to the concrete panels. The method of attaching the bricks to the panel was also examined, as it was feared that the bricks would eventually pop out of their housings due to cyclic expansion and contraction.

A further investigation was performed for alternatives that could be implemented in place of the existing design. An early proposition included adding a green wall to the face of the panels but was considered unviable with the climate of State College. Another idea extended the existing panel depth to 4 feet beyond the interior walls in order to produce better shading for the interior spaces. One last proposal shrunk the profile of the façade profile to less than a foot and a half. This proposal was considered the best alternative to the current system and adopted as a design objective.

In order to shrink the panel profile, the panel must be designed to resist wind and gravity loads while remaining uncracked. An excel spreadsheet was created in order to check the proposed dimensions. However, before completing the strength analysis the weight was first reconsidered.

As mentioned before, the existing façade uses 2-inch brick to imitate the appearance of real brick construction. This was seen as inefficient. Not only does it add excess mass to the panels, but if the bricks, are in fact simply typical masonry bricks cut in two, they may be susceptible to popping out of their housings. The panel concrete and masonry behave differently when introduced to moisture. The clay used to make typical bricks expands and contracts at a different rate than concrete, absorbing a higher percentage of moisture. It was proposed to replace these half bricks with thin brick.

Thin brick is denser than traditional masonry, aligning more with the properties of the precast panel. The brick, a half-inch thick, is textured on the face in contact with concrete and adheres to it during the process of curing. They are laid down before the panel concrete is poured in a grid formed by polystyrene or rubber. The concrete is then poured over the brick and the grid is removed later. The thin brick is engineered to behave similarly to concrete, absorbing less water, about 3-6% versus 8-17% of traditional masonry. The issues that raised concern in the existing design are resolved with the use of similarly behaving materials.

With the weight resolved, applying the thin brick to the façade and measuring its new mass, the existing panel dimensions were analyzed for strength. A few gravity and wind checks were conducted in order to calculate the minimum panel thickness, as well as the minimum flange depth required in order to meet strength requirements without cracking. 4.25 inches were required to maintain structural integrity, but 5 inches was used to allow for stress induced under the erection and transportations processes; a precast manufacturer who had come to lecture during the semester also suggested this.

The flange depth was under two constraints. Strength limits how small the flange could be, as it braces the face of the panel against wind loads and also provides the bearing connection at the column, and the cantilevered slab prevents the panel to be placed directly against the columns. Connections were considered first.

Two types of connections were designed for, one placing the bearing connection at the top of the panel, while the other places it at the bottom. A dap steel connection was examined first, as that is what is used in the existing design. Reinforcement development length for this connection type requires the rebar to penetrate the concrete 17 inches, more than what was desired for panel depth. A corbel connection was then considered. The corbel required only 9 inches of rebar development, which would provide a slimmer profile along the lines of 16”.

| Precast Panel Dimensions       |          |            | Self Weight Check Upright   |          |         |
|--------------------------------|----------|------------|-----------------------------|----------|---------|
| Panel Height                   | 141.125  | in.        | Weight/in.                  | 137.5369 | lb./in. |
| Panel Depth                    | 5        | in.        | Inertia of Panel            | 2032473  | in.4    |
| Brick Depth at Face            | 0.75     | in.        | Moment                      | 1191423  | lb.in.  |
| Flange Height                  | 10       | in.        | Stress                      | 41.36329 | psi.    |
| Brick Height at Flange         | 0.5      | in.        |                             |          | OK      |
| Flange Depth                   | 15.75    | in.        | Self Weight Check Prostrate |          |         |
| Panel Width                    | 263.25   | in.        | Weight/in.                  | 8.166667 | lb./in. |
| Return Thickness               | 14       | in.        | Inertia of Strip            | 125      | in.4    |
| Return Depth                   | 10       | in.        | Moment                      | 14730.64 | lb.in.  |
| Return Height                  | 121.125  | in.        | Stress                      | 294.6128 | psi.    |
| Volume Concrete                | 157.593  | ft.3       |                             |          | OK      |
| Weight Concrete                | 23638.96 | lb.        | Wind Check On Face          |          |         |
| Volume Brick                   | 18.52405 | ft.3       | Weight/in.                  | 4.249333 | lb./in. |
| Weight Brick                   | 2222.886 | lb.        | Inertia of Strip            | 125      | in.4    |
| (factored) Total               | 36206.58 | lb.        | Moment                      | 10578.86 | lb.in.  |
| (factored) Total with Planters | 43930.29 | lb.        | Stress                      | 211.58   | psi.    |
|                                |          |            |                             |          | OK      |
| Wind Force                     |          |            | Wind Check On Flange        |          |         |
| (factored)                     | 50.992   | psf.       | Weight/in.                  | 24.98697 | lb./in. |
|                                |          |            | Inertia of Flange           | 2812.5   | in.4    |
|                                |          |            | Moment                      | 172855.3 | lb.in.  |
| Cracking Stress                |          |            | Stress                      | 460.9476 | psi.    |
|                                | 477.2971 | psi        |                             |          | OK      |
|                                |          | (factored) |                             |          |         |

Figure 1.16: Panel Redesign Strength Checks

The final profile measures 15.75" at the flange with thin brick. Prior concerns of shading were resolved with shades, which can attach directly to the façade. By decreasing the flange depth, material was saved, allowing for lighter panels and a faster erection time. One drawback to this redesign is its connections. Since a corbel was considered appropriate for the panel depth, the bearing connection was moved to the top of the panel, which puts much of the concrete in tension leading to a potential for cracking over time. One solution that was not explored due to time constraints is pre-tensioning the concrete panels. Although this would add cost to the façade, and is not a typical application for pre-tensioning, it would neutralize the tension due to gravity with tensioned steel chords running through the concrete vertically, compressing the concrete.



## STRUCTURAL REDESIGN

## STRUCTURE AND COST MANAGEMENT

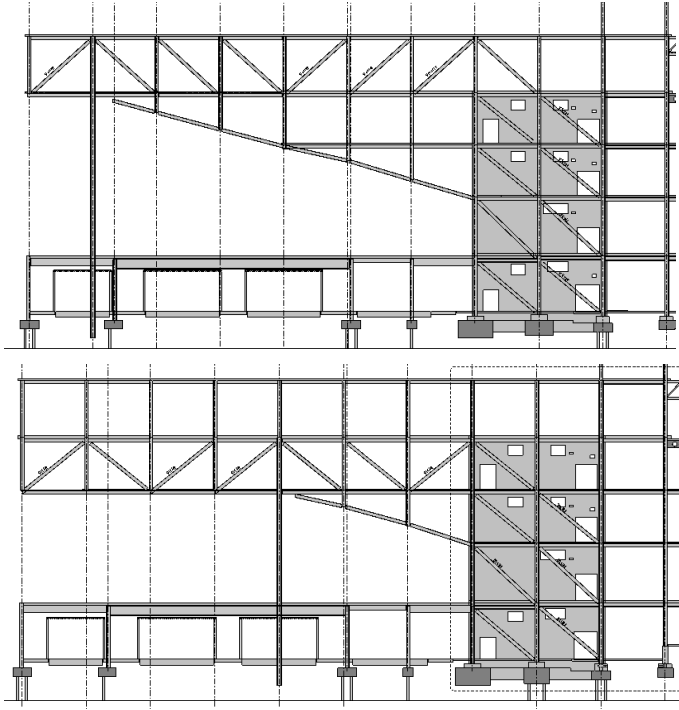


Figure 1.17: Cantilever Redesign

live load deflection. This fact has necessitated nearly every member in the four main supporting trusses in the cantilever to be moment connected.

By introducing a column to the end of this overhang, the need for moment connections would be removed, allowing each web member to be pinned. This would save on construction costs and expedite erection, increasing constructability with less field welding.

The existing cantilever by virtue of itself induces a very large moment at its base, requiring the need for bracing in the bays beyond its two main base columns to resist an overturning moment. Using a column at the end of the cantilever would fundamentally change the end conditions eradicating the overturning moment and eliminating bracing beyond the main supports; fewer members therefore are needed to be erected.

Using more than one column would further reduce stresses in the trusses, as the trusses would have one more point to which forces could be distributed. Unfortunately with these changes come implications, including architectural interference.

KGB Maser's second goal is to maximize energy efficiency in the building. Team mechanical and electrical engineers examined several options to increase energy efficiency as discussed previously. The structural system costs \$90 per square foot, an unusually higher number due mainly to the 150-foot-plus cantilever that overhangs the plaza entrance between the life sciences and material sciences wings. It was proposed that redesigning this particular corner could reduce the cost of the structure, and the savings could then be applied to the distribution systems.

Removing the cantilever completely was a viable option considered. By inserting a column at the end, the stresses in the truss members could be reduced drastically allowing them to be sized based on strength rather than stiffness. Stiffness governs the design of the existing cantilever. The 154-foot overhang is limited to just 2 inches of

ARCHITECTURAL IMPLICATIONS

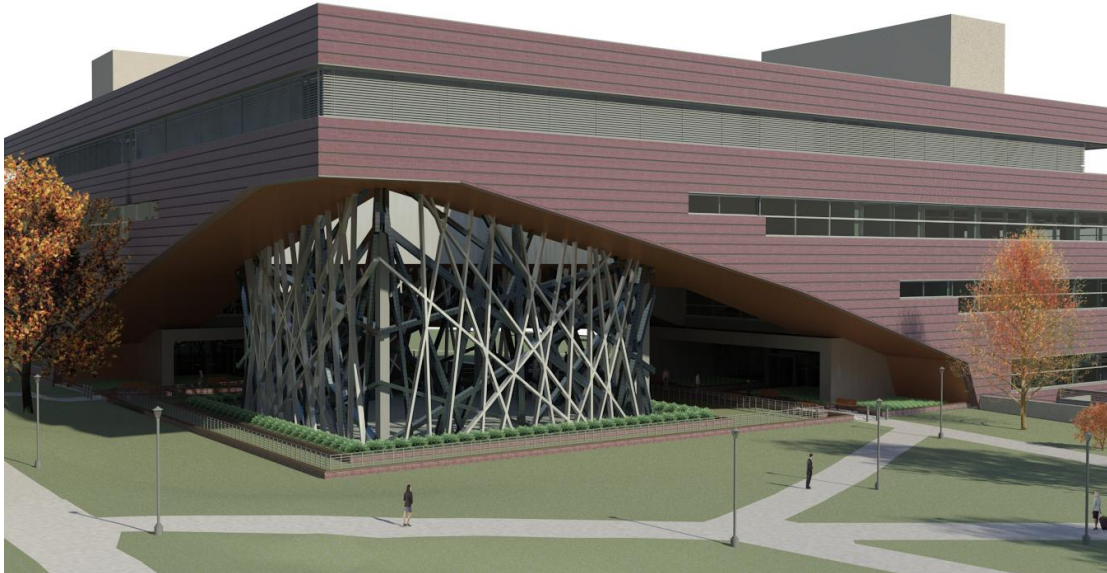


Figure 1.18: Exterior Render in Revit Architecture

Introducing a naked column underneath the overhang would ruin the visual effect created by the architect. It was envisioned by KGB Maser that a feature could be used along with the columns in order to smooth over their presence. Drawing inspiration Beijing's Olympic stadium, The Bird's Nest, a mesh of overlapping metallic tubes

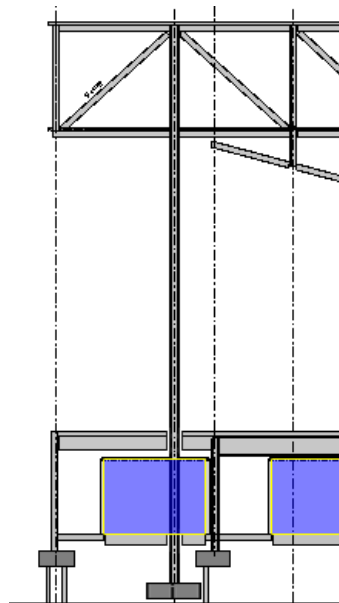


Figure 1.19: Isolation Lab Column Interference

was proposed to envelope the plaza following the footprint of the window box in the cantilever. This architectural feature would also serve to brace the columns intermediately to reduce their buckling loads. This feature could successfully mask the columns, but it could not solve the problem encountered at the basement level.

Directly below the cantilever courtyard are 3 isolation labs that sit sequestered from the surrounding foundation, on top of two 2-foot thick slabs. Another 1-foot slab then surrounds these three thicker slabs before the foundation for the rest of the building is met at its edge. The engineers were able to limit vibrations in these laboratories to 130 micro inches per second. The 2 columns proposed in the redesign would run right through two of these labs.

Moving the isolation labs would require reorganizing the entire basement, possibly necessitating further systems redesign. It was posited that the easiest solution would be to simply extend the columns deep into the foundation, several feet below the bottom of the isolation slabs, to pile caps that would then receive the truss loads. The isolation slabs would have to be poured around the column, allowing approximately a one-inch gap between the concrete and column. In order to minimize vibrational propagation from the columns into the labs, a compressive material would fill in the gap creating a barrier between the columns and the concrete slab.

After an analysis was run on the cantilever with two columns in place at opposite corners of the window box, the truss members were sized for strength. The concept was a success as all strength and deflection requirements could be met while drastically reducing the amount of members allowing the existing ones to be sized smaller. Constructability was increased with the use of pinned connections, and only one extraneous task introduced to the construction process was the erection of a column. Since the columns would be too large to ship as two long pieces, each would be shipped in halves and bolted and welded together in the field.

## SUMMARY OF PROPOSED DESIGN COST IMPLICATIONS

KGB Maser's main design schemes in Façade, Structure, Mechanical/Energy, and the Architectural Redesign, are currently being priced that there will be a savings of close to \$350,000. This savings however is relying on the cost of the cage structure to not trump the savings, at least in terms of upfront costs. The Mechanical/Energy Redesign may cost a significant amount of money upfront but does have the capability of paying for itself with time.

Currently the structural redesign has comprised a savings of close to \$2.3 million in upfront costs for the structural systems. This savings come from the comparison of the detailed estimate performed by our team. However, our detailed estimate of the existing structure came in at a total of \$10,566,550. This cost does not include general conditions, nor does it cover having multiple cranes on site to erect the steel. It is believed by our team, that given the conservative nature of the detailed estimates that were completed, that a higher savings could come from the use of the columns beneath the cantilever.

| Summary of System First Costs                  |                 |                     |                            |                  |
|--|-----------------|---------------------|----------------------------|------------------|
|  | Façade Redesign | Structural Redesign | Mechanical/Energy Redesign | Courtyard Design |
| Existing Cost                                  | \$3,295,766.00  | \$10,566,550.00     | \$19,188,000.00            | \$271,745.00     |
| Proposed Cost                                  | \$3,051,834.00  | \$8,275,735.00      | \$21,040,000.00            | \$604,910.00     |
| Savings/Expenses                               | \$243,932.00    | \$2,290,815.00      | (\$1,852,000.00)           | (\$333,165.00)   |
| <b>Total First Cost Savings = \$349,582.00</b> |                 |                     |                            |                  |

Additionally, the existing and proposed systems were compared on a life cycle cost basis. Only the first and operating costs associated with the mechanical system was analyzed. Per year, the proposed mechanical system saved 14.1% on energy costs. However, the rise in initial cost needed to be tested over the life cycle of the mechanical system to ensure altering designs was a worthwhile investment. A life cycle cost was done comparing the VAV and active chilled beam systems over 30 years. The evaluation considered the potential switch from Penn State's existing coal powered power plant to natural gas. The life cycle cost analysis was performed without inflation and with inflation rates of 2% and 5%. The table below summarizes the Net Present Value of the systems in different scenarios.

| Life Cycle Cost Summary |              |              |              |                   |              |              |
|-------------------------|--------------|--------------|--------------|-------------------|--------------|--------------|
|                         | Coal Plant   |              |              | Natural Gas Plant |              |              |
|                         | Real Rate    | 2% Inflation | 5% Inflation | Real Rate         | 2% Inflation | 5% Inflation |
| VAV                     | \$54,813,916 | \$63,883,395 | \$63,856,220 | \$64,693,985      | \$77,435,022 | \$90,744,775 |
| ACB                     | \$55,346,191 | \$62,693,273 | \$62,647,108 | \$59,478,486      | \$69,307,263 | \$69,259,831 |
| Percent Savings         | -0.97%       | 1.86%        | 1.89%        | 8.06%             | 10.50%       | 23.68%       |
| NPV Differential        | (\$532,275)  | \$1,190,122  | \$1,209,111  | \$5,215,499       | \$8,127,758  | \$21,484,944 |

Note: Operating cost savings from reduction in fume hood velocities were not included in this study.

## CONSTRUCTION MANAGEMENT BIM PROCESSES

### ARCHITECTURAL DESIGN BIM PROCESS



Figure 1.20: Preliminary Sculpture Sketch

The BIM process for the development of the cage structure and the landscape architecture of the courtyard began with a pencil and paper to begin brainstorming ideas. Moving on, we were able to take site pictures of the existing building and see how our designs would affect the architecture. Microsoft Paint was used to quickly drawn in our designs and see how these designs would look alongside real life aspects. Below is one of the sketches as a JPEG from Microsoft Paint.

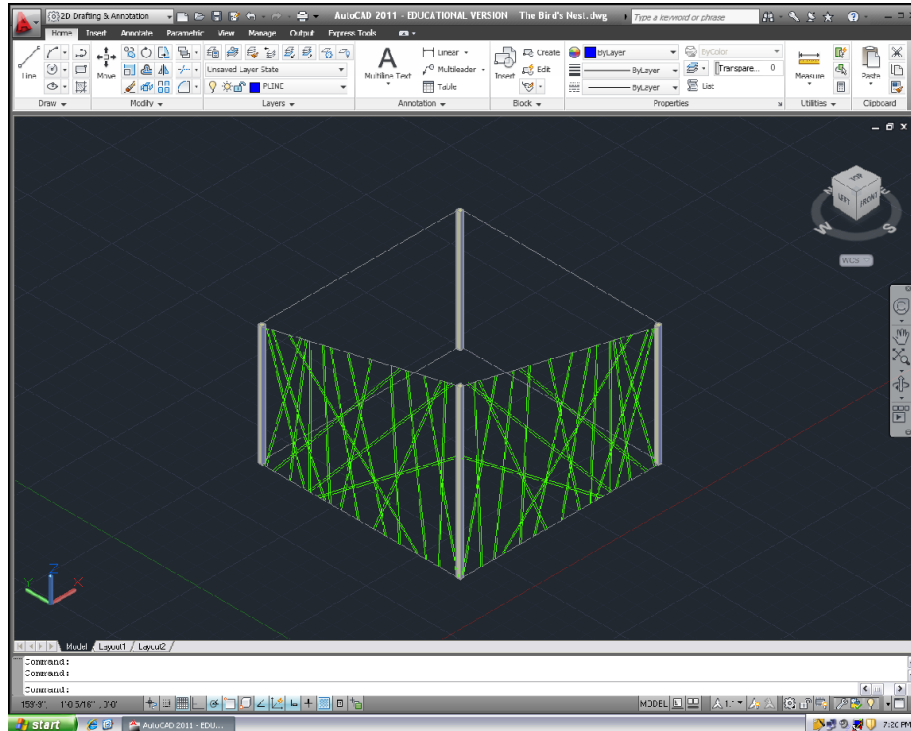


Figure 1.21: AutoCAD Model of Steel Sculpture

The next step in our design process was to begin to work in programs that have interoperability with Revit Architecture. It was necessary to have the interoperability with Revit Architecture, because this is the main default program from which all of KGB Maser’s modeling content was derived. The cage structure was again simply modeled and developed in AutoCAD 2011 as a 3D DWG seen below. Dimensions were taken from the Revit Structural model to know where the columns would attach and what dimensions the cage structure would have to fulfill in order to provide bracing support.

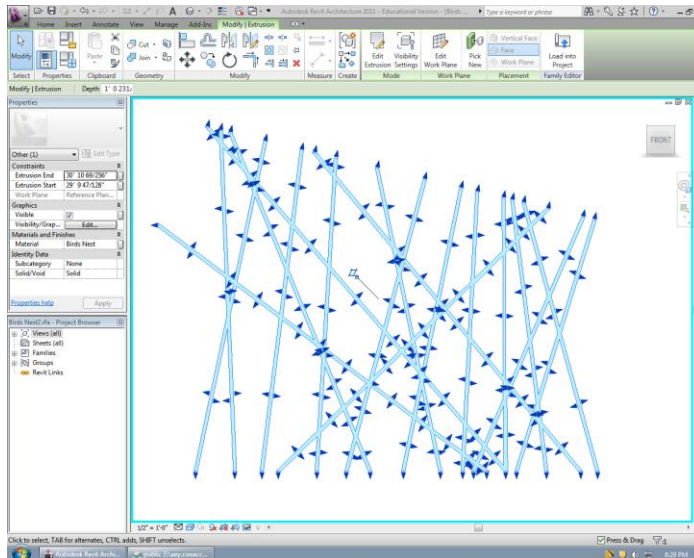


Figure 1.22: Steel Sculpture Revit Modeling

From this point, with a 3D DWG we were able to import the DWG into Revit Architecture and create a generic model Revit Family. (RFA File) Creating a 3D model of the 2D lay out was as simple as tracing the 2D layout with the solid function of Revit Families. After tracing the 2D layout, a thickness must be applied to the structure. After the solid is drawn, it is as simple as click and drag to modify each segment of the solid, as seen below in the image showing the blue arrows to modify each segment.



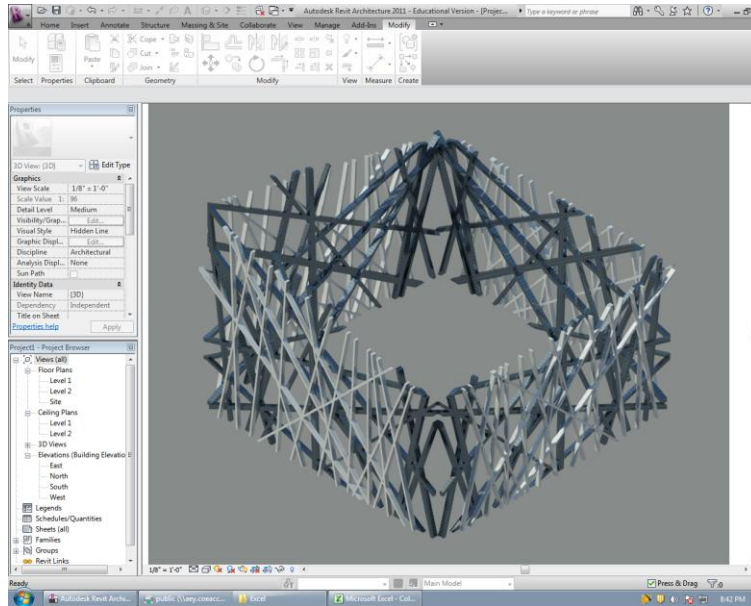


Figure 1.23: Advanced Model of Steel Sculpture

With the geometry of one of the panels set, it was easy to create the other four sides of the cage structure. The other three sides of the cage were simply mirrored aspects of the original design. After setting the geometry to its final design, the materials were chosen using the Properties Tool of Revit. Materials were chosen and rendering was completed to apply these materials to a realistic image. A sample of one of our progress renderings can be seen below.

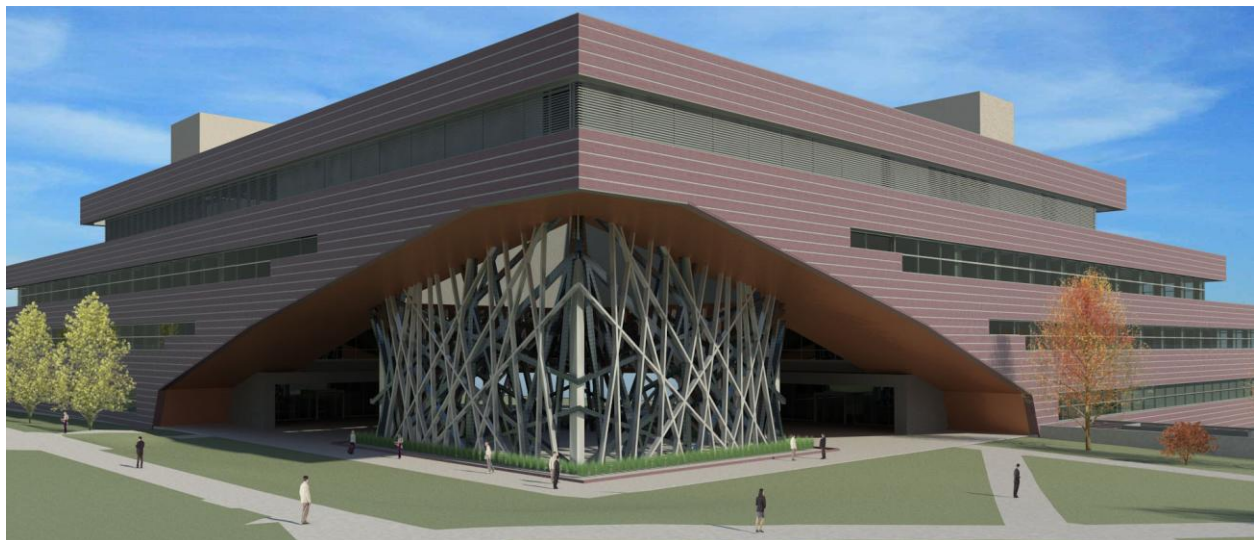


Figure 1.24: Preliminary Courtyard Space Render

After the Revit Family is designed and all materials have been chosen, the family can be imported into the central file via the Component Tool, and the family will have to be loaded from its saved location. If the family needs to be edited, the family should be selected in the central model and click edit family in the top tool ribbon.

MODEL BASED ESTIMATION BIM PROCESS

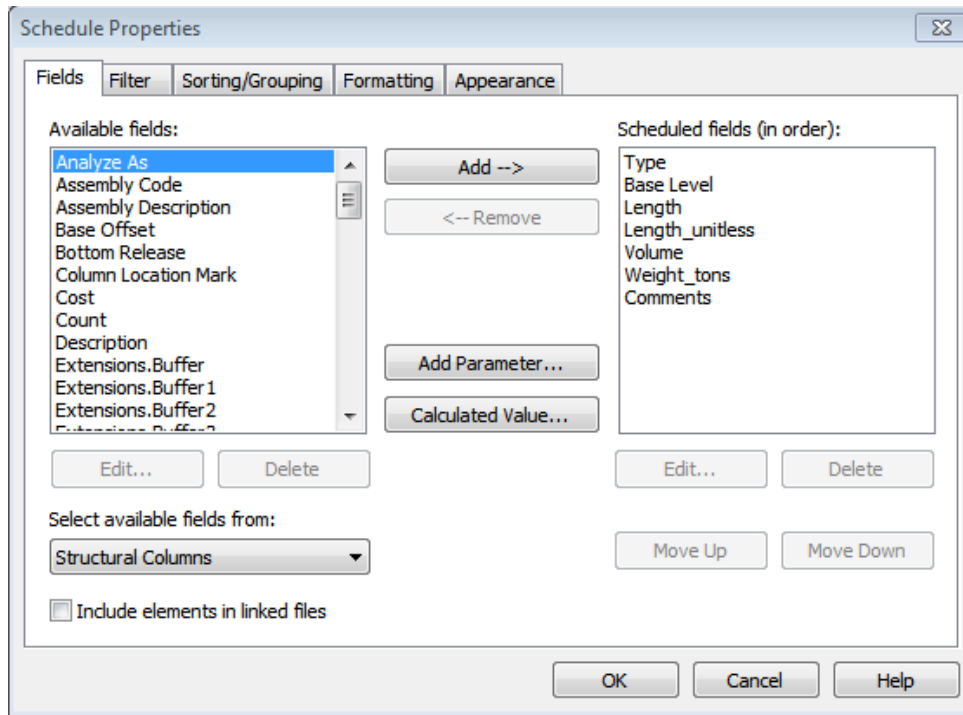


Figure 1.25: Modifying Schedule Parameters

This model based estimation process will cover the process that was used for the estimation of the structural steel. The structural steel was modeled in Revit Structure and the quantities were able to be exported via Revit schedules. The image below shows the creation of a Revit Schedule.

| Structural Column Schedule |                |            |             |          |
|----------------------------|----------------|------------|-------------|----------|
| Type                       | Length_unitile | Volume     | Weight_tons | Comments |
| 2-L3x3x1/4                 | 173.979167     | 3.64 CF    | 0.900238    |          |
| 2-L3x3x1/4: 22             | 173.979167     | 3.64 CF    | 0.900238    |          |
| 16"x12" PIER               | 15             | 9.72 CF    | 2.405788    |          |
| 16"x12" PIER: 2            | 15             | 9.72 CF    | 2.405788    |          |
| 24"x24" PIER               | 1287.5         | 4765.43 CF | 1179.444108 |          |
| 24"x24" PIER: 81           | 1287.5         | 4765.43 CF | 1179.444108 |          |
| 30"x30" PIER               | 412            | 2321.67 CF | 574.6125    |          |
| 30"x30" PIER: 32           | 412            | 2321.67 CF | 574.6125    |          |
| 33"x24" PIER               | 399.5          | 2197.25 CF | 543.819375  |          |
| 33"x24" PIER: 26           | 399.5          | 2197.25 CF | 543.819375  |          |
| 54"x54" PIER               | 23             | 292.81 CF  | 72.470444   |          |
| 54"x54" PIER: 10           | 23             | 292.81 CF  | 72.470444   |          |
| 66"x60" PIER               | 14             | 215.00 CF  | 53.2125     |          |
| 66"x60" PIER: 8            | 14             | 215.00 CF  | 53.2125     |          |
| HSS4X4X.25                 | 27.416667      | 0.67 CF    | 0.166355    |          |
| HSS4X4X.25: 4              | 27.416667      | 0.67 CF    | 0.166355    |          |
| HSS4X4X.500                | 39.129321      | 1.79 CF    | 0.44207     |          |
| HSS4X4X.500: 4             | 39.129321      | 1.79 CF    | 0.44207     |          |
| HSS5X5X.250                | 65.627161      | 2.04 CF    | 0.50395     |          |
| HSS5X5X.250: 6             | 65.627161      | 2.04 CF    | 0.50395     |          |

Figure 1.26: Revit Schedule Export

The first thing to consider when making a Revit Schedule is what fields are needed. For estimation purposes, the type of each piece, the lengths, and weight, are the main fields of interest. However, in order to create a schedule field that is useful in Microsoft Excel, the unit must be taken away from the fields that you wish to do calculations with. For example, the length field is given a unit of feet, in order to be able to perform calculations with ease in Microsoft Excel, the unit had to be deleted out using the Calculated Value function of the Schedule Properties. The calculated value function will prompt for an equation in which this case, Length/1' will provide a unitless length. The units have to be canceled out via a mathematical equation. For square feet of area, it would be necessary to divide by ((1')^2).

By using the Sorting/Grouping function of the Schedule Properties, it is possible to sort each instance of the schedule by any of the fields selected before. Sorting by Type enables the schedule to calculate totals for each field of each type. Instead of exporting the schedule to Microsoft Excel and calculating Type totals, Revit Schedules can calculate the total Length, Weight, and other fields for each type in the model. This can be seen in the image above that shows the sorting of all instances by Type and the creation of a footer for each type that will calculate the total of each field. The following image will also show the schedule that will be created with these Fields and Sorting options.



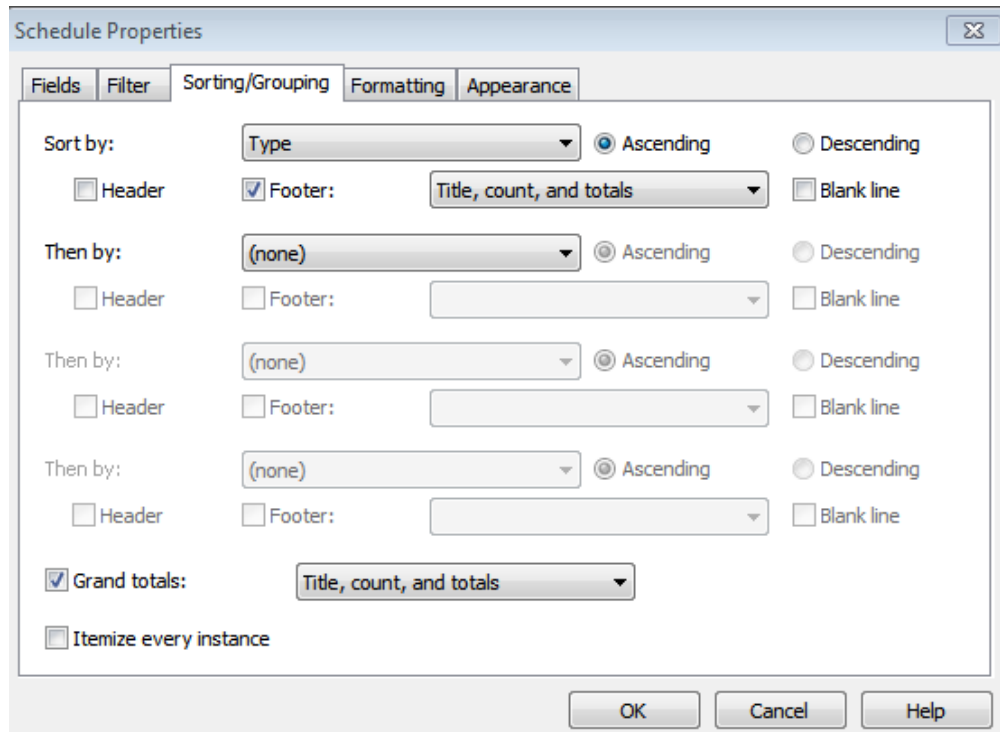


Figure 1.27: Fields and Sorting Options in Revit

After creating the schedule in Revit, it was possible to export the schedule to Microsoft Excel with the Revit Export option. To export to Microsoft Excel, a TXT file report from Revit was used and opened in Microsoft Excel. This enabled each Type to have its totals already calculated, and ready for cost information from RS Means. Each type of instance was researched through RS Means cost information, and the cost related fields were entered into the excel spreadsheet. A column was created for Material, Labor, Equipment, and Total cost for each type. The total cost of the schedule is easily calculated by using the Autosum function in Microsoft Excel to total the Cost column. An example of the spreadsheet in Microsoft Excel can be seen below.

|    | A               | B       | C    | D        | E     | F         | G                     | H    | I               |
|----|-----------------|---------|------|----------|-------|-----------|-----------------------|------|-----------------|
|    | Type            | Total   | Unit | Material | Labor | Equipment | Total                 | Unit | COST            |
| 3  | 2-L3x3x1/4      | 173.97  | LF   | 3.65     | 14.7  | 1.55      | 19.9                  | LF   | \$ 3,462.00     |
| 4  | HSS12-3/4x0.250 | 0.2299  | TONS | 1.65     | 0.15  | 0.1       | 1.9                   | LB   | \$ 873.62       |
| 5  | HSS12X8X.500    | 2.8771  | TONS | 1.65     | 0.15  | 0.1       | 1.9                   | LB   | \$ 10,932.98    |
| 6  | HSS4X4X.25      | 0.1663  | TONS | 1.65     | 0.15  | 0.1       | 1.9                   | LB   | \$ 631.94       |
| 7  | HSS4X4X0.5      | 0.442   | TONS | 1.65     | 0.15  | 0.1       | 1.9                   | LB   | \$ 1,679.60     |
| 8  | HSS6X6X0.5      | 1.3648  | TONS | 1.65     | 0.15  | 0.1       | 1.9                   | LB   | \$ 5,186.24     |
| 9  | W10X68          | 51.53   | LF   | 47       | 3.8   | 2.75      | 53.55                 | LF   | \$ 2,759.43     |
| 10 | W14X109         | 84.95   | LF   | 71.5     | 2.55  | 1.95      | 76                    | LF   | \$ 6,456.20     |
| 11 | W14X120         | 294.75  | LF   | 82       | 2.58  | 1.97      | 86.55                 | LF   | \$ 25,510.61    |
| 12 | W14X132         | 889     | LF   | 86       | 3.2   | 2.2       | 91.4                  | LF   | \$ 81,254.60    |
| 13 | W14X145         | 99.25   | LF   | 98.94    | 2.72  | 2.07      | 103.73                | LF   | \$ 10,295.20    |
| 14 | W14X176         | 1189.79 | LF   | 119.95   | 2.9   | 2.21      | 125.06                | LF   | \$ 148,795.14   |
| 15 | W14X193         | 174.25  | LF   | 131.47   | 3     | 2.28      | 136.75                | LF   | \$ 23,828.69    |
| 16 | W14X211         | 410.45  | LF   | 143.68   | 3.1   | 2.36      | 149.14                | LF   | \$ 61,214.51    |
| 17 | W14X233         | 362.83  | LF   | 158.58   | 3.23  | 2.45      | 164.26                | LF   | \$ 59,598.46    |
| 18 | W14X257         | 193.91  | LF   | 174.85   | 3.37  | 2.56      | 180.78                | LF   | \$ 35,055.05    |
| 19 | W14X283         | 1376.08 | LF   | 192.47   | 3.52  | 2.67      | 198.66                | LF   | \$ 273,372.05   |
| 20 | W14X311         | 59.95   | LF   | 223.45   | 3.68  | 2.79      | 229.92                | LF   | \$ 13,783.70    |
| 21 | W14X370         | 150     | LF   | 253.44   | 4.02  | 3.05      | 260.51                | LF   | \$ 39,076.50    |
| 22 | W14X43          | 348.36  | LF   | 30       | 2.29  | 1.75      | 34.04                 | LF   | \$ 11,858.17    |
| 23 | W14X48          | 100.84  | LF   | 33       | 2.3   | 1.76      | 37.06                 | LF   | \$ 3,737.13     |
| 24 | W14X53          | 18      | LF   | 36.5     | 2.32  | 1.78      | 40.6                  | LF   | \$ 730.80       |
| 25 | W14X550         | 316.58  | LF   | 359.05   | 4.75  | 3.5       | 367.3                 | LF   | \$ 116,279.83   |
| 26 | W14X61          | 1627.49 | LF   | 43.5     | 2.38  | 1.82      | 47.7                  | LF   | \$ 77,631.27    |
| 27 | W14X68          | 510.56  | LF   | 44.5     | 2.4   | 1.82      | 48.72                 | LF   | \$ 24,874.48    |
| 28 | W14X74          | 406.16  | LF   | 51       | 2.44  | 1.87      | 55.31                 | LF   | \$ 22,464.71    |
| 29 | W14X82          | 341.6   | LF   | 56       | 2.48  | 1.89      | 60.37                 | LF   | \$ 20,622.39    |
| 30 | W14X90          | 4032.34 | LF   | 61.5     | 2.51  | 1.92      | 65.93                 | LF   | \$ 265,852.18   |
| 31 | W14X99          | 342.7   | LF   | 68.5     | 2.53  | 1.94      | 72.97                 | LF   | \$ 25,006.82    |
| 32 |                 |         |      |          |       |           |                       |      | \$ 1,372,824.32 |
| 35 |                 |         |      |          |       |           | TIME                  |      | \$ 1,743,486.89 |
| 37 |                 |         |      |          |       |           | CONNECTIONS           |      | \$ 2,039,879.66 |
| 39 |                 |         |      |          |       |           | Total Including O & P |      | \$ 2,386,659.20 |

Figure 1.28: MS Excel of A Schedule Export

## 3D COORDINATION BIM PROCESS

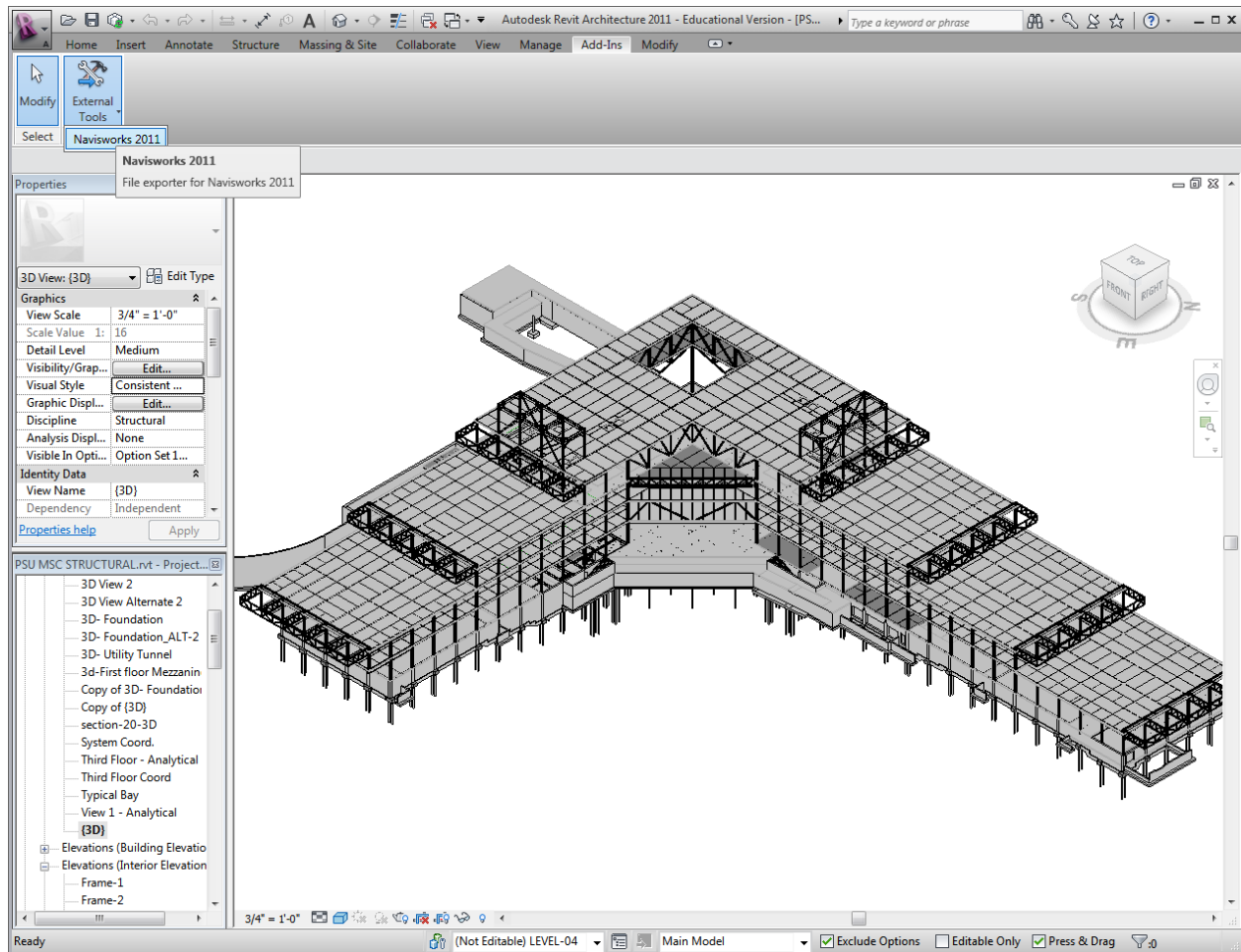


Figure 1.29: Navisworks Coordination Model

The 3D coordination process begins with the creation of discipline specific models in each of the modeling software programs. It is not necessary that every model come from an Autodesk based software, but it is beneficial to maintain 3D solid geometry instead of 3D faces. Secondly, the models were exported from these modeling programs to Navisworks Manage. The PSU MSC STRUCTURAL.rvt model was able to be exported to Navisworks via the Add-Ins External Tools Navisworks file exporter. This exporter creates a NWC file that can be opened directly in Navisworks and used for 3D coordination. The image below shows the Revit file exporter to Navisworks.

After the files were established, they were able to be appended together in Navisworks to create a coordination model. With the coordination model created, the clash detective tool of Navisworks was used to find where systems clashed with each other. A hard clash is where two objects physically occupy the same space and collide with each other. A clearance setting can also be set to account for insulation around piping if it is not modeled. The clash detective tool has two selection trees in which models can be chosen to check for clashes against the other models. Our models for clash detection did not contain the full coordinate requirements for construction,

but an example of this can be seen below in a Navisworks image of the Millennium Science Complex Coordination model from Whiting-Turner.

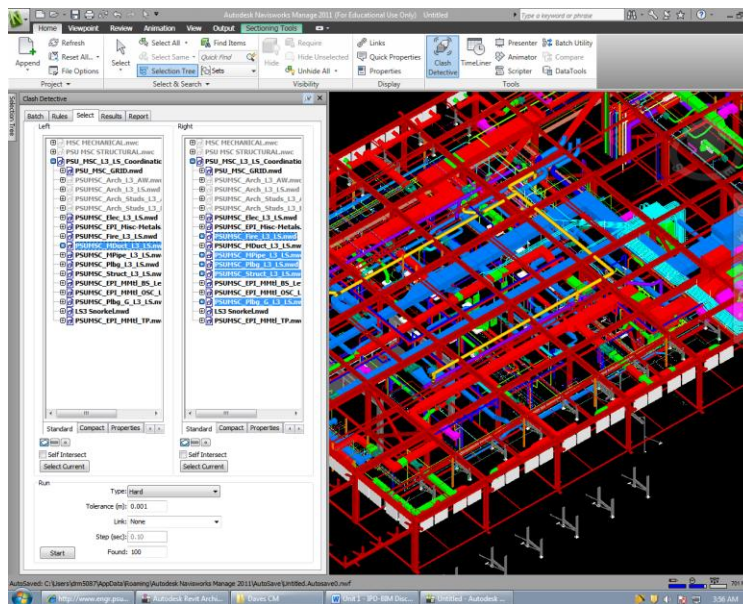


Figure 1.30: Clash Detection in Navisworks

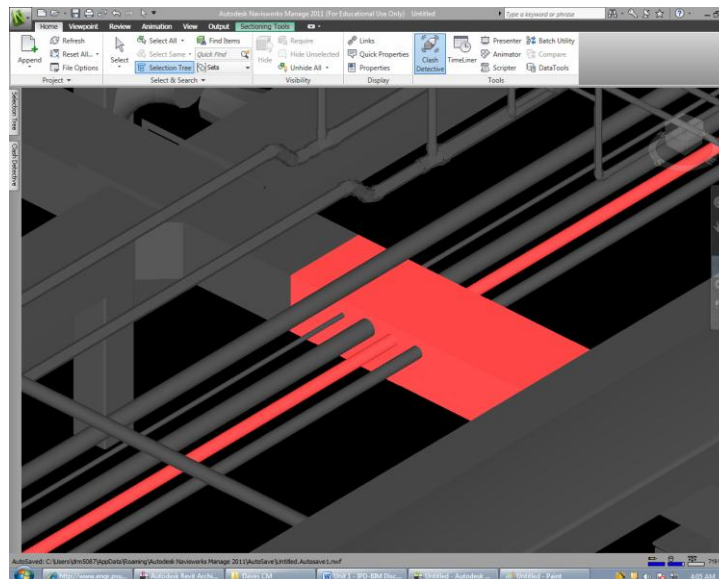


Figure 1.31: Sample Clash in Navisworks

With the coordination model in Navisworks and the layers chosen to be clash detected, the clash detection can be started. After the clash detection is complete, the results tab will show instance by instance of each clash. Each clash can be examined and measured with the Review Tools to find a fix for each clash. A clash detection report

can also be exported as an HTML file for team members to view. Each instance of the clash detection will save the last camera view that was shown for each clash. The final step is to go back to the original modeling program, perform the necessary changes to each discipline model and the export the new models to Navisworks to test for clash detection again. Below is a sample image of a clash and how the camera can be set up to view clashes.

## LIGHTING/ELECTRICAL BIM PROCESSES

Building information modeling can be used for lighting design in different software. There is no program that can perform all analyses accurately. Programs for coordination such as Revit and Navisworks can produce renderings, but cannot perform in-depth calculations. Programs for calculations include AGI32, Daysim, and 3D Studio Max. File type sharing exists between these programs, but may involve “clean-up” before importing to ultimate destinations. This section outlines how BIM was used in lighting designs and the aforementioned process of transporting files from geometry platforms (Revit Architecture) to analysis platforms (AGI32 and 3D Studio Max).

## MODELING FIXTURES AND FAMILIES



Figure 1.32: Student Area Revit Section

For this thesis project, it is paramount that all appropriate information be shared between disciplines. Challenges in sharing information are first encountered within different Revit platforms. When a family is created for a light fixture in Revit Architecture, those parameters will operate within Revit Architecture only. This is the same or other platforms such as Revit MEP. For example, when creating light fixture families for the Student Area redesign, there is an option to create the family in Revit MEP or Architecture. If the recessed fixture is created in Revit Architecture and loaded into an MEP-based model, the fixture may not cut out its place in the ceiling. If the fixture is created in MEP, then it is able to have all necessary electrical and lighting properties such as operating voltage, power usage,

and photometrics. A sample family type parameter setting can be seen in Figure 1.33 below. Again, when this family is used in Revit MEP and mounted on an architecture model, it does not cut a space within the ceiling for its recessed mounting. These issues are minimal in the overall process of using BIM for design coordination. Figure 1.32 illustrates a sample section of KGB Maser’s redesign of the student study areas. The luminaires visible in this section of the building can be created accurately to the specification of the lighting redesign. For a further discussion on the lighting redesign, see Unit 3 of this document. Once family parameters have been modeled, their properties can be extracted in schedules within any platform of Revit. Upon creation of these schedules, the construction manager can assign prices for each fixture type as well as the labor costs involved with installing them.

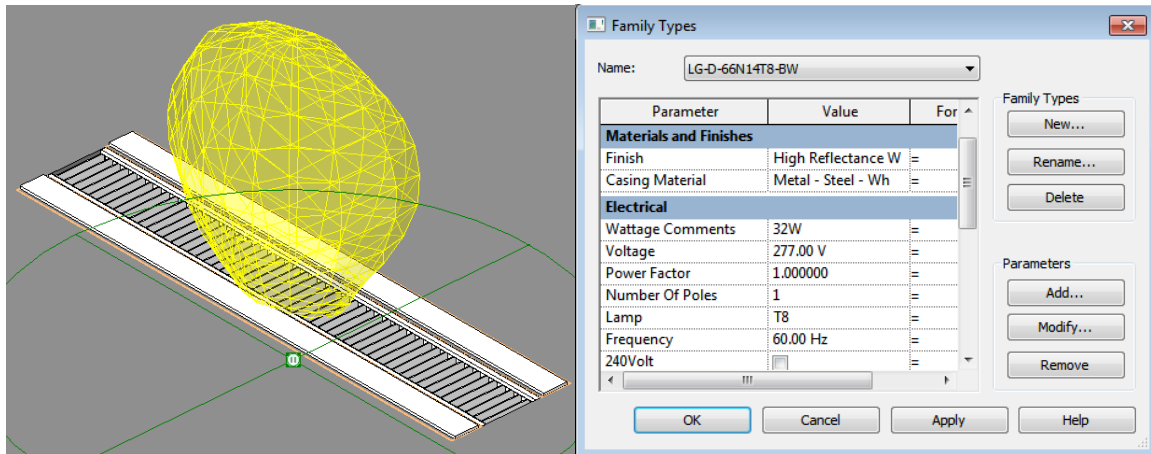


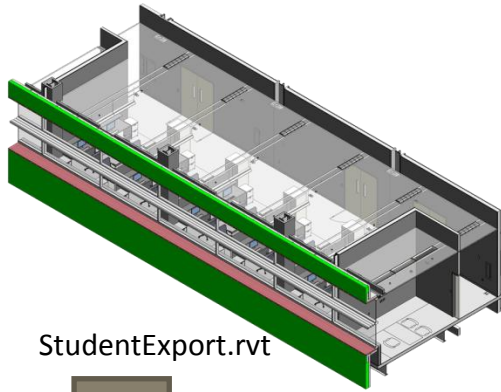
Figure 1.33: Custom Luminaire Properties

As discussed in Lighting Technical Assignment 1, light loss factors can also be assigned to family types within Revit. For more information on Revit task plane illuminance estimates, see Lighting Technical Assignment 1. Once fixtures and equipment is accurately modeled into the central file, equipment can be circuited to appropriate panelboards. For a more in-depth discussion about modeling power systems and families in Revit Architecture, please see Building Stimulus’s thesis report, as this report does not cover circuiting in Revit MEP.

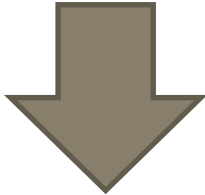
## MODEL SHARING BETWEEN AUTODESK REVIT AND AGI32

The first question that needs to be answered when sharing models is “what format does my model need to be in at my final destination?” KGB Maser has chosen two routes to answer this question. The student study area lighting analysis was performed ultimately in AGI32 and the office design was completed in a combination of Revit Architecture and AGI32. The final space – the courtyard beneath the cantilever – was completed in 3ds Max Design with assurance in AGI32.

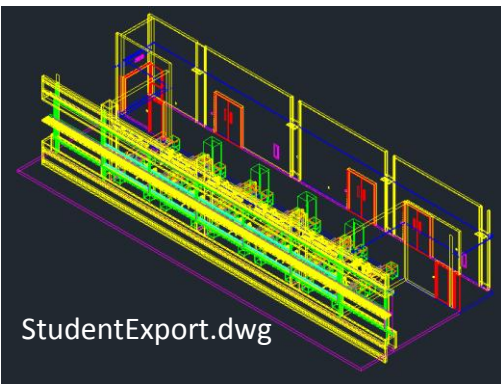




StudentExport.rvt



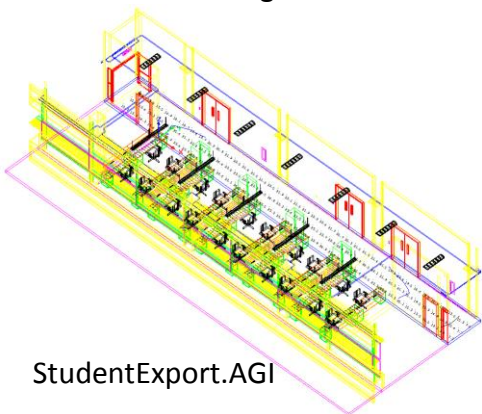
Export parameter change to "ACIS Solids"



StudentExport.dwg



Import to AGI32 where material properties are assigned



StudentExport.AGI

Figure 1.34: Simplified model sharing process Revit to AGI32

The ultimate format for analysis in AGI32 is an AutoCAD .dwg file extension. There are particular variables within AGI32 that need to be considered when exporting files from the model source also. AGI32 interfaces with solids, 3D faces, and meshes from AutoCAD. Secondly, the designer should not have luminaires visible when exporting from Revit. Luminaires can be defined, positioned, and oriented within AGI32.

When exporting from Revit, the designer must be viewing the project in a 3D view. Revit will export whatever format the view is in – plans are 2D drawings when exported and 3D views are 3D drawings when exported. Knowing that AGI32 utilizes solids and 3D faces, the export parameters can be set to "ACIS Solids" when the export dialog box is viewed.

Upon opening in AutoCAD, the .dwg file must be exploded in order to organize material types upon import into AGI32. Components in Revit are imported in block format in AutoCAD. These blocks can be exploded into 3D solids. The easiest way to assure that materials are modeled appropriately in AGI32 is to create new layers named as the material type. It is possible to change material types for surfaces once imported into AGI32, but the process becomes too tedious and time consuming with more complex models such as this student area. For the study area AGI32 model, most of the material types had already been exported to an appropriate layer by Revit, but components with multiple materials – such as particle board cabinets with wooden tops – had to be exploded and sorted by material type.

Once the .dwg export is organized by material type, it can be "cleaned-up" in AutoCAD. This part of the model sharing process is important when working with very detailed models. In the example of the study area export shown in Figure 1.34, very detailed items such as cabinet caster wheels, cabinet handles, computer screens, and office chairs must be changed in order for smooth import into AGI32. Such detailed components, when exploded in AutoCAD, cause the analysis software to produce an error stating that it cannot read or analyze the associated import layer. The clean-up process must target such components by changing wheels and other curved components into squares and meshes that are appropriately sized to run in AGI32. Some components are available in simplified forms within AGI32 – chairs, computer screens, and other furniture items.

It is important to note that Revit is a source for analysis

geometry, but analysis cannot be taken back to Revit in the reverse order. For example, if the previously mentioned process results in an analysis that produced less than acceptable light levels, the designer cannot simply change the luminaires in AGI32 and reverse the process into Revit. The model in AGI32 must be re-worked to achieve design goals, and then the final design must be re-modeled in Revit. In conclusion, the advantage of BIM software for this lighting design application is the availability of accurate room geometry for analysis. The main drawback is that there is not a two-way communication between the two software platforms.

## MODEL SHARING BETWEEN REVIT AND 3D STUDIO MAX

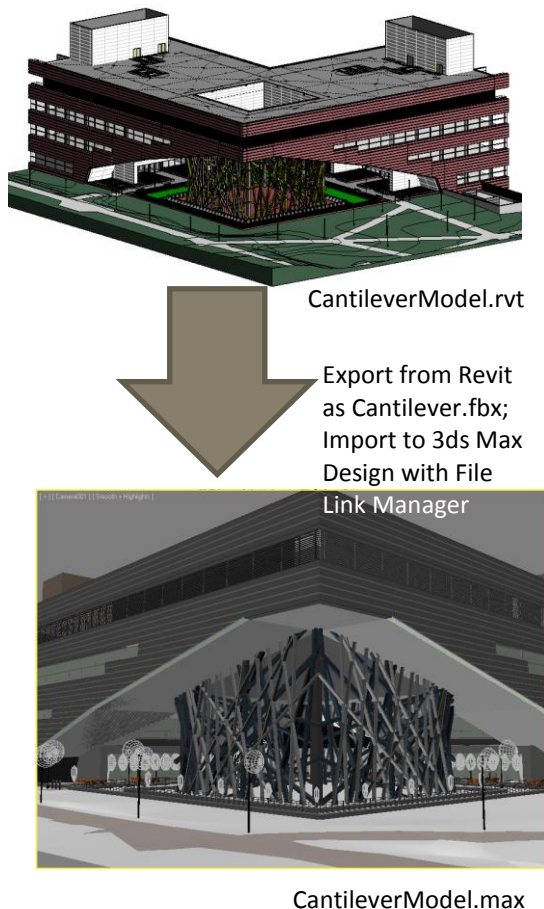


Figure 1.35: Simplified model sharing process Revit to 3ds Max

A second avenue for lighting design with Building Information Modeling software is the .fbx export from AutoDesk Revit Architecture. A simplified model flow is illustrated in Figure 1.35 shown here. AutoDesk 3D Studio Max Design is a great tool for rendering environments and using material properties to their fullest advantage. In this section of Unit 1, a discussion of possibilities using Revit and 3ds Max to achieve lighting design objectives will be examined.

As with the previous example of file sharing, the ultimate question that will need to be answered is “in what format does my final file need to be imported?” The answer to this question when using 3ds Max Design is the .fbx file extension. From Revit Architecture, this file format is easily accessible from the file menu. Benefits from using an .fbx file include no need to assign additional object parameters (as needed in the previous example) and the completeness of the information contained within the .fbx format. However, the latter advantage can also be a disadvantage.

The .fbx file extension exports the entire model and its parameters in the current 3D view. This means that every wall, button, knob, light fixture, photometric distribution, or any other entity within the model. This level of detail is great for composing nearly one-hundred percent accurate renderings, but drastically increases file size in the end file format (.max). For example, KGB Maser’s Revit model for the cantilever portion of the Millennium Science Complex has a

file size of 236,448 kB. When the model is exported to an .fbx format, the file size decreases to 61,001 kB. Once the .fbx is imported into 3ds Max Design, the file size increases to 916,942 kB. This great jump has to do with the level of detail contained in the 3ds model capabilities. These capabilities include accurate daylight rendering through radiance plug-ins, highly accurate material properties, photometric lighting, and movie-making abilities among many other design features.



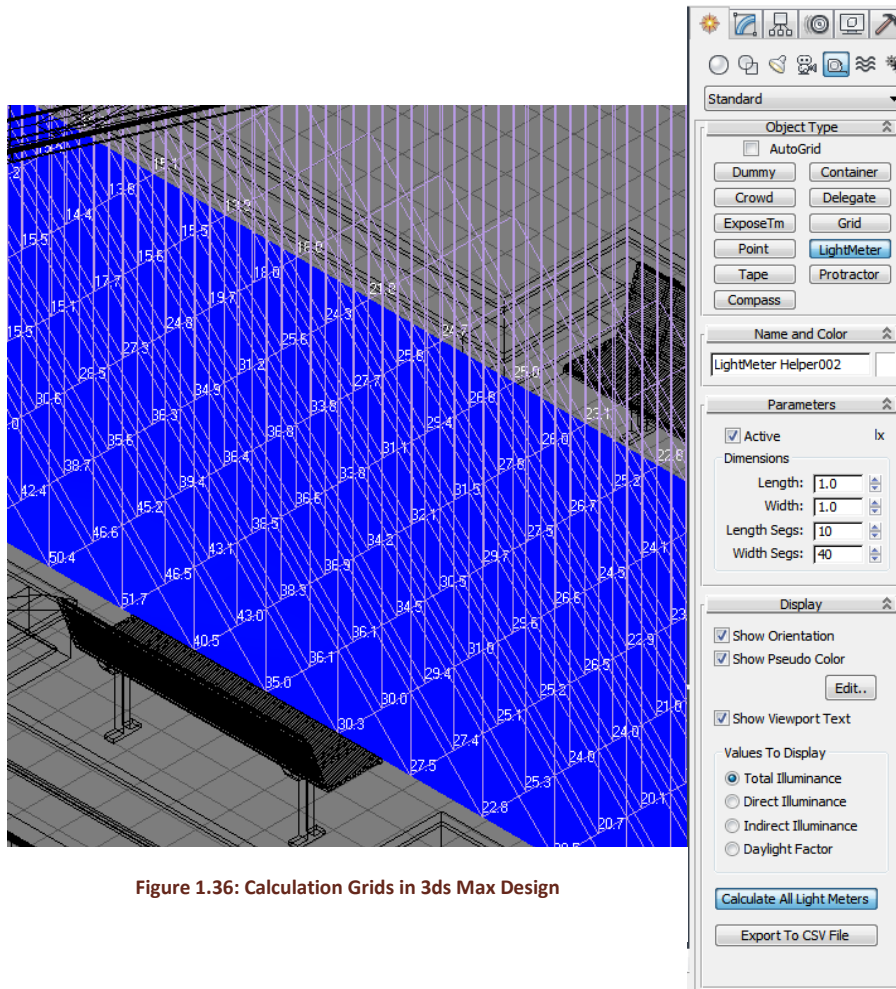


Figure 1.36: Calculation Grids in 3ds Max Design

In order to reduce rendering time, as with the previous example, the Revit model must be “cleaned-up” to reduce the number of problematic surfaces in the file share. In the case of KGB Maser’s central model, all irrelevant lighting fixtures, interior walls, furniture, and other components had to be deleted. The final product to be exported as an .fbx file extension only contained the cantilever courtyard materials, building shell, floors, columns, and applicable luminaires. The rest of the model was not included by way of a section box around the rest of the building.

One specific feature that will be examined as part of the IPD/BIM section of this thesis is the ability of 3ds Max

Design to perform light level estimations – more specifically the calculation of total illuminance. When modeling the calculation grid, its size can be determined by a click-and-drag method, followed by changing the number of segments along the grid’s length (x-axis) and width (y-axis). The display options can be toggled depending on the clutter within the view. Figure 1.36 shown here illustrates an example calculation grid. Once all grids have been placed, the “Calculate All Light Meters” button will process the algorithms within 3ds Max to calculate the desired statistic. Once complete, each “LightMeter Helper” can be exported as a .csv file (“comma delimited” or “comma separated value”) to be opened in Microsoft Excel. Once in Excel, the values from the light meters can be compiled in a pivot table, thus allowing the engineer/designer to visualize the minimum and maximum calculation points. *Note: 3ds Max has default settings to include a specific daylight condition.* If daylight is not being considered, as in the case of this thesis, the user will need to change the scene parameters to exclude sun and sky conditions. Additionally, the pseudo color image settings may be customized in the display settings of the light meter properties window. An example can be seen in Figure 1.37 below:

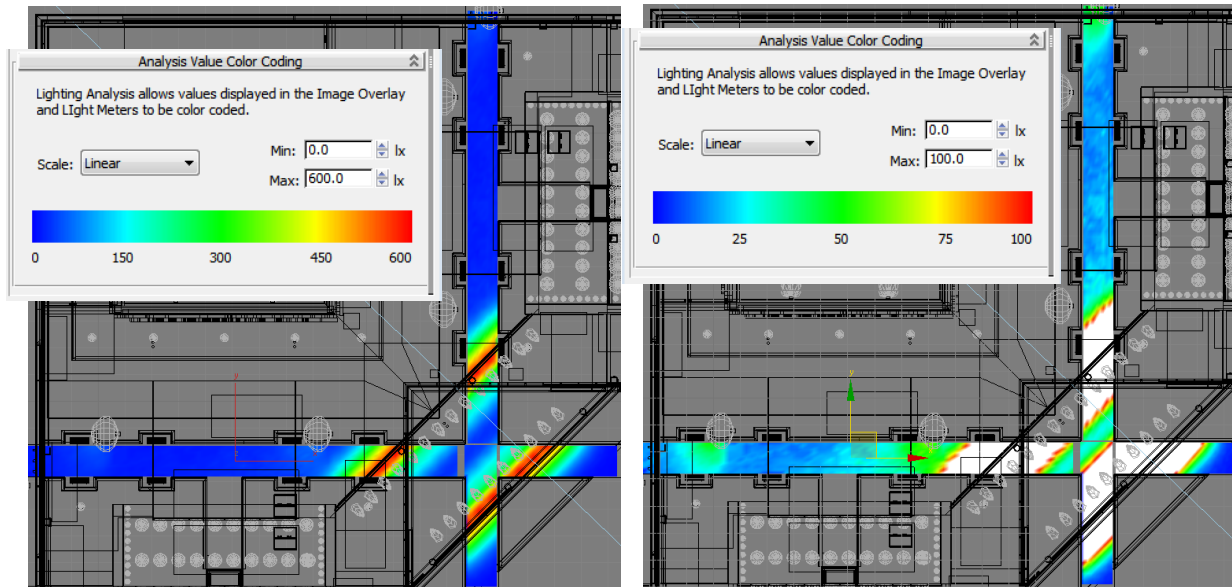


Figure 1.37: Pseudo Color Illuminance Settings in 3ds Max Design

In addition to the challenges of model size, there is a challenge when “turning on” luminaires within 3d Studio Max Design. Once imported, the .fbx file will contain all photometric data that has been compiled within the Revit model, but will import the fixtures as turned off. The “Light Lister” tool can only hold so many photometric files before the user must select the luminaires in smaller parts by selection box. Once these luminaires are turned on, the photometric patterns become white in color – as seen in Figure 1.37 above. Following analysis, the results from 3ds Max were compared to output values from AGI32.

| Calculation Values: AGI32 vs. 3ds Max Design |                      |      |       |                      |       |       |
|--|----------------------|------|-------|----------------------|-------|-------|
| Calculation Grid                             | AGI Illuminance (fc) |      |       | 3ds Illuminance (fc) |       |       |
|  | Min.                 | Avg. | Max.  | Min.                 | Avg.  | Max.  |
| Paths  | 1.10                 | 7.72 | 63.20 | 0.102                | 23.15 | 59.00 |

Each program handles lighting calculations in a different manner. AGI32 is a lumen-method-based calculation, whereas 3D Studio Max has a different calculation method.

## MECHANICAL BIM PROCESSES

Building information modeling software has been used throughout mechanical redesign efforts for the Millennium Science Complex. BIM adds additional information to design documents that allow the engineers, architect, owner, and operator to more fully understand the components of design. Autodesk’s Revit Architecture, Revit MEP, and Revit Structure were used to coordinate designs from all disciplines. For mechanical design, a Revit MEP central model was created. Revit Architecture and Revit Structure models were linked to the same coordinates of the Revit MEP to provide architectural and structure references during design.

## MODEL SHARING BETWEEN REVIT ARCHITECTURE AND TRANE TRACE

The first step in mechanical analysis is to accurately predict the loads that will occur in the building. Once loads are obtained, the mechanical system can properly be sized. An energy modeling program can be used to obtain the proper loads. For the analysis of the Millennium Science Complex, Trane TRACE was chosen to model the loads. There are two ways that rooms and spaces can be modeled in Trane TRACE. The first method is to manually input each room's area, exterior walls, openings, and roof area. For a project as large as the Millennium Science Complex, this approach would not be feasible to be completed timely. Another method for importing rooms into Trane TRACE is to use the gbXML file import method. The process begins with a Revit Architecture model with room tags in it or a Revit MEP model with proper space tags. The Revit MEP of the Millennium Science Complex was supplied to KGB Maser for our analysis with proper space tags of each room and was used for gbXML export. After the model has been exported to gbXML format, it can be opened in Trane TRACE. The conversion process takes minimal time and afterwards, the spaces or rooms that were tagged in the Revit model show up as rooms in the Trane TRACE model. It is important to realize that there are corrections that need to be made within the Trane TRACE file after import. Occasionally, excess walls and openings show up in rooms. It is important to reference the main Revit model to determine if these walls and openings should factor into energy modeling or if they should be deleted.

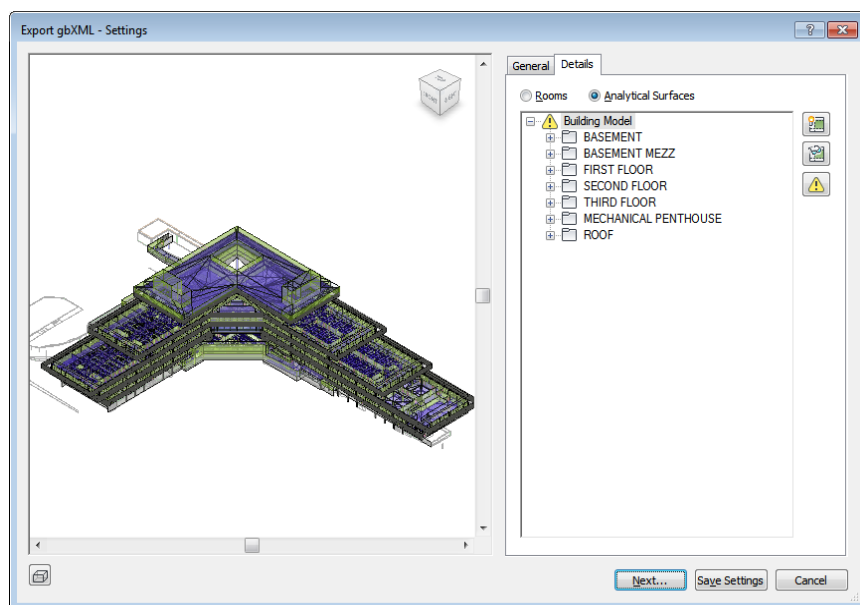


Figure 1.38: gbXML Export from Revit

Despite having relatively accurate space areas and openings in Trane TRACE, the existing conditions were not able to be replicated entirely. The façade of the existing design consists of a precast panel structure that overhangs the glazing of the interior spaces by roughly 2.5 feet. Additionally, the glazing is divided into two areas by a shading device. Within Trane TRACE, only one feature of the shading feature can be modeled per opening. Additionally, with the proposed use of interior shades, it was not possible to model the three

shading aspects of the proposed façade conditions. In energy modeling calculations, the overhang by the existing precast panel and the shading depths for the proposed façade were modeled. This results in a seemingly conservative estimate, but do the the results of the energy simulations, it seems that additional shading will only have a small impact on operating cost savings.



Figure 1.39: Existing Facade

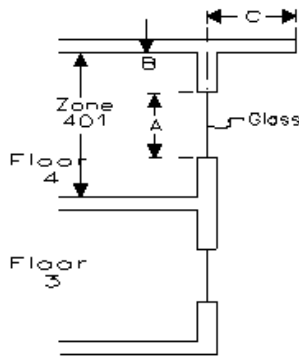


Figure 1.40: TRACE Help Description of Overhang Definition

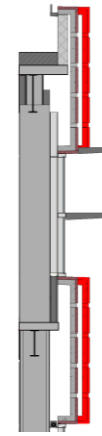


Figure 1.41: Proposed Facade

## REVIT MEP LOAD CALCULATION CAPABILITIES

The existing Revit Architecture model provides an additional avenue for obtaining space loads. The architectural model can be opened within Revit MEP. Underneath the “Analyze” tab in Revit MEP is a selection called “Heating and Cooling Loads.” Building information such as the construction of various elements in the building, the infiltration class, the mechanical service, to the building, and the building type can be adjusted as necessary. In Figure 1.42 and Figure 1.43, a screenshot of the mentioned workspace in Revit MEP is shown. When attempted for the Millennium Science Complex’s architectural model, the accuracy of the output report was of concern. The Revit MEP list of available options did not include a laboratory related option. The closest option was a school/university classification. A school/university report showed greater loads than an identical report run as an office. Trane TRACE, despite difficulties during transition from Revit Architecture to gbXML import was preferred for accurate energy calculations. However, the downside of using Trane TRACE is that any changes made to the building Revit model cannot be synched. A Revit MEP heating and cooling load report can be created quickly after model changes have been made.

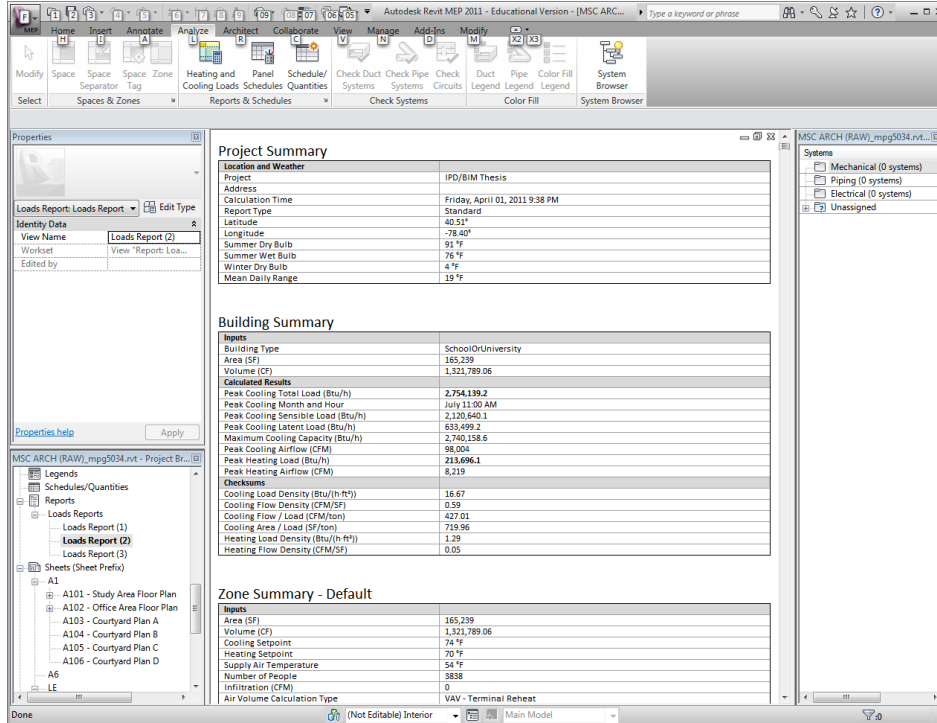


Figure 1.42: Heating and Cooling Load Calculations in Revit MEP

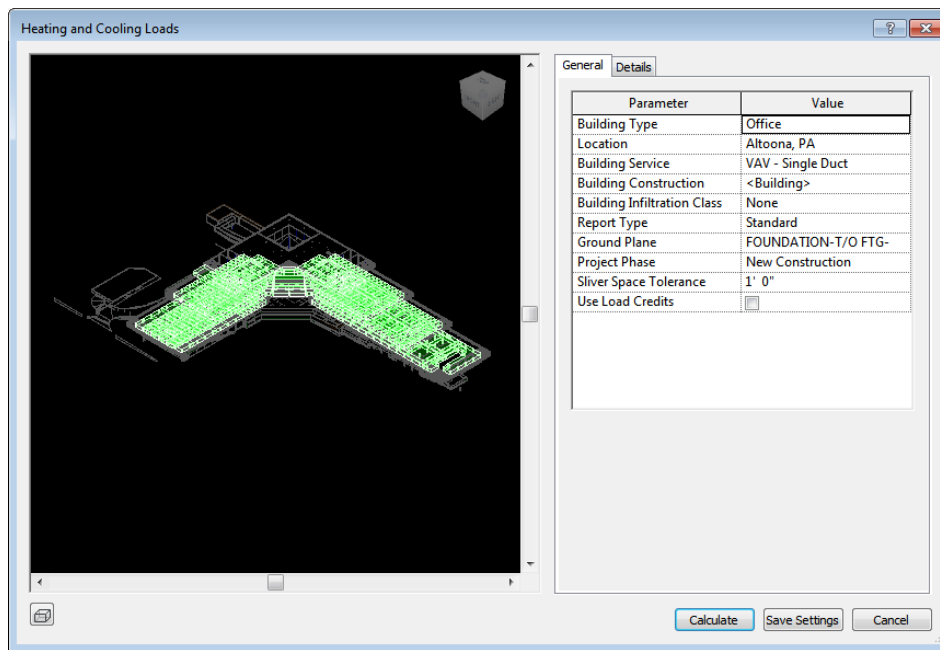


Figure 1.43: Space Heating and Cooling Loads from Revit MEP

## CHILLED BEAM FAMILIES

Once the final façade strategy was finalized, the Trane TRACE model was ran to obtain the final loads that will drive the mechanical design. For the active chilled beam redesign, the space peak loads were exported to a Microsoft Excel workbook. The ventilation outputs were analyzed based on ASHRAE Standard 62.1, latent loads, and ventilation requirements. With both ventilation and peak loads obtained, chilled beams can be sized for each space. The Excel workbook tracked the impact of two different types of active chilled beams, Trox 2-way DID 632 high capacity beams and Price-HVAC ACBL one-way beams. One-way beams were located along the perimeter walls to handle envelope loads directly. Two-way beams were placed perpendicular to exterior walls to conveniently fit in the established reflected ceiling plan. The combination of the airflows from the two beams should result in effective mixing and a thermally comfortable space.

Often the ventilation requirements drove the need for the amount of chilled beams, especially in exterior lab zones requiring 6 air changes per hour. In order to avoid excess cooling, the flow rate of chilled water to each beam was tracked based off of manufacturer selection and sizing data. The combination of Revit MEP and downloaded manufacturer chilled beam files allows for this information to be included in the design model.

Price and Trox both made Revit files available of their chilled beam products, although the formatting of the two families varied. Figure 1.44 and Figure 1.45 demonstrate the differences in appearance and editable properties of the two types of chilled beams.

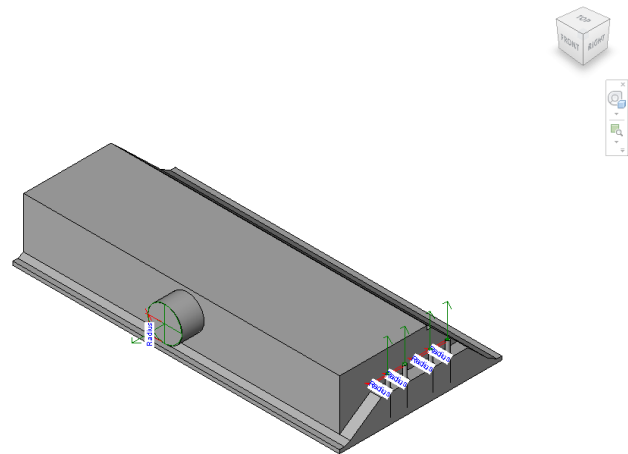
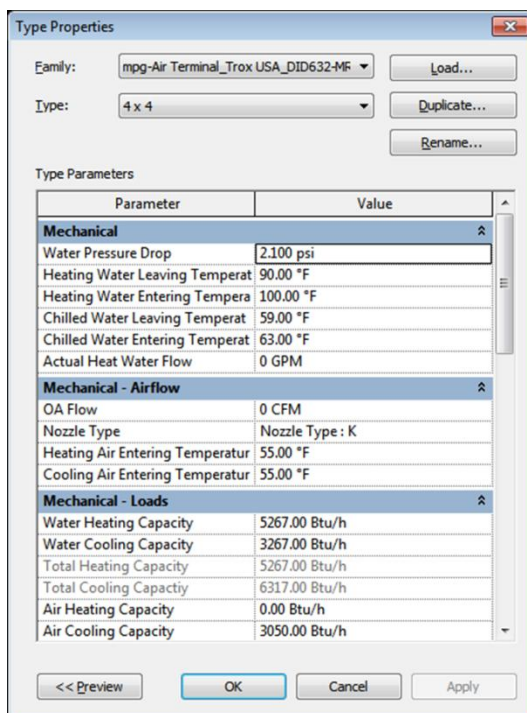


Figure 1.44: Type Properties and 3D view of TROX DID 632 Active Chilled Beam



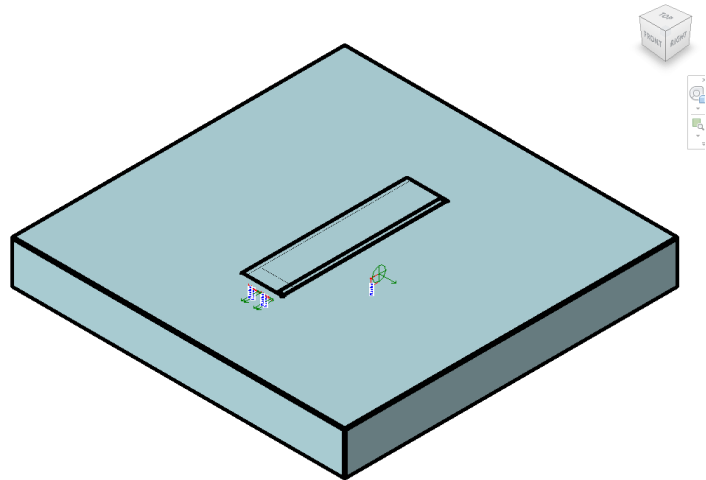
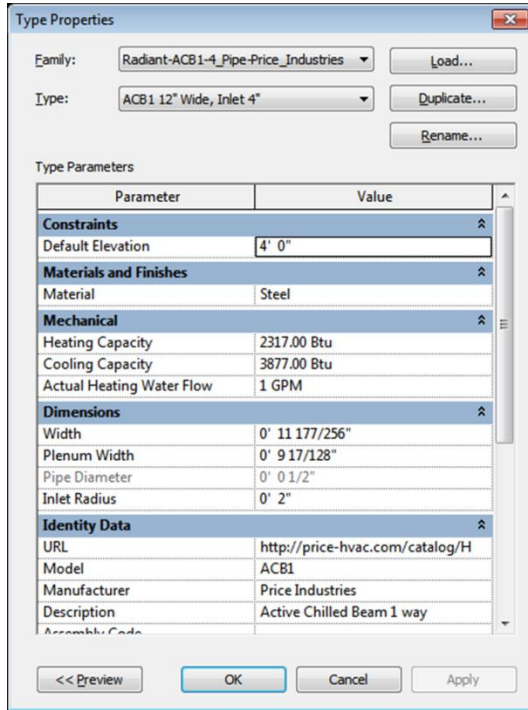


Figure 1.45: Type Properties and 3D view of Price-HVAC ACBL Chilled Beam

Despite the availability of manufacturer chilled beam models, providing a mechanical system redesign in Revit MEP with the downloaded chilled beams required some adjustments. Within Revit MEP, a typical diffuser can be assigned a specified CFM to supply to a space. A duct connected to this diffuser can then “read” the amount of airflow required by that diffuser and store the information in the ductwork’s properties. Within Revit, the automatic sizing feature can be used to size ductwork based on the CFM of the diffuser. Essentially, ductwork can be sized efficiently without manually keep track of the airflow required by each branch of ductwork. However, coordination of ductwork within the available space in the ceiling plenum still needs to be done manually.

The TROX chilled beam family needed to be altered in several ways as outlined in the following table. The key alteration was changing the air flow parameter to allow for different CFM for each beam to be specified in the model instead of being constant. Since only 2’ x 4’ sized beams were used, it was beneficial to allow this parameter to be changed in the main model. The Price-HVAC ACBL chilled beam download only needed to be carefully place in the model since it was designed with the need for a host surface.

| Summary of TROX Chilled Beam Adjustments |  |  |
|--|--|--|
| Parameter                                | Downloaded Setting                               | Adjusted Setting                           |
| Flow Configuration                       | Calculated                                       | Preset                                     |
| Flow Direction                           | In   | In   |
| Family                                   | Air Terminal                                     | Mechanical Equipment                       |
| Location of Inlet                        | Side   | Top (Cost Option)                          |
| Air Flow                                 | Instance: Keeps CFM constant for the same family | Type: Allows different CFM for same family |



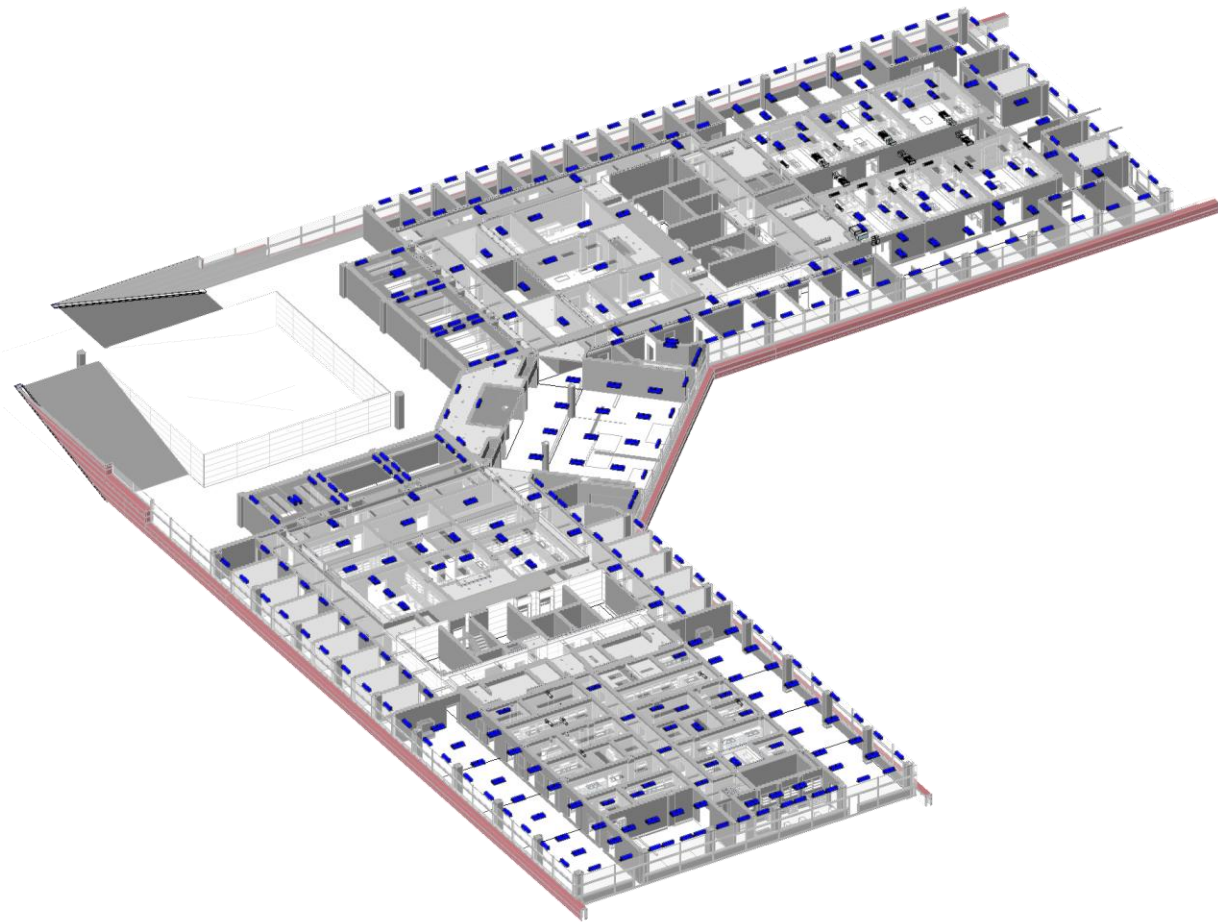
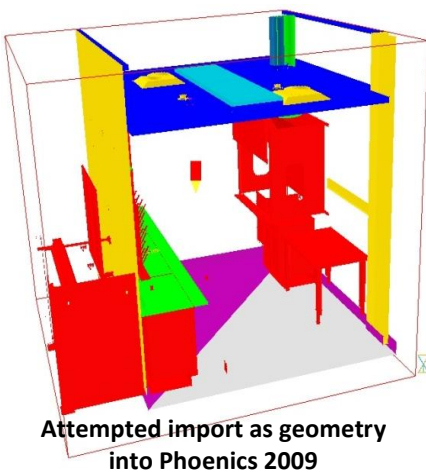
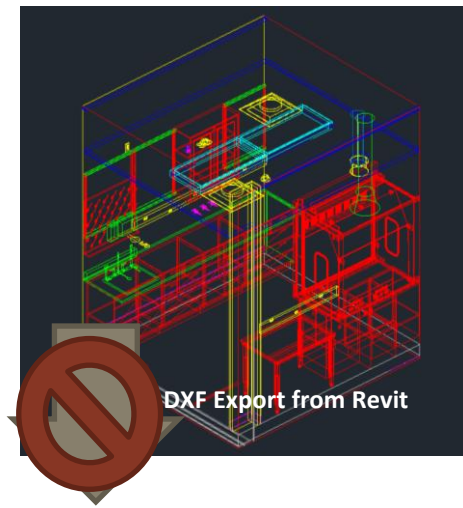
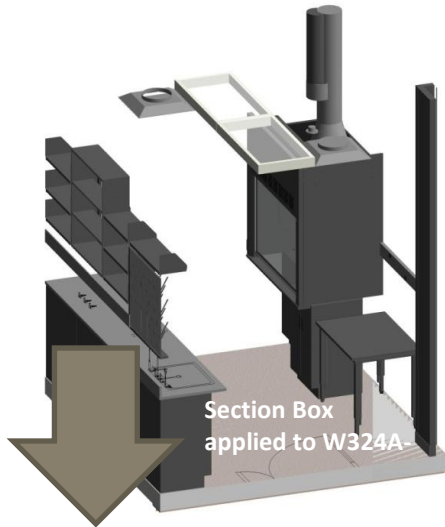


Figure 1.46: Chilled Beam Layout in 2D

Chilled beams were coordinated on paper with the reflected ceiling plan and the Excel Workbook that tracked compliance with ventilation and space loads. The next step was to transfer the schematic placement of beams into the Revit MEP central file. While placing beams, an error message arose that stated: "The default system "Default Supply Air (mpg5034)" is now over 50 elements. To improve performance, Revit is no longer calculating the critical path pressure drop and the more complex duct sizing has been disabled. If you want to use these features, you must define logical systems in the model instead of using the default system." Therefore, in order to allow for Revit MEP to calculate ductwork sizing based on specified CFM to each chilled beam, an additional step was needed. After a chilled beam was placed, the beam needed to be selected and added to a duct system. Duct systems were defined based on location in the floor based on zoning. This step is not due to classifying chilled beams as mechanical equipment and is necessary if modeled as air terminals. The goal of designing in Revit is to supply information such as pressure drop or airflow needed within a duct. Embedding information into the model's elements and creating systems allow a design engineer in Revit MEP to quickly reference information.

## OPPORTUNITIES FOR MODEL SHARING BETWEEN REVIT AND PHOENICS



When creating a CFD model of a sample fume hood room for analysis, the model was created by taking dimensions from the Revit Architecture model, converting the dimensions into metric units, and building the room element by element.

To streamline the tedious process of creating elements, the possibility of exporting geometries from Revit Architecture into a CFD modeling program such as Phoenix 2009 was explored. From investigation within Phoenix 2009's help files, it was found that CAD files such as .stl, and .dxf could be imported as objects.

A section box narrowed around W324A-Hot room in a 3-D view isolated the elements that were desired for a CFD model. From this view, a CAD DXF file can be exported. Once, exported into DXF format, the file was reviewed to ensure the geometries that were needed showed up in the export. The import into Phoenix as a geometry shape did not occur smoothly. Multiple attempts were made to import the geometry in the correct form. The best attainable model is depicted as the last image in Figure 1.47: Attempted Revit to Phoenix 2009 Process.

The CAD geometry import process was not found to be effective for modeling indoor air flows. However, CAD geometries can be used to model exterior flows, such as wind through a neighborhood, more effectively. KGB-Maser believes that a great opportunity lies in completing the process from a Revit Architecture model to a CFD modeling platform. CFD modeling can produce accurate simulations of airflow in spaces and can be used to test designs and correct problems. If geometries can be effectively transferred, the opportunity exists for CFD to ensure the effectiveness of more areas of design. It should be noted that simulations and input of additional parameters take a reasonable amount of time to complete. The immediate accurate modeling of space geometries would eliminate time spent building the elements and ensure accurate element representation within the CFD model.

Figure 1.47: Attempted Revit to Phoenix 2009 Process

COORDINATION BETWEEN STRUCTURAL, MECHANICAL, AND ARCHITECTURAL REVIT FILES

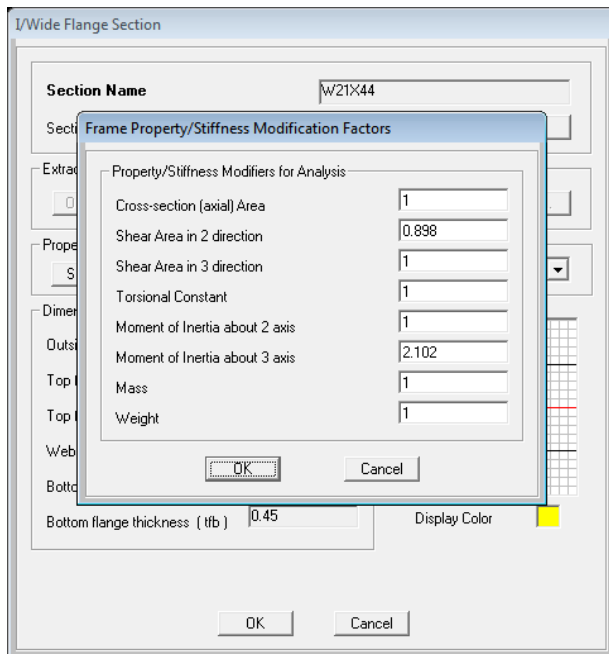


Figure 1.48: LB30X44 Property Modifiers

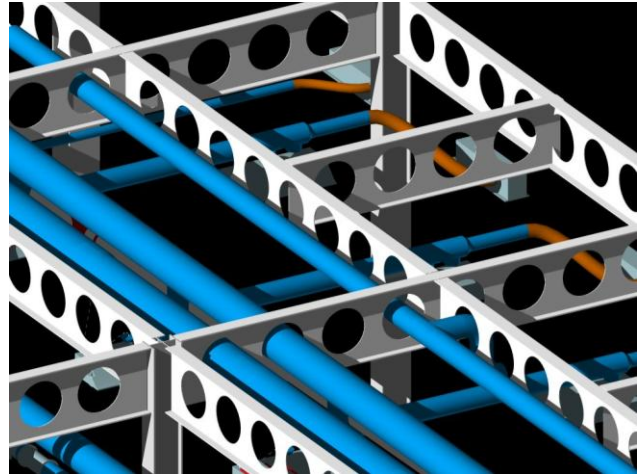


Figure 1.49: Mechanical and Structural Coordination

too large to fit through reasonably sized cellular beams. In order to achieve this design, the structural engineer required rough estimates of duct sizes that were to be run through the cellular member. The structural engineer then sized the cellular beam system according. During this time, the mechanical engineer devised a scheme to run ductwork through the cellular beams and reach the chilled beams previously placed.

The use of cellular members with active chilled beam ductwork was a design goal of KGB Maser. The theory behind the initial idea was that main ductwork would run below the cellular members because they would be

The design of the mechanical system required coordination with the cellular members. The Revit Structure linked file was referenced when designing ductwork in the plenum space. Chilled beams were placed in the acoustic ceiling grid according to the Revit Architecture model. Distribution of chilled beams was accomplished without affecting the lighting scheme and with constant reference to the structural system.

STRUCTURAL BIM PROCESSES

FAÇADE

Throughout the entire process, depth of the panel was given special consideration. Not only does depth affect the shading of interior spaces, it limits the amount of insulation that can be inserted between the panel and the interior wall of the building. It was ideal to decrease the depth of the panel as much as could be afforded by the mechanical and lighting/electrical disciplines. Of course the controlling factor of the depth ended up being strength against wind. The depth of the panel decreased, as well as the depth and therefore inertia of the top flange.

It was anticipated that the panel could be modeled with the appropriate changes and applied to the entire Revit model we had been given at the start of the semester. There is no master panel that changes all of the façade

simultaneously. Every panel, individually, would have needed to be changed in order to replicate the redesign in the model. This task would have been tedious and time consuming, so it was decided that only one panel, as a representative to the rest of the façade, would be modeled in Revit to illustrate the new design.

Dimensions were taken from an excel spreadsheet which was used to check the panel's strength. These measurements were then used to assemble the 3D extrusion, complete with brick face and perimeter flanges. The model then served as a source for quick takeoffs for the rest of the team.

## FLOOR SYSTEM

The program used to analyze the existing conditions and redesign, was SAP2000, chosen for its versatility and ability to analyze virtually any 3D structure. SAP does not include cellular shapes in its library of frame types, so wide flanges had to be edited in order to emulate the behavior of a cellular beam; a W21X44 was chosen to represent an LB30X44 for example. Shear area was reduced by 20% and Inertia was increased twofold. The resulting modified w-shape gave a good approximation of the behavior an LB30X44 as the results were as expected, aligning with deflections previously calculated.

As mentioned before, using cellular beams in a laboratory setting isn't typical because the ducts required to ventilate the lab spaces are usually larger and more intricate. Reorganizing the plenum therefore required the 30-inch cellular beams to be modeled in Revit, so the mechanical engineer could model necessary ductwork and equipment in 3D to provide a proof of concept.

Revit allows the editing of certain member properties including those of cellular beams. Unfortunately, the shapes provided by AutoDesk were few in number and hard to edit. Inputting numbers manually into the properties menu of an LB20X14 yielded only problems. Even though the numbers were taken from a standard LB30X44, whose dimensions met all code requirements and limits, Revit was consistently incapable of extruding the new dimensional values, leading to voids that were mashed together. This extrusion was clearly inaccurate and of little use to the MEP engineer who was depending on the structural Revit model to use in laying out his mechanical equipment. Therefore a new family was created from scratch whose extrusion accurately reflected the appearance of a cellular shape. Replacing the existing frames in the central revit model, was as simple as changing beam properties from a menu. However, some frames were drawn beyond the extent of the boundary line when inserted into the model. These, shorter, beams were fixed by editing the family of the cellular beam in Revit.

Originally it was thought that the floor system modeled in SAP would simply be exported into Revit, serving as a base for the complete reconstruction of the building redesign. Even if SAP had been able to successfully model the correct extrusion, the link to export information from SAP to Revit does not exist for 2011 Autodesk applications. The link in question is provided by CSI, the software company behind SAP, which had not yet updated their link, which only worked with 2010 applications. An idea had been brought up to use the 2010 Revit software to enable the link, but the process would have downgraded the current software and disabled some of the features that the other disciplines may have needed. Using the 2010 software would have also prevented the use of the existing conditions Revit model, as it was created in Revit 2011. The older software would not have recognized the newer model, costing the team valuable time in recreating the building top to bottom with the appropriate structural, mechanical and lighting/electrical systems.

Since the redesign would focus mainly on the third floor, it was originally thought that only that floor would be modeled due to the complexity of each system. Fortunately, the BIM teams were provided with a complete model



of the existing conditions, which saved us an enormous amount of time in modeling the information that was not changed.

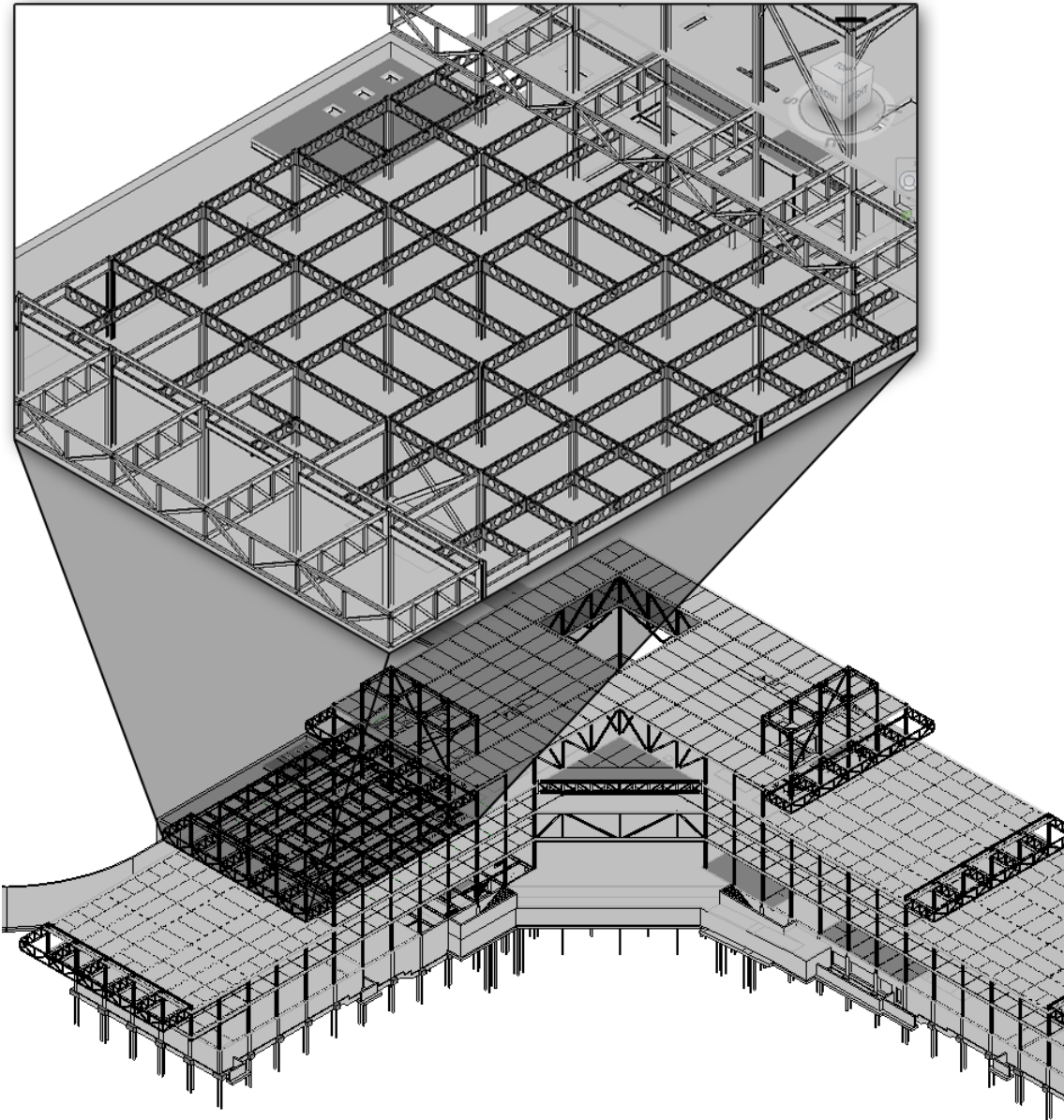


Figure 1.50: Cellular Beams Revit Model

The existing conditions Revit model provided each team with a wealth of information. If one needed to find the location of a certain member, rather than search through the construction documents and attempt to visualize its location relative to the overall building, the model could be searched for the same member and viewed in 3D. Its ability to provide context to an element where a 2D drawing could only give information about one plane, is invaluable to understanding and studying the building. Losing that information would have been an immeasurable disadvantage to the entire redesign process.

So rather than importing the redesigned floor system from SAP, a new member was created in Revit and used to replace the existing floor members. In a relatively short time, the structural floor model was complete and ready to be used for the mechanical layout. This provided the MEP engineer a 3D plan in which he could configure and model his system. Immediate feedback was available to alert him of the presence of collisions or of any unanticipated issue with the structural system.

The process of modeling did feature a few errors, which were brought into light by the mechanical engineer. Beam voids were not perfectly aligned due to Revit's default placement of members between columns. One end of the cellular beam would meet the flange of a column and the other would meet a column's web; this might have been vice versa with the next member, moving the voids one or two inches from the center of the beam before it. The mechanical engineer had to weave his equipment to and fro in order to avoid hitting the edges of each void in the beams. There were also smaller beams that exemplified this same issue, their voids lining up in completely the wrong place with the beam before or after it. This issue would have been completely looked over if it weren't for modeling it in 3D, where issues like this one could be discovered and resolved before being sent to final construction documents.

Since the lateral system was desired to remain unchanged, some members in the 3rd floor had to remain wide flanges. This was initially an issue, as it was planned to run all mechanical equipment through the structural system. The mechanical engineer was able to simply move his equipment below the level without any significant consequences.

## CANTILEVER

Analysis was done in SAP. An entire corner of the building was modeled for maximum accuracy. The model itself took around 12 hours to complete with the existing member sizes and loads. The trusses were then altered for the premeditated redesign and the model was run. Strength was checked in each member by exporting the results obtained from a SAP analysis into excel that was set up to read the results and use their values to check members in an interaction equation. Excel was able to immediately identify members that did not meet strength requirements, expediting the process of analytical iterations. The analytical model was then checked that it met deflection requirements of  $L/360$ . Strength ultimately controlled in all the redesigned trusses, whose web members were oriented for tension. Column size was based on an unbraced length of 32', a dimension taken from the birdcage sculpture; its mess of frame elements contains larger HSS tubes, which intersect at the columns' midpoints to provide bracing.

To visualize all these changes, the existing revit model was altered to accommodate the changes proposed. It was originally thought that the gravity model from SAP could simply be exported to Revit, so the same model did not have to be replicated twice in two different programs. This was not possible as explained above. Since all the redesign information was stored in SAP, the analytical model had to be referenced while changing members in the existing revit model.

First the superfluous bracing and web members were deleted from the existing revit model then the section properties of the existing members were changed from a pull down menu. The columns were inserted into the model by dragging down the existing truss member to the right base level. This process was seamless and did not cause any unforeseen problems or issues with the other systems. The resulting model made evident the space freed in the mechanical penthouse. Only two of the four main trusses use bracing on this level, and it is present in only two bays.



Before this model was completed, the lighting/electrical engineer had planned on lighting a space inside the building, not considering the plaza an especially interesting space as of that time. When the idea of a column was proposed, its architectural consequences made the plaza an even more undesirable location to light. The column intruded into the space completely destroying any subtlety that had been desired of its presence in the plaza. Once a proper architectural solution was suggested, it was modeled in Revit. Modeled in 3D, the lighting/electrical engineer saw potential for lighting and changed his proposal.

## TEAM INTERACTION & BIM PROCESS

**KGB Maser**  
BIM/IPD Group #3  
Team Meeting

**Meeting Minutes**

**Subject:** Team Meeting #14  
**Location:** 333 Sackett  
**Meeting Date:** January 25, 2011

**Attendees:**

| Name           | Option                  | Email           |
|----------------|-------------------------|-----------------|
| Jason Brognano | Lighting/Electrical     | jb2133@psu.edu  |
| Michael Gilroy | Mechanical              | mgp5034@psu.edu |
| Stephen Kijak  | Structural              | sak5003@psu.edu |
| David Maser    | Construction Management | dmm5097@psu.edu |

**Attachments:** None  
**Prepared By:** Jason Brognano  
**Via:** Hard Copy

**I. Outstanding Items**

| Item | Res. Party | Description   |
|------|------------|---|
| I.1  | DM, MG, SK | This research page<br>- Make a list of all thesis research that has been accumulated this semester<br>- Use the following format:<br>"Research Title"<br>"Link to website" or "Publication name/pages"<br>- Will be added to the website as information is used |

**II. Milestone Tasks Outstanding**

| Item | Res. Party | Description  |
|------|------------|--|
| II.1 | JB         | - Lighting design of study area – 80% complete<br>- Daylight analysis of study area – 5% complete<br>- Meeting with Mike this week to choose glazing properties<br>- SKM components loaded to PTW model – 0% complete<br>- *BIM model sharing issues to be clarified this week with John Herring   |
| II.2 | MG         | - Zone level energy model – 80% complete<br>- Façade redesign ideas Living Wall – Under investigation with Steve and Dave<br>- Thermal envelope analysis. Under investigation with Dave<br>- Overall Façade study- 65% complete<br>- Work to begin on 3 <sup>rd</sup> floor energy model after ASHRAE conference attendance  |
| II.3 | DM         | - Façade constructability issues being reinvestigated due to new design proposals<br>- Façade Detailed estimate not started due to façade design not finished<br>- Crane Analysis investigated to look at other possible crane use for steel erection.<br>- Site logistics and phasing of steel erection started in 4D Navisworks model.<br>- Schedules created and imported to Revit Architecture model to begin estimation preparation |
| II.4 | SK         | - Continue on Floor Design and Vibrational Research – Completion date extended beyond expected finish date<br>- Finalize façade design including concrete type and thickness – connections to be designed concurrently with Lateral System<br>- Revit Structure model – upon completion of floor system, the start of the Revit Structure model will commence  |

**III. Meeting Schedule**

| Item  | All | Next Meeting is Tuesday February 1 at 3:45pm |
|-------|-----|--|
| III.1 | All | Next Meeting is Tuesday February 1 at 3:45pm |

Notes:

1 | Page

Figure 1.51: Sample Meeting Minutes Form

communication of the designs generated by our team. KGB Maser will use BIM to design, visualize, simulate, and analyze the designs that are developed for Millennium Science Complex.

This is a strong clear mission, and the goals we set as a team were to fulfill this mission statement. Throughout the entirety of the BIM/IPD Senior Thesis KGB Maser met at a minimum once a week to discuss progress and changes to the design. During these meetings, we were able to keep each other focused on our goals and mission. Below is a chart of the goals we set in the BIM Execution Plan.

To maintain an accurate gauge of team progress and responsibilities, the team had weekly meetings to discuss upcoming due dates, project progress, and details regarding tasks and activities throughout the 2010-2011 academic year. These meeting minutes contained valuable information regarding team member analysis documentation, responsibilities for various stages of design, a rough estimate of lead and lag time, and team standards for formatting documents. Information exchange is key to facilitating an efficient team and the meeting minutes were a central piece of KGB Maser's chain of communication.

KGB Maser set out in the beginning with BIM goals as a team, and the potential BIM uses that could help achieve these goals. The BIM Mission Statement for KGB Maser is as follows:

*KGB Maser will utilize BIM to streamline the design process, and effectively communicate building system designs to team members and advisors. BIM will be used as part of an integrated process to facilitate the investigation, coordination, and*

| PRIORITY<br>(HIGH/ MED/<br>LOW) | GOAL DESCRIPTION  | POTENTIAL BIM USES   |
|---------------------------------|---|--|
| MED                             | WE WILL UTILIZE BIM TO INVESTIGATE AND DEVELOP POSSIBLE FAÇADE REDESIGNS FOR MILLENNIUM SCIENCE COMPLEX.                  | 3D COORDINATION, STRUCTURAL ANALYSIS, LIGHTING ANALYSIS, ENERGY ANALYSIS, COST ESTIMATION                                    |
| HIGH                            | WE WILL UTILIZE BIM TO EVALUATE AND DEVELOP METHODS TO REDUCE THE ENERGY CONSUMPTION OF MILLENNIUM SCIENCE COMPLEX.       | MECHANICAL ANALYSIS, ENERGY ANALYSIS, LIGHTING ANALYSIS  |
| HIGH                            | WE WILL UTILIZE BIM TO INVESTIGATE AND DEVELOP VALUE ENGINEERING EFFORTS FOR OTHER SYSTEMS OF MILLENNIUM SCIENCE COMPLEX. | 3D COORDINATION, STRUCTURAL ANALYSIS, MECHANICAL ANALYSIS, LIGHTING ANALYSIS, ENERGY ANALYSIS, 4D MODELING, COST ESTIMATION. |
| HIGH                            | WE WILL UTILIZE BIM TO IDENTIFY CONCERNS ASSOCIATED WITH PHASING ON CAMPUS.   | 4D MODELING, SITE UTILIZATION PLANNING   |
| HIGH                            | WE WILL UTILIZE BIM AND MODEL BASED ESTIMATION PROGRAMS TO QUICKLY ASSES COST ASSOCIATED WITH DESIGN CHANGES.             | COST ESTIMATION, DESIGN REVIEWS  |
| MED                             | WE WILL UTILIZE BIM TO EFFECTIVELY TRACK THE SCHEDULE IMPLICATIONS OF DESIGN CHANGES.                                     | 4D MODELING, DESIGN REVIEWS  |

Figure 1.52: BIM Execution Plan - BIM Goals

Keeping these goals in mind early on, KGB Maser was able to evaluate potential BIM Uses by qualifying each BIM use for its value to the project, value to the responsible party, and our team capability rating on the particular BIM Use. Below is the BIM Use Analysis Worksheet that was completed by KGB Maser to evaluate potential BIM Uses.

| BIM Use*                  | Value to Project | Responsible Party | Value to Resp Party | Capability Rating   |            |            |
|---------------------------|------------------|-------------------|---------------------|---------------------|------------|------------|
|                           |                  |                   |                     | Scale 1-3 (1 = Low) |            |            |
|                           | High / Med / Low |                   | High / Med / Low    | Resources           | Competency | Experience |
| Maintenance Scheduling    | Med              | Facility Manager  | High                | 3                   | 2          | 1          |
|                           |                  | Contractor        | Low                 | 2                   | 1          | 1          |
|                           |                  | MEP Engineers     | Med                 | 2                   | 1          | 1          |
| Digital Fabrication       | Low              | Contractor        | Low                 | 1                   | 1          | 1          |
|                           |                  | Subcontractors    | Med                 | 2                   | 1          | 1          |
| Record Modeling           | Med              | Contractor        | Med                 | 2                   | 2          | 2          |
|                           |                  | Facility Manager  | High                | 1                   | 2          | 1          |
|                           |                  | Designer          | Med                 | 3                   | 3          | 3          |
| Cost Estimation           | High             | Contractor        | High                | 2                   | 1          | 1          |
| 4D Modeling               | High             | Contractor        | High                | 3                   | 2          | 2          |
| Site Utilization Planning | High             | Contractor        | High                | 3                   | 3          | 2          |
| Layout Control & Planning | Med              | Contractor        | Med                 | 2                   | 2          | 1          |
|                           |                  | Facility Manager  | High                | 1                   | 3          | 3          |
|                           |                  |                   |                     |                     |            |            |
| 3D Coordination           | High             | Contractor        | High                | 3                   | 3          | 3          |
|                           |                  | Subcontractors    | High                | 1                   | 3          | 3          |
|                           |                  | Architect         | High                | 2                   | 2          | 2          |

Figure 1.53: BIM Execution Plan - BIM Use Evaluation

Knowing what BIM Uses that the team would employ, KGB Maser completed the Information Exchange Worksheet of the BIM Execution Plan that specifically breaks down what each team member will need, and who is responsible for delivering that modeling content in each information exchange to complete the BIM Use. For example, a Cost Estimation BIM Use will have a file receiver of the CM-Student, but for a structural cost estimation, the Structural-student is responsible for delivering a 3D Revit Structural model that is to the highest level of detail. Each of the BIM Uses were evaluated with the Information Exchanges that needed to happen, and the Information Exchange Worksheet was completed.

**INFORMATION EXCHANGE (IE)**

| Information |   | Responsible Party |                     |
|-------------|---|-------------------|---------------------|
| A           | Accurate Size & Location, include materials and object parameters | ARCH              | Architect           |
|             |   | CON               | Contractor          |
| B           | General Size & Location, include parameter data                   | CE                | Civil Engineer      |
|             |   | FM                | Facility Manager    |
|             |   | MEP               | MEP Engineer        |
| C           | Schematic Size & Location   | SE                | Structural Engineer |
|             |   | TC                | Trade Contractors   |

| BIM Use Title                               |                       | Existing Conditions Modeling |            |       | Cost Estimation |            |       | 3D Coordination |            |       |
|---|-----------------------|------------------------------|------------|-------|-----------------|------------|-------|-----------------|------------|-------|
| Project Phase                               |                       | Design                       |            |       | Design          |            |       | Design          |            |       |
| Time of Exchange (SD, DD, CD, Construction) |                       | DD                           |            |       | DD              |            |       | DD              |            |       |
| Responsible Party (Information Receiver)    |                       |                              |            |       | CM Student      |            |       | CM Student      |            |       |
| Receiver File Format                        |                       |                              |            |       |                 |            |       |                 |            |       |
| Application & Version                       |                       |                              |            |       |                 |            |       |                 |            |       |
| Model Element Breakdown                     |                       | Info                         | Resp Party | Notes | Info            | Resp Party | Notes | Info            | Resp Party | Notes |
| <b>A</b>                                    | <b>SUBSTRUCTURE</b>   |                              |            |       |                 |            |       |                 |            |       |
|   | Foundations           |                              |            |       |                 |            |       |                 |            |       |
|   | Standard Foundations  | B                            |            |       | A               | SE         |       | B               | SE         |       |
|   | Special Foundations   | B                            |            |       | A               | SE         |       | C               | SE         |       |
|   | Slab on Grade         | B                            |            |       | B               | SE         |       | A               | SE         |       |
|   | Basement Construction |                              |            |       |                 |            |       |                 |            |       |
|   | Basement Excavation   | C                            |            |       | B               | SE         |       | B               | SE         |       |
|   | Basement Walls        | B                            |            |       | B               | SE         |       | A               | SE         |       |
| <b>B</b>                                    | <b>SHELL</b>          |                              |            |       |                 |            |       |                 |            |       |
|   | Superstructure        |                              |            |       |                 |            |       |                 |            |       |
|   | Floor Construction    | A                            |            |       | A               | SE         |       | A               | SE         |       |
|   | Roof Construction     | A                            |            |       | A               | SE         |       | A               | SE         |       |
|   | Exterior Enclosure    |                              |            |       |                 |            |       |                 |            |       |
|   | Exterior Walls        | B                            |            |       | A               | CM/S       |       | A               | CM/S       |       |
|   | Exterior Windows      | C                            |            |       | B               | LE/M       |       | A               | LE/M       |       |
|   | Exterior Doors        | C                            |            |       | B               | ARCH       |       | B               | ARCH       |       |

Figure 1.54: BIM Execution Plan - Information Exchange

## LESSONS LEARNED

### CONSTRUCTION MANAGEMENT

The lessons learned during this senior thesis project involve Integrated Project Delivery and the use of Building Information Modeling to ease the sharing and possibilities of the information. The main lesson learned from integrated project delivery is the more open you are with your team, the more information you can get and receive from them. The biggest thing that I wish could have happened in an integrated approach is to know when each model was updated and what aspects of the model were updated. The ability to easily share information, could allow the modification of models by the architectural and engineering design firms, and could easily notify the construction management firm of what the changes were. Also learning more about sharing as much information as early as possible is vital to a successful integrated project delivery team. Last year in a previous integrated project delivery team, our communication was not sufficient and our progress suffered. This year our team was able to openly communicate about their own designs, and communicate with each other how all of the designs would affect their own. I look forward to taking what I have learned from working in an open, integrated team with me into my career.

As the construction industry moves more and more to the unanimous implementation of BIM, it is important to take the lessons learned in this thesis on BIM with me. The lessons I have learned with BIM is how to seamlessly make useful Revit Schedules to export to Microsoft Excel or other model based estimation programs. I have learned how to create detailed families for unique project components. I have learned that 4D modeling is not simply a video to show the entire project duration. 4D modeling can be used to show explicit details of certain processes and how they will occur. IPD/BIM Thesis has taught me to remain open minded and to share as much information with my team as possible. I have learned how to evaluate and effectively incorporate different BIM Uses. I have learned a lot this year to take on with me to my career.

### LIGHTING AND ELECTRICAL

Major lessons learned from participating in IPD/BIM thesis revolve around two main ideas – model sharing abilities and full-service design. More companies are shifting to BIM related software platforms such as Revit, even in the lighting and electrical sector of engineering. MEP design firms are beginning to utilize Revit MEP in conjunction with traditional computer aided drafting and annotation software to streamline designs. One of the advantages of BIM software, such as Revit, is the ability to only change a datum once and it will cascade through the model and be changed in all other instances within the project. This saves design time and reduces the number of type mismatches when documents are sent to be published. Additionally, I have gained much needed knowledge about lighting and electrical specific model sharing processes and programs (as seen in this unit). The tools I will be able to take from this academic exercise pushes my abilities farther into the future of engineering design.

Secondly, this program has further prepared me for work in a full-service environment. The company that will be employing me to start my career is a full-service architectural and engineering firm. Through working with a member of each architectural engineering discipline, I have gained valuable knowledge related to other areas of study that both impact my designs and other disciplines. I have further learned the importance of team values such as respect, responsibility, and punctuality. I am thankful for participating in this program and hope that it has continued success at Penn State and in other academic institutions.

## MECHANICAL

Mechanical design during the IPD/BIM thesis seemed to play a part in every decision that was made. The active chilled beam system impacted reflected ceiling plans, equipment power requirements, coordination with structure for plenum space, and impacts on cost and schedule. Often times, it seemed the load information contained by the chilled beams in the model was less valuable than their total quantity, placement, or ductwork requirements. As the mechanical engineer, much time was spent to ensure the chilled beams were accurately sized especially due to a more complex design for a laboratory facility.

While each discipline is undoubtedly equally important, the goal of improving operating costs put a lot of pressure on the mechanical design. Early estimates of ductwork sizes were provided for the structural engineer's cellular beams before deep analysis of distribution systems was completed. While analyzing chilled beams, a concurrent shading study was done to keep pace with the lighting engineer's façade study. Time constraints limited the amount of system Revit modeling that could be achieved. However, per the construction manager's request, chilled beams were sized and placed in the Revit MEP model for easier chilled beam estimation.

Some opportunities have also been identified for enhancement of BIM interfacing. CFD modeling can be an extremely effective tool to model indoor airflow conditions. However, the construction of a CFD model is more difficult than a Revit model. Revit models cannot be imported into CFD models for indoor airflow modeling purposes. If a better link can be obtained between the architectural models and CFD interfaces, CFD's role in HVAC design could drastically increase.

Overall, the team performed well together. Information was distributed at weekly meetings to update team members on discipline specific progress. To further enhance the analysis of the Millennium Science Complex, I feel that a room with all four disciplines working concurrently on models and analyses would be better served to facilitate communication. Often times I desired an answer to a quick question, but different schedules or work stations prohibited pertinent questions from getting prompt answers.

Entering the MEP design industry upon graduation, I feel the knowledge gained in BIM Thesis and BIM Studio relates to the capabilities and frustrations of using BIM software. More detailed information about a mechanical design can be input into a model, but the importance of the end use of such information must be weighed versus the time spent incorporating the additional data.

## STRUCTURAL

Coming into the pilot BIM/IPD program, I had little knowledge of the BIM process. I was under the impression that BIM was simply the use of computer modeling to analyze and convey information more easily. I had no idea of the integration that was involved. The things that once annoyed me about Revit (central models had always caused more frustration than it helped) were now essential to integrated project delivery and the process of communication. To me, communication was the most intriguing part of BIM. Developing ideas to fit a range of functions rather than just the structural objective was more realistic than the traditional thesis. It was through communication that these ideas could be solidified into tangible concepts that were more realistic than simply the most "cost effective" solution. Those considerations that were taken when compromising with the Gil about cellular void size, or when deciding what depth was most efficient for the façade panel with Jay, made this pilot thesis a worthwhile experience. To have learned the general process of communication and information sharing before entering into the field of engineering is invaluable.



## CONCLUSION

KGB Maser has worked hard throughout the 2010-2011 academic year to achieve goals set in the fall semester. Through integrated project delivery and building information modeling platforms, we can say with confidence that our goals for this capstone project have been achieved.

The first team goal undertaken was reducing energy consumption for the Millennium Science Complex. Main measures of success in this section are a lowered operating cost and a lower net present value of 30 year life cycle cost analysis. As seen in the “Energy Consumption Reduction” section of this unit, the engineering team redesigns produced a 14.1% energy savings annually with respect to the existing VAV design. In life cycle cost analyses, the existing system was favored if coal remains the main source for the campus power plant and inflation is not considered. With inflation and either natural gas or coal as a primary fuel source for the campus plant, the new design is favorable. By saving in energy consumption annually, this design goal can be considered to be achieved.

The façade redesign is intertwined with KGB Maser’s energy consumption reduction goal. The new façade panels and the addition of 3’-0” overhangs contribute to decreasing the indoor environment load on the mechanical system and decreasing dependency on electric lighting in perimeter spaces. The latter portion of the energy savings produced an average of 6.97% energy savings in the perimeter zones controlled by team lighting redesign. With the application of vacancy sensors, this savings has opportunity to further increase savings. Additionally, reducing façade panel thickness can conceivably reduce prime energy in manufacturing the panels. As with the previous team goal, these savings in cost and energy have allowed this goal to be achieved.

The structural redesign by KGB Maser for the Millennium Science Complex is an integral part to our team’s success and funding for other long term investments. The structural redesign is considered a success in the fact that the upfront cost of the structural steel package was reduced in cost by close to \$2,300,000. The upfront savings comes primarily from the addition of the W14X550 columns under the cantilever. Another success of KGB Maser’s structural redesign is the addition of castellated beams. The castellated beams in an integrated design approach are able to be used for mechanical duct, electric conduit, and other trades to flow through the open spaces. This is an advantage over the existing design that had a very congested, and complicated plenum coordination. KGB Maser’s structural redesign is a success in saving upfront costs and reducing the complications for plenum coordination.

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