GOVERNMENT OFFICE CENTER
MID-ATLANTIC U.S.

SENIOR THESIS FINAL REPORT

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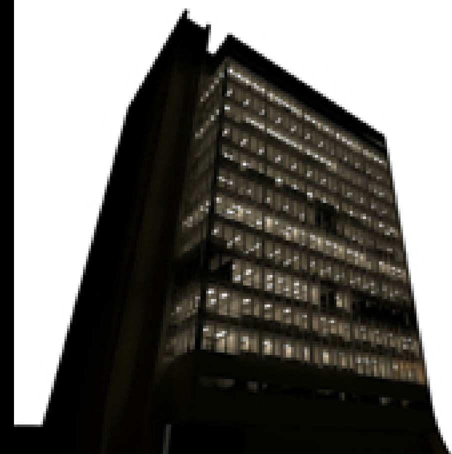
Alexander Ward
Construction Management
James Faust

GOVERNMENT OFFICE CENTER

MID-ATLANTIC U.S.

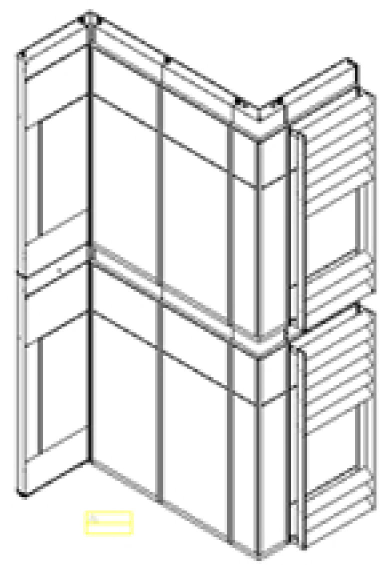
ALEXANDER WARD | Construction Management
http://www.engr.psu.edu/ae/thesis/portfolios/2012/AWW5024/index.html



PROJECT SUMMARY

U.S. General Services Administration	OWNER
Balfour Beatty Construction	CM
TranSystems Corporation	ARCHITECT
Thornton Tomasetti	STRUCTURAL ENGR.
Greenman - Pedersen, Inc.	MEP ENGINEER

ARCHITECTURAL FEATURES



The East and West facades consist of a uniform and continuous tan brick from the top of the building to the bottom, while the North and South facades are large glass curtain walls spanning almost the entire building height. The replacement of the existing curtain walls with an improved unitized curtain wall system constitutes a significant portion of the project.

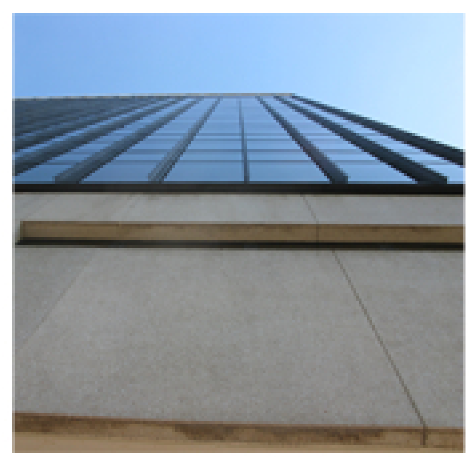
The first three floors contain courtrooms and rooms that serve functions relating to courtroom activities, while the remainder of the building contains the offices, file storage, IT spaces, and other functions needed to serve an office building of this size.

BUILDING HEIGHT: 14 Stories | SIZE: 316,000 SF

STRUCTURAL SYSTEM

Existing structural steel frame supports the building, with a middle bay spanning East to West, flanked on either side by narrower bays of equal width which connect to the curtain wall frame. Floor loads are handled by one-way slab-on-deck before being transferred to trusses. Existing W-Shape steel columns transfer loads vertically to the foundations. New Hollow Structural Section steel members will be installed to support the load of the new curtain wall.

MECHANICAL SYSTEM



This renovation project calls for the replacement of six (6) air handling units with an average cooling capacity of 80 tons. Existing perimeter electric baseboard heating will be replaced with VAV boxes with hot-water reheat. Five (5) natural gas-fired boilers with rated outputs of 1800 MBH will replace existing boilers.

LIGHTING / ELECTRICAL SYSTEMS

A significant portion of the scope of the lighting work in this renovation includes the replacement of existing lamps with more energy efficient LED lighting. This renovation project also calls for the addition of a new photovoltaic array on the lower roof of the existing structure.

CONSTRUCTION LOGISTICS

Due to the needs of the owner, the demolition and construction work for this project will be phased and performed such that the building can be safely occupied while minimizing impact on the ongoing functions within the building. The cost for this project is capped at $42.5 million, and the project will be delivered under a Design-Build system with an Advisor to the Owner and a Construction Management Contractor.

1.0 EXECUTIVE SUMMARY

This report is designed to present the four analyses that were conducted as part of the final thesis report on the Government Office Center renovation and modernization project. In combination, the analysis topics offer insight into a fundamental theme of the importance of active owner involvement to the success of a construction project.

Analysis #1: Implementation of Building Information Modeling

Although this project will significantly impact future facilities management efforts, very little information is being pushed downstream through BIM to support the needs of facilities management staff. This analysis evaluates the benefits of implementing BIM for field and facilities management purposes. While the results demonstrate that there is minimal need for added BIM applications in the field for the Government Office Center, this analysis also demonstrates the value added by two specific BIM for Facilities Management processes.

Analysis #2: SIPS Study for Curtain Wall Activities

Since a major portion of the scope of this project involves the highly repetitive process of replacing the curtain wall systems, the project schedule can be directly reduced through the implementation of Short Interval Production Scheduling. This analysis demonstrates that the benefits of implementing SIPS for the activities that make up this demolition and replacement process include a 25-week schedule savings worth $1.65 million to the owner. This analysis also incorporates an electrical breadth study through evaluation of the feasibility of an alternate building-integrated photovoltaic curtain wall system, and demonstrates a payback period under two years for this system.

Analysis #3: Integrated Processes

As the construction industry moves toward more integrated solutions to unique and complex project delivery challenges, the teams that face these challenges would benefit from an investigation into the benefits of having an engaged owner, as well as the identification of the process and integration failures that can plague a high performance retrofit project. This analysis draws themes from the experiences of industry professionals and evaluates the impact of these failures on the delivery of systems critical to high performance retrofit projects, and clearly demonstrates the vital importance of an engaged owner to the success of such a project.

Analysis #4: Progressive Collapse

The Government Office Center will eventually require structural upgrades to meet the federal requirements for progressive collapse prevention that were implemented decades after the original construction of the building. This analysis analyzes the cost and schedule impacts of adding a progressive collapse system to the scope of this renovation project or a future project, showing that such a system would be ideally included as part of the current renovation project. This analysis also incorporates a structural breadth study through the partial design of a theoretical section of this system.

2.0 ACKNOWLEDGEMENTS

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Ryan Solnosky – AE Graduate Student
PACE Industry Members
My Family and Friends

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3.0 Project Overview

3.1 Introduction

The Government Office Center is a modernist high-rise originally designed and constructed in the mid-1970s, and is essentially a rectangular building with sides facing nearly North, South, East, and West. The East and West facades are a uniform tan brick from top to bottom, without any breaks for windows. The North and South facades are large glass curtain walls spanning almost the entire building height, allowing relatively uniform diffuse daylight to enter the building from the North while more intense, direct sunlight enters the building from the South.

The first three floors contain courtrooms and rooms that serve functions relating to courtroom activities. The remainder of the building contains the offices, file storage, IT spaces, and other functions needed to serve an office building of this size. Due to the nature of the core functions of the Government Office Center, the construction process must allow the building to remain fully occupied and operational for the duration of the project. Therefore, significant coordination must be in place in order to ensure that building occupants, files, and furniture are appropriately relocated to allow demolition and construction activities to take place while minimizing the impact on ongoing functions within the building.

The existing curtain wall on the North and South facades will be replaced with a unitized, aluminum-framed curtain wall assembly. The intent of this portion of the renovation is to offer drastic improvement to the thermal performance of the building envelope, which in turn reduces the demand on the mechanical systems of the Government Office Center. During this project, a temporary engineered weather wall, as illustrated in Figures 1 and 2, will separate the work zone from the occupied building areas. The existing system will then be removed on a specific floor, working from top to bottom. A material hoist on the Northwest corner of the building will allow for the transfer of materials and large waste products into and out of the building.

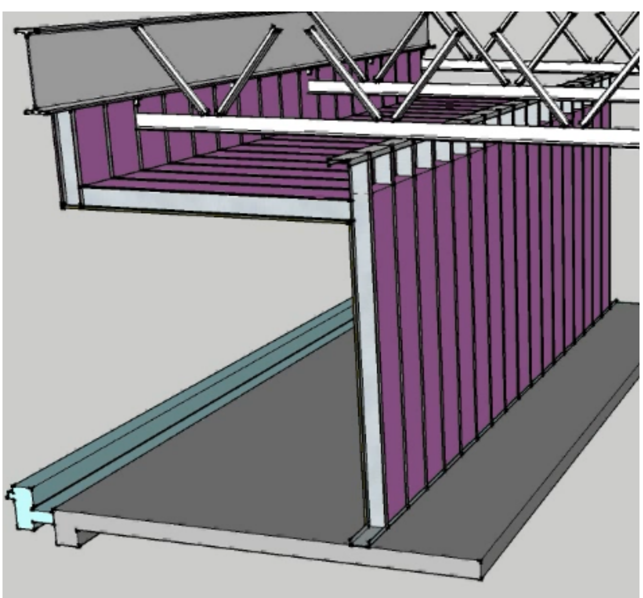

Figure 1: View of Temporary Weather Wall Under Construction
Photo Courtesy of Balfour Beatty Construction

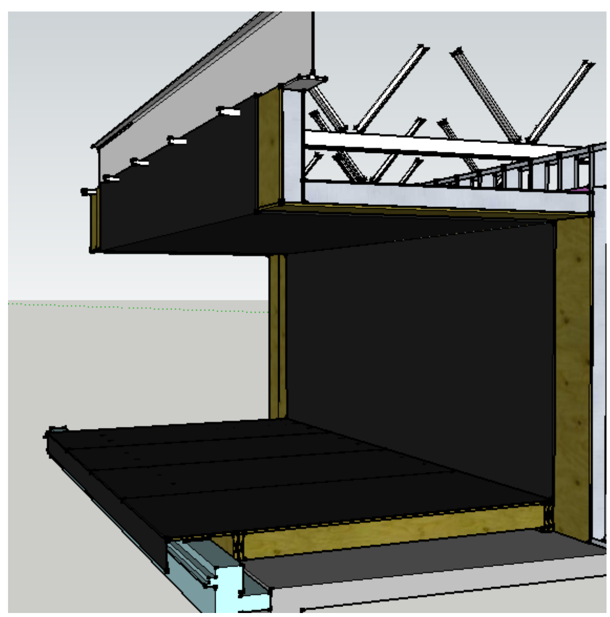

Figure 2: Virtual Mockup of Completed TWW Segment
Photo Courtesy of Balfour Beatty Construction

Mechanical rooms are located on the 1st and 14th floors. Air handling units present in the Government Office Center will be replaced and improved through the addition of variable flow valves. Existing perimeter electric baseboard heating will be replaced with VAV boxes with hot-water reheat that will distribute to new perimeter slot diffusers. The existing cooling tower and chillers will be replaced and converted to variable primary flow. Also, existing boilers will be replaced with more energy-efficient natural gas-fired boilers.

After review of the Government Office Center renovation project, discussions with members of the project team, and interactions with industry members at the PACE Roundtable, several potentially problematic aspects of this project were identified for analysis as part of future research. Challenges involving the difficulty of tying into existing mechanical systems, as well as the limited information flow to the owner for facilities management purposes, suggest that great value can be found through the implementation of BIM in the field and for facilities management. The highly repetitive nature of curtain wall demolition and replacement activities lend themselves to the implementation of production management controls like SIPS. Also, because this building was constructed decades before federal progressive collapse requirements were put in place, the Government Office Center will require significant structural upgrades to meet these requirements. Most importantly, the role of the owner in successfully completing a high performance retrofit project is extremely important, and may have had measurable impacts on the end result of this project.

3.2 Client Information

The General Services Administration is an agency of the U.S. government that is responsible for the management of federal property across the country. GSA has a limited budget to handle operations, maintenance, renovations and new construction work, so it must evaluate its options carefully before choosing to undertake a major project like the Government Office Center in the Mid-Atlantic U.S.

This renovation project was set in motion for a variety of reasons. First, GSA is receiving funding from the American Recovery and Reinvestment Act of 2009 for the project. Part of the purpose of the American Recovery and Reinvestment Act is to stimulate the economy by funding a large number of public projects, and GSA is receiving approximately $750 million from the ARRA for its share in this effort.

Second, GSA and their consultants for this project determined that it would be less expensive to modernize the Government Office Center than to construct a new building to replace it. Thus, the savings generated by choosing to renovate rather than rebuild enable GSA to use funds on additional cases in need of critical maintenance.

Another reason for this renovation is to meet federal government demands for LEED accreditation in its buildings. Through improvement of the façade and mechanical systems performance of the Government Office Center, this renovation and modernization seeks to achieve a LEED Silver rating. In addition, this improved performance will reduce its dependence on ever-rising energy costs and improve environmental air quality by switching to natural gas-fired boilers and adding an array of photovoltaic panels to the lower roof of the building.

Because the building will be occupied for the entirety of the demolition and construction sequence, GSA stresses that proper occupant relocation during these activities is key defining factor of the success of this project. As part of its original effort to win this renovation project, Balfour Beatty Construction developed an animated visualization of how groups of building tenants will be relocated within the building as work progresses. This animation helped the construction management team to demonstrate its understanding of how building occupancy would impact the phasing of demolition and construction activities.

3.3 Project Delivery Method

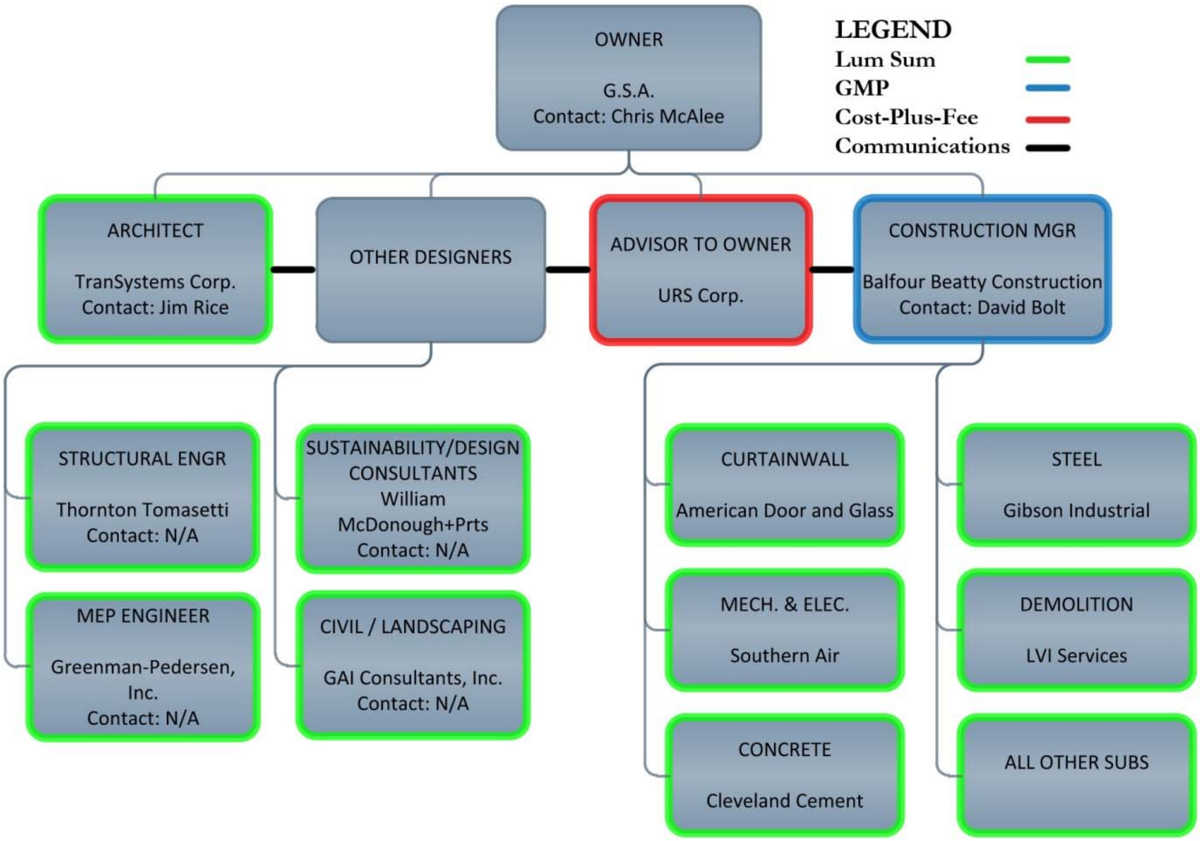

Figure 3: Project Organizational Chart

The Government Office Center renovation and modernization project is being delivered under a Design-Build system with an Advisor to the Owner and a Construction Management Contractor. Balfour Beatty Construction was selected for preconstruction services with the option for GSA to extend the scope of the project to include the renovation work itself. After this option was activated, Balfour Beatty Construction began awarding lump sum contracts to a variety of subcontractors to handle the scope of work involved in the Government Office Center renovation project, as shown in Figure 3 above. Perhaps most significant among these subcontracts, based on scope of work, are the curtain wall contract, mechanical and electrical contract, and demolition contract.

The Guaranteed Maximum Price contract is appropriate for the construction management team because of its involvement in the preconstruction phase of this project, giving Balfour Beatty Construction a fair opportunity for reward while holding them accountable to some degree for proper performance of the renovation work. Lump sum contracts are logical for subcontracts and for design and consulting efforts on a renovation project like this. The cost-plus-fee contract with the Advisor to the Owner is also appropriate, since the cost of work is limited already by the GMP with the Construction Management Contractor.

Payment and performance bonds are required for this project, as well as Owner's insurance to protect the Owner and project team from liability for major damages to the Owner's property during the demolition and renovation work.

3.4 Project Team Staffing Plan

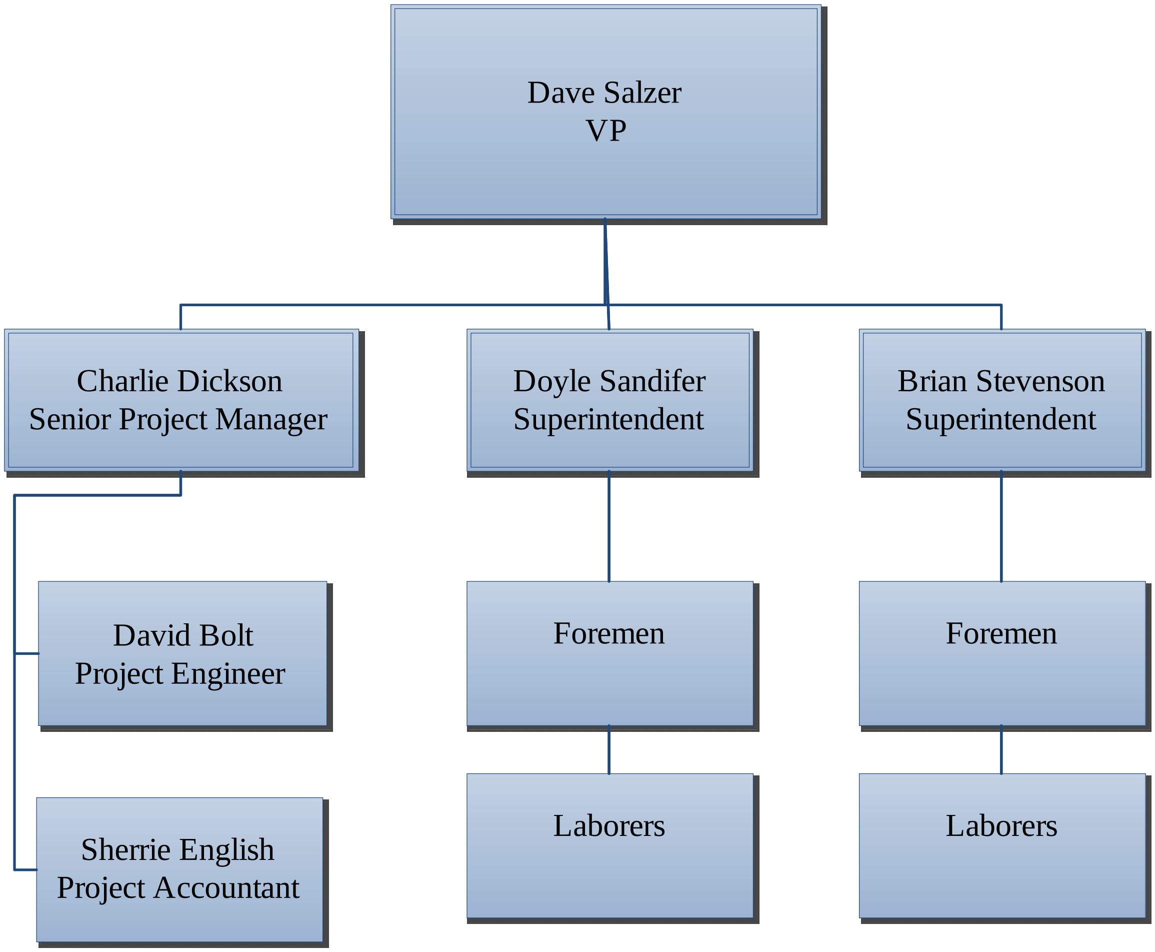

Figure 4: Project Team Staffing Plan

The Government Office Center renovation project is managed by Balfour Beatty Construction, with the roles indicated in Figure 4 above. Given the size of this project, a senior project manager supervises and controls overall project flow, while two superintendents manage on-site crew operations on a day-to-day basis. The senior project manager is supported by a project engineer and project accountant, and reports to a vice president who typically oversees several projects at any given time. Aside from the vice president, all project management staff members are stationed on site and work out of a job trailer.

4.0 Design And Construction Overview

4.1 Building Systems

4.1.1 Demolition

Demolition makes up a critical portion of the renovation of the Government Office Center. However, due to the ongoing occupation of the building during the demolition activities, as well as the salvage and recycling goals of the owner, there are specific instructions for how to handle many aspects of the demolition. For example, demolition of existing built-up roofing must be performed outside normal working hours. Also, particulate discharge resulting from demolition, cutting, grinding, and sandblasting operations must be controlled, and water sprinkling must be used, where relevant, as a means to control dust generation.

Before beginning demolition work, photographs must be taken of the existing conditions, including each window wall interior and exterior, each roof including existing items to remain during construction, and mechanical rooms from a variety of different vantage points.

The project specifications call for very specific descriptions regarding the conditions that must be met for a variety of materials being removed from their existing locations as part of the demolition process. These specific guidelines illustrate one of the goals of the owner for this project, which is to salvage and recycle as much non-hazardous demolition waste as possible. Concrete demolition requires the removal of reinforcement and other metals from the concrete and pulverization of the concrete to a maximum 1½ inch size, while masonry must be pulverized to a maximum ¾ inch size. Wood materials and structural steel to be recycled must be sorted and stacked according to size, type, and length. Large, clean pieces of gypsum board and acoustical ceiling panels and tile must be stacked and stored in a dry location. Large pieces of carpet and pad must be tightly rolled and stored in a closed container. Equipment, tanks, and fixtures must be drained, have their openings sealed, and be protected from exposure to weather. Piping and conduit must be reduced to straight lengths and stored by type and size. Lamps should be separated by type and protected from breakage.

The extensive existing aluminum and glass curtain wall system must be demolished, along with partitions and finishes within the perimeter zone of the building adjacent to the curtain wall. Also, certain existing HVAC systems within the building will be removed and replaced as part of the scope of work of this project. The existing systems to be removed include a cooling tower and chillers, boilers, air handling units, and perimeter electric baseboard heating system.

Asbestos is known to be on this project site, and will affect the demolition work to be performed. All work involving the contact, disturbance, dismantling, and/or disposal of hazardous materials must comply with the applicable requirements of 29 CFR 1926/1910 and 40 CFR 761, particularly (in the case of asbestos) 40 CFR, Part 61, Subparts A and M. Work must also comply with applicable state and municipal safety and health requirements. Specifically, existing built-up roofing systems, including membranes, felts, asphalt, tar, sealant, or adhesive on the roof and flashing system contain asbestos. Therefore, during the demolition of the existing lower and upper roof areas, all roofing materials and components are to be handled as Asbestos Containing Roofing Material (ACRM).

4.1.2 Structural Steel

The existing structural steel frame supports the building, with a middle bay of open space spanning from the East to West sides of the Government Office Center. This middle bay is flanked on either side with narrower bays of equal width which connect to the curtain wall frame. Floor loads are handled by one-way slab-on-deck before being transferred to trusses. Existing W-Shape steel columns transfer loads vertically into the foundations of the building.

New Hollow Structural Section steel members will be installed on the North and South facades to support the load of the new curtain wall. No crane will be used on site, instead this need will be handled by the use of davits.

4.1.3 Cast-in-Place Concrete

Cast-in-place concrete exists on this site in the form of foundations and slab-on-deck flooring. This renovation project will require the addition of a new level slab for a new revolving door on the foundation level, as well as filling in gaps where it was necessary to chip away existing concrete.

4.1.4 Mechanical System

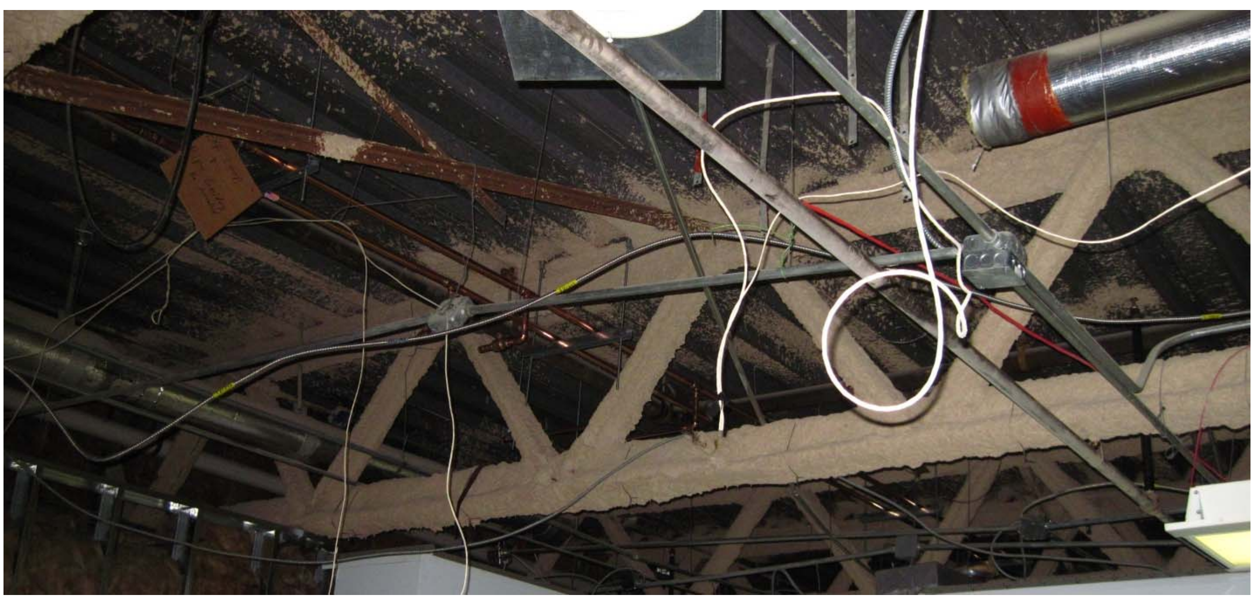

Figure 5: Exposed ceiling with view of new hydronic piping

Mechanical rooms are located on the 1st and 14th floors. Air handling units present in the Government Office Center will be replaced and improved through the addition of variable flow valves. Existing perimeter electric baseboard heating will be replaced with VAV boxes with hot-water reheat piping, as shown in Figure 5 above, that will distribute to new perimeter slot diffusers. The existing cooling tower and chillers will be replaced and converted to variable primary flow. Also, existing boilers will be replaced with more energy-efficient natural gas-fired boilers.

All ductwork existing in the Government Office Center that is not removed and replaced is scheduled to be cleaned as part of the scope of this renovation project. Sub-metering will be installed to help the building facilities management team to monitor and control energy use within the Government Office Center. The air filtration system will also be upgraded as part of the renovation and modernization of this building.

Existing fire sprinklers within the workspaces surrounding the curtain wall will be partially demolished and adjusted to serve as fire protection between the weather wall and building exterior during the construction phase. Substantial sections of existing fire protection systems will be demolished and replaced with new, NFPA 13 compliant sprinkler coverage that is fully coordinated with the new ceiling layout.

4.1.5 Electrical System

The Government Office Center is currently powered by an existing 480/277, 3 phase, 4 wire system that is backed up by a 175 kW, 219 kVA emergency generator. As part of this project, some electrical panels will be replaced to handle the renovated lighting system. Other new electrical work includes the necessary connections for two new chillers.

4.1.6 Masonry

Existing concrete masonry unit walls in the South area of Level 2 will be rebuilt with greater reinforcement to act as part of the lateral load resisting system. Large existing expanses of masonry on the East and West facades will not be involved in the scope of the renovation of the Government Office Center.

4.1.7 Curtain Wall

The existing curtain wall on the North and South facades will be replaced with a unitized, aluminum-framed curtain wall assembly. The intent of this portion of the renovation is to offer drastic improvement to the thermal performance of the building envelope, which in turn reduces the demand on the mechanical systems of the Government Office Center. Structural properties for this curtain wall system include the ability to withstand a basic wind speed of 90 miles per hour, while thermal movements should not cause undue stress on any building element that connects to or is part of the curtain wall system. The system is designed such that water drains to the exterior face of the curtain wall without any harm to neighboring surfaces or insulation.

During this project, a temporary engineered weather wall, as shown in Figure 6 below, will separate the work zone from the occupied building areas. The existing system will then be removed on a specific floor, working from top to bottom. A material hoist on the Northwest corner of the building will allow for the transfer of materials and large waste products into and out of the building.

Figure 6: Temporary weather wall

A single firm is required by the project specifications to assume undivided responsibility for fabrication, installation, and coordination of all elements of the building enclosure renovation. Responsibility for the design is in the hands of a design entity with extensive international experience in engineering, project management, fabrication, and installation of curtain wall systems.

4.1.8 LEED Certification Goals

The Government Office Center renovation and modernization project must achieve a minimum LEED Silver Certification. The cost of the initial application is carried by the A/E, while all other costs are the responsibility of the CM. Recycling and salvage of demolition waste as well as recycling of construction waste is an important part of this effort. Since the renovation of the curtain wall and mechanical systems will greatly improve the energy performance of the Government Office Center, several LEED points will also be earned from the Energy and Atmosphere credits.

4.2 Project Cost Evaluation

The actual costs for this project are provided by Balfour Beatty Construction and shown below. These costs are not intended to represent actual bid costs for the project, and have been rounded slightly for inclusion in this technical assignment.

Actual Building Construction Cost

Total:	$40,226,000
Per SF:	$127.30

Total Project Cost

Total:	$42,476,000
Per SF:	$134.42

Major Building Systems Costs

As shown in Table 1 below, several major building systems costs are provided, both in total and in cost per square foot.

System	Total Actual Cost	Cost / SF
Curtain wall	$9,507,000	$190.14
Mechanical/Electrical	$12,100,000	$38.29
Steel	$450,000	$1.42
Demolition	$647,000	$2.05
Fire Sprinkler	$442,000	$1.40
Drywall	$2,084,000	$6.59
Roof	$1,085,000	$46.92

Table 1: Project systems costs

4.3 Local Conditions

The Government Office Center is located in the Mid-Atlantic U.S., where no clear preferred methods of construction exist. However, as a renovation of a large public building that must maintain operability of the occupants within the Government Office Center, there are challenges for the construction management team regarding more specific local conditions. For example, since substantial on-site parking will be blocked from tenant access during the life of the renovation project, alternative parking locations must be established for displaced building occupants as well as contractor and subcontractor parking needs. The construction manager has identified various parking lots and garages near the site that are available for use, and has rented out the parking lot closest to the Government Office Center, as shown in Figure 7 below.

Figure 7: Partial view of parking area near GOC that is used by construction management personnel

Due to the requirement of recycling at least 50% of construction waste for the Government Office Center, as well as salvaging or recycling as much demolition waste as possible, a well-defined waste removal plan has been developed for use on this project. Limited available space on site led the construction management team to place a single dumpster on site, into which all demolition and construction waste is placed. Waste Management replaces the dumpster as needed, and sorts, weighs, and records statistics on the contents of each dumpster, allowing a designated A/E to track whether the project is meeting its LEED requirements by earning points for specific anticipated credits. However, the fees for this service are not defined, as there is no signed contract between Waste Management and Balfour Beatty Construction.

The nature of this renovation project is such that soil and subsurface water conditions are not directly relevant. Instead, a more relevant concern is whether the existing parking lots and parking structure on site can support the temporary loads that construction activities will burden them with. According to the structural engineer, there should be no cause for concern based on the site layout plans described in the following section of this report.

4.4 Site Plans Summary

*See Appendix B for Site Plans

Existing Conditions

Given that this project is a major systems renovation of an existing structure, it is critical to note that the important aspects of the existing conditions of this project differ substantially from those of the construction of a new building. For example, the building is to remain fully operational during the demolition and construction phases of the project. As a result, a certain level of available parking is required on site, limiting available space for the construction management team to work with. Furthermore, there are existing roads that surround the project site, under which the majority of the existing utilities are located. Any connections to these utilities as part of the scope of work will require consideration of how to handle resulting traffic issues.

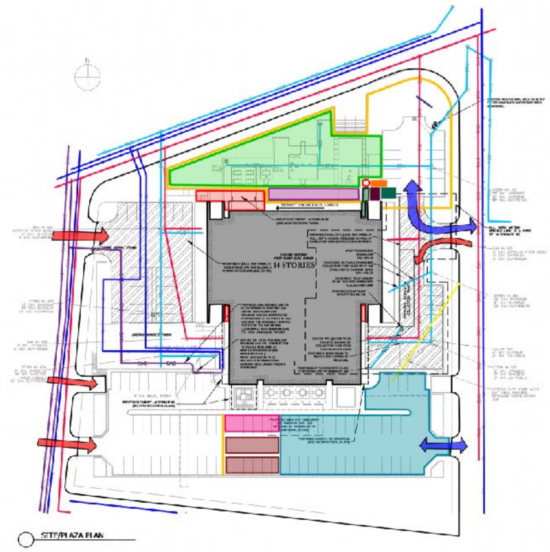

Figure 8: Site Layout

Also, it is important to note that the site plans do not distinguish between existing and proposed gas lines, but these lines can be distinguished due to the fact that the building currently has no natural gas connection. Therefore, the gas line connecting the building to the utilities under the road should be taken as the proposed gas line.

Site Layout Planning

This renovation project is being performed on a fairly constrained site, as shown in Figure 8 above. Using parts of the existing parking areas on site, the construction management team will place trailers, temporary air handlers, and material laydown and storage areas according to the needs of the project. The space is limited to the extent that there is no on-site parking available to the construction management team or the subcontractors.

A potential issue with the current layout is that the construction staging area is placed somewhat inconveniently in relation to the location of the material hoist. However, since space is limited, it is preferable to have the curtain wall laydown area near the material hoist. Site entrances may also prove to be an issue for the construction management team, as larger trucks may have difficulty with the turning radius demanded by the Northwest construction site entry.

Note that the work involved in each phase presented is highlighted in orange to indicate demolition and replacement of existing building features, such as mechanical rooms (Phase 0), curtain walls (Phase 1A), and roofing (Phase 3).

4.5 Detailed Project Schedule

*See Appendix C for the Detailed Project Schedule

Since this project is a fairly complex renovation of a government building, design and preconstruction services were critical in determining the feasibility of this project before commitment of substantial federal spending was made. Preconstruction services were awarded to the construction manager in late November 2009 and limited to a period of one year. Notice to proceed was given on August 1, 2011. The renovation and modernization of the Government Office Center is scheduled for completion on January 31, 2014.

The project schedule is divided into six phases of work, which often overlap over the course of the renovation. The critical aspects of the renovation of the Government Office Center include the demolition of existing curtain wall and mechanical systems, followed by installation of new, more energy efficient systems to replace them. In order to minimize the impact of the construction project on the ongoing activities within the building, there will be significant overlaps between demolition and construction activities in an effort to shorten the duration of the overall construction process.

Construction activities began with demolition of a section of curtain wall on the South building elevation to allow for installation of a temporary material hoist. In preparation for the curtain wall replacement process, temporary weather walls will be installed between October and November 2011 inside the North façade of the building and between November and December 2012 inside the South façade. Demolition and replacement of the curtain wall on the North façade of the Government Office Center will take place between November 2011 and April 2012, while corresponding work on the South façade will take place between December 2012 and May 2013.

Due to the need for continuous occupancy of the Government Office Center throughout the construction process, a temporary air handling unit will be installed on the South parking deck starting in late October 2011 in order to meet the heating, ventilating, and air conditioning loads while permanent units in the building are replaced. In late November 2011, renovation of mechanical rooms in levels 1 and 14 will begin. The new natural gas boilers and automatic temperature control (ATC) systems will undergo the commissioning process in March 2012. Demolition and renovation of the West toilet stack will take place between November 2011 and September 2012, while corresponding demolition and renovation of the East toilet stack will take place between December 2012 and October 2013.

Finishes in the North and South building areas will be installed during the five months following completion of their respective curtain wall renovations. The final major phase of construction work for the Government Office Center involves roofing renovation in August of 2013, reinforcement of the CMU walls in level 2 during October 2013, and installation of a photovoltaic panel array in September and October 2013. The need to maintain the building envelope throughout the construction process requires the construction team to install temporary weather walls during the curtain wall replacement and to only remove sections of roofing that can be replaced within the same day.

To handle increased building loads and improve the stability of the existing structural system, a set of structural steel members will be installed during the renovation of the Government Office Center. Truss reinforcement on levels 9-13 will take place in October 2011 after ceiling demolition activities are completed in these areas, as shown in Figure 9 below. Hollow Structural Section (HSS) steel beams will be installed on levels 3 through 14 on the building perimeter to support the new curtain wall system.

Figure 9: An example of a truss that will be reinforced

A key scheduling concern for this project is the need to maintain occupancy during the entire construction period. Significant coordination must be in place in order to ensure that building occupants, files, and furniture are appropriately relocated to allow demolition and construction activities to take place while minimizing the impact on ongoing functions within the building. Major construction processes that occupy substantial interior spaces must be optimized for minimum schedule requirements such that these spaces may be promptly returned to the building occupants to serve their intended purposes.

4.6 General Conditions Estimate

*See Appendix D for General Conditions Estimate

The costs of general conditions items for the Government Office Center renovation project are summarized by category in Table 2 below. While some data represents accurate costs for the project, the majority of cost information for this estimate was derived from R.S. Means Building Construction Cost Data 2011. Without including contingency, this project has weekly general conditions expenses of approximately $17,000.

Line Item	Unit Rate	Unit	Quantity	Cost
Project Supervision and Staffing	$ 15,205.00	Week	130	$ 1,976,650.00
Temporary Facilities & Safety	$ 1,844.38	Week	130	$ 239,770.00
Temporary Utilities	$ 40.85	Week	130	$ 5,310.00
Contingency	$ 1,100,000.00	LS	1	$ 1,100,000.00

Table 2: General conditions cost summary

The Project Supervision and Staffing category shown above represents the greater part of the total general conditions costs, and includes the project management staff for the Government Office Center renovation project. These staff members include the Vice President, Senior Project Manager, Superintendents, Project Engineer, Accountant, and labor. All unit rates for these positions were determined using R.S. Means aside from the unit rate for the Vice President. The cost of this position for the project was reached based on the assumption that the Vice President has a higher weekly cost than the Senior Project Manager, but does not devote all of his time to this specific project.

The Temporary Facilities & Safety category includes rented trailers for storage and field office purposes, construction site fencing, dumpster costs, signage, and builder's risk insurance. The assumption that personal protective equipment is included as needed in subcontractor bids eliminates its cost impact on the general conditions for this project. All other items in this category aside from fencing are derived from R.S. Means cost data.

Because the Government Office Center will remain occupied and functional throughout the course of the renovation project, nearly all temporary utilities will be provided directly by the owner, rather than be included in project costs for mark-up. A line item for temporary toilets on site was included, based on R.S. Means cost information.

Overall, the general conditions items included in this estimate make up $3.3 million, or approximately 8%, of the total project cost. This value is typical for construction projects, and the breakdown of these general conditions cost items seems reasonable based on the specifics of the Government Office Center renovation project.

4.7 LEED Evaluation

*See Appendix E for LEED Scorecard

With the support of sustainability consultant William McDonough + Partners, the Government Office Center renovation project is expected to earn a Gold performance rating under the U.S. Green Building Council's (USGBC) LEED 2009 for Existing Buildings: Operations and Maintenance (LEED EBO&M) rating system. In order to achieve a Gold rating, at least 60 of 110 available points must be earned in addition to all prerequisite requirements for certification.

Based on an analysis of project goals, specifications, and discussions with project management staff, the Government Office Center renovation project should expect to earn 62 points, with 35 additional points achievable via minimal to moderate increase to the project scope and budget, as shown in Table 3 below. Earning a Gold rating exceeds the typical certification goals of the General Services Administration for most of its recent construction projects throughout the country. However, because this construction project is intended to modernize the existing building and drastically reduce its carbon footprint, a LEED Gold performance rating is a much more appropriate level of certification than simply LEED Certified.

Category	Y	?	N	Total
Sustainable Sites	10	9	7	26
Water Efficiency	9	4	1	14
Energy and Atmosphere	20	11	4	35
Materials and Resources	7	2	1	10
Indoor Environmental Quality	12	3	0	15
Innovations in Operations	3	3	0	6
Regional Priority Credits	1	3	0	4
Total	62	35	13	110

Table 3: LEED 2009 for Existing Buildings: Operations & Maintenance Point Summary

The majority of projected points under the Sustainable Sites category come from Credit 4: Alternative Commuting Transportation. Due to the urban characteristics of the surrounding environment, on-site parking is limited and most occupants will need to carpool or use available public transportation. Other points, such as those from Credit 1: LEED Certified Design and Construction and Credit 5: Site Development – Protect or Restore Open Habitat, are irrelevant for the Government Office Center renovation project, since the existing building is not previously LEED certified, nor will the project restore significant site space to native vegetation.

Water efficiency efforts are important to this renovation projects. As a result, the project team aims to earn points through water metering and improved indoor plumbing fixture and fitting efficiency. The Water Efficiency category is a worthwhile pursuit for the Government Office Center renovation and modernization project, since the existing building is already in need of upgraded restroom facilities.

Since the vast majority of the scope of this renovation project is intended to optimize energy performance, the Energy and Atmosphere category is perhaps the most important LEED category in relation to the project goals. Most points projected for achievement by the Government Office Center renovation project in this category will come from Credit 1 for optimizing energy efficiency performance and from Credits 2.1-2.3 for existing building commissioning efforts. The anticipated point totals coming from the Energy and Atmosphere category are in line with the goals of the project.

As a renovation project, the Materials and Resources category is not a major priority. However, the project specifications require purchase of a certain percentage of recycled or renewable materials, as well as a substantial demolition and construction waste salvage and recycling program. While most points in this category apply directly to purchases and waste stream management during the life of the building, the Government Office Center renovation project will reduce its carbon footprint using the previously mentioned methods, regardless of the fact that these efforts will earn almost no points under the LEED EBO&M rating system.

Indoor Environmental Quality is certainly a concern for a 14-story urban office building like the Government Office Center. With a wide selection of single-point credits, this renovation project should earn most with ease, and is projected to earn nearly all points in this category. For example, improved lighting through daylighting, views, and lighting controls will be achieved as part of the renovation effort.

The Innovation in Operations and Regional Priority Credits categories have the smallest relative value when compared to the other LEED rating sub-categories. With a variety of available options, it is safe to assume that the Government Office Center project will earn a few points in these categories. Overall, the LEED Scorecard produced for this report suggests a fairly even distribution of points among the categories, with emphasis on the Energy and Atmosphere and Indoor Environmental Quality categories over the other remaining categories.

4.8 Building Information Modeling Use Evaluation

*See Appendix F for Building Information Modeling Use Evaluation Graphics

Based on the BIM uses described in the *BIM Project Execution Planning Guide*, eight potential BIM uses were identified for the benefit of the Government Office Center project. These eight uses are intended to meet nine value adding objectives for the project. By ranking the importance of these goals on a three-tiered priority rating scale, the project team members can later determine whether to pursue the BIM uses identified by this process.

The BIM uses of greatest importance to the Government Office Center renovation project include Phase Planning (4D Modeling), Building Systems Analysis, and Existing Conditions Modeling. Phase Planning through 4D Modeling helps the project team to plan the phased occupancy requirements that will be critical to successful delivery of the project. The 4D Model will also greatly benefit the current occupants of the building, who will be able to more easily visualize how the phasing schedule will impact ongoing building functions. Building Systems Analysis will help the project delivery team to ensure that the mechanical, electrical, and curtain wall systems of the Government Office Center perform to the design and sustainability standards specified. Finally, Existing Conditions Modeling will generate a representative model based on the building as it stands prior to the initiation of renovation work. Modeling the existing building and site conditions will prove to be a vital asset to the design and construction team as they engage in the renovation and modernization efforts.

Moderately important BIM uses for this project include Construction System Design (Virtual Mock-up), 3D Coordination, and Sustainability (LEED) Evaluation. Through the Construction System Design process, the project management team seeks to improve the constructability of the curtain wall by evaluating virtual mock-ups. Virtual mock-ups have also been implemented for this project to improve the temporary weather wall design regarding worker and building occupant safety concerns. By implementing 3D Coordination on this project, the project delivery team strives to eliminate costly field conflicts and improve on-site productivity through use of clash detection processes and design reviews. In order to achieve the project goal of optimizing building performance, the project delivery team will utilize the Sustainability (LEED) Evaluation BIM process to enable tracking of energy use and indoor air quality in the Government Office Center for comparison against LEED standards.

The final BIM uses for the Government Office Center also provide value for the project, but not to the extent that the previously mentioned BIM uses reach. These third-tier BIM uses include Design Authoring and Cost Estimation. With the Design Authoring BIM process, the design team for this renovation project created a means to visualize the design and improve collaboration between the users of BIM and the building occupants. Generation of accurate quantity take-off and cost estimates through use of a BIM Cost Estimation process enabled the early project team to determine the changes in project costs due to additions or modifications to the design during its development. Sustainability (LEED) Evaluation also falls in this category as a means to complete a project goal that differs from the goal mentioned in the previous paragraph. At this priority level, the Sustainability Evaluation tool can be used to align scheduling and material quantities tracking, which can directly lead to the achievement of certain LEED points, such as Materials and Resources credits for sustainable purchasing.

As shown in the Level 1 Process Map in Appendix E, the ways in which BIM was used for the Government Office Center renovation project varies depending on the stage of the project. During the Schematic Design phase, existing conditions were modeled for later use, preliminary cost estimates were generated for go-no-go decision making, 3D coordination was performed to identify early space challenges, virtual prototypes for replacement systems were developed, phase planning began to identify occupancy concerns, and initial systems analyses were performed to provide a baseline for the renovation effort. Aside from existing conditions modeling, each of these BIM uses are carried through the Design Development and Construction Documents phases with increasing levels of accuracy and detail included. In these phases of the project, construction system design through virtual mock-ups provides a means to analyze a construction method for constructability and safety concerns prior to implementing the construction method on site. In particular, the temporary weather wall that will separate occupied office space from construction activities and the environment during the curtain wall replacement process was analyzed in this manner. Finally, sustainability (LEED) evaluation efforts will occur primarily during the construction operations phases in order to track actual systems performances and other building aspects for adherence to attempted LEED requirements.

5.0 ANALYSIS #1: IMPLEMENTATION OF BUILDING INFORMATION MODELING

5.1 Problem Identification

Due to the unique challenges that face the Government Office Center renovation project, the construction team must find a way to properly install new mechanical equipment and tie the new equipment into existing system duct and piping. Since the building will remain occupied for the duration of the construction process, work must also proceed according to a tenant phasing plan that will relocate tenants and file cabinets to create isolated and safe work areas. In addition, although the scope of this project will significantly affect building operations and facilities management in the future, surprisingly little has been done to push information downstream through BIM for the benefit of facilities management staff.

5.2 Research Goal

The purpose of this analysis is to evaluate the benefits of implementing Building Information Modeling (BIM) for use on site during the construction process and as a means to meet the needs of the owner during program development and as a useful facilities management tool.

5.3 Methodology

- Contact Balfour Beatty Construction for data on current methods of on-site location of information, as well as desired improvements to these methods
- Contact GSA for information on how their facilities are managed
- Interview other owners of substantial property to identify themes
- Identify and choose options that can bring existing BIM work into the field
- Analyze impacts of selected field BIM implementation methods
- Develop virtual mock-up to meet previously identified facilities management needs
- Analyze virtual mock-ups for added value per added cost
- Draw conclusions based on the application of BIM to support facilities management efforts
- Develop a summary of how an owner can benefit from leveraging BIM

5.4 Background Information

The use of Building Information Modeling (BIM) has grown substantially in the last several years. BIM software is largely used by architects and designers to model building systems and features in three dimensions, which can later facilitate the production of drawings for a project. General contractors and construction management firms are relying more heavily on modeled content for clash detection and simulated progression of construction activities. Unfortunately, modeled content tends to be more popular for use in marketing and proposal development ("Hollywood BIM") than for use in a method that provides clear and quantifiable value for a project. In this age of information, opportunities to extend the valuable use of BIM are limited only by the creativity of the people who utilize BIM and that of the people who develop software and interactions between existing programs.

The following individuals have earned great appreciation for their instrumental roles in the completion of this analysis:

Jason Reece……………. Balfour Beatty Construction
Steve DeVito…………... GSA
Craig Dubler…………… Penn State OPP
David Bolt……………... Balfour Beatty Construction

5.5 Factors Influencing the Need for Improved BIM Use

5.5.1 Field Use

While the uses of BIM have continued to grow steadily in recent years, field personnel have started seeking improved means of accessing construction information on the job site. Full-size plans are increasingly being viewed as cumbersome and inconvenient, and intricate 3D models are becoming the norm.

Questions about drawings and conflicts between trades are routinely directed to the job trailer, where they are resolved with the support of the project management staff. This process would be viewed as waste under lean construction principles.

5.5.2 Facilities Management

Owners are finding it increasingly important to have information about their properties and the building systems within them readily available for facilities management purposes. Small, single property owners and large, multiple property owners alike need the ability to locate performance data, operations procedures, maintenance history, and other information, and they need this information for many reasons and on many occasions. In particular, owners of more extensive property holdings often maintain private databases that store a set of information as deemed necessary by facilities management staff. With advances in technology and construction methods, building systems are becoming progressively more complex, consequently demanding greater detail and accuracy of information contained within these databases.

5.6 Relevance to the Government Office Center

The Government Office Center renovation project involves significant upgrades to mechanical equipment, lighting systems, and the curtain wall façade. However, due to the nature of building design and construction at the time of its original erection, information regarding the existing conditions is often incomplete or inaccurate.[1] In addition, while the current project team performed some modeling efforts, a highly detailed model of the building was never created, due to time requirements for modeling existing conditions (many of which are unknown) in comparison to the benefit that the project team would have gained from this model.[2] BIM was used, however, to provide detailed illustrations of the safety measures planned for the

[1] Whalen, Jesse. (19 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)
[2] Bolt, David. (10 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

construction process. In addition, the construction management team created a model and animation of the temporary weather wall that will maintain the enclosure of the Government Office Center during the curtain wall demolition and replacement process.

After speaking with construction management staff on site, the team does not feel that they have issues with locating information when necessary. A shared network drive contains house information, and a cloud storage site shares pertinent information with subcontractors, who will often print their own drawings for use in the field. Because the project team is comfortable with the status quo, BIM implementation for the benefit of the construction team in the field is unnecessary.

However, BIM implementation can greatly benefit the facilities management efforts of the owner. Collaboration with construction management personnel on site at the Government Office Center renovation project is critical to the success of the implementation of BIM for facilities management. Large property owners, such as the GSA and the Office of Physical Plant (OPP) at the Pennsylvania State University, often find themselves "data mining" by hand in order to locate product and equipment properties that must be stored conveniently for maintenance and other service needs.[3] According to OPP, this process takes approximately eight days to populate their database for a typical building, and the process does not even begin until the construction project has reached substantial completion.

Additionally, property owners like GSA and OPP can benefit from other products created through BIM for Facilities Management efforts. For example, an effective implementation of BIM for Facilities Management would facilitate a simplified building asset tracking process. Tracking assets such as air handling units, chillers, boilers, VAV boxes, and other equipment creates value for an owner by storing pertinent information in a single location. Possible information could include replacement costs, warranty period dates, service history, predicted energy performance, energy performance history, location within the building, relationship to other components within a system, etc.[4] Furthermore, a carefully planned data storage system will enable facilities management staff to run reports on documented building assets, which helps the staff to anticipate expenses and to plan budgets and future projects. Through this strategy, facilities management staff could almost instantly generate reports on assets with sub-optimal energy performance history that have a certain range of replacement costs and that will no longer be covered by warranties after a given date (as an example). In other words, any data category such as replacement cost or warranty end date can be used as a filter for facilities management staff to locate assets for planning efforts.

Another more innovative strategy for implementing BIM for Facilities Management is by making a certain set of information available on a tablet device for use by maintenance and facilities management personnel. This strategy could be as simple as providing customized information to a building mechanic based on the specifics of a preventative or unscheduled maintenance task order, which might include the identification of systems and components affecting a situation, the service history for these components, energy performance history, operations and maintenance manuals, start up and shut down procedures, a list of available spare

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[3] Dubler, Craig. (20 January 2012). Penn State OPP. (A. Ward, Interviewer)
[4] DeVito, Steve. (17 January 2012). GSA. (A. Ward, Interviewer)

parts, tools needed to complete work, and access points for these building assets. However, this strategy could also be implemented more sophisticatedly through a more interactive 3D environment that provides all previously described content within an intuitive model of the building. Unfortunately for the Government Office Center renovation project, neither the asset tracking nor the tablet access BIM for Facilities Management strategies is being pursued.

5.6.1 GSA BIM Guide for Facility Management

GSA, the owner of the Government Office Center, is certainly aware of the importance of using BIM for Facilities Management purposes. In fact, they recently published the eighth member of their guide series, and this guide is focused on the idea of BIM for Facilities Management.[5] The introduction to the guide explains that facilities information and data is generated through the course of design and construction for all projects. GSA hopes that BIM for Facilities Management will enable them to leverage this data throughout the life of the building to support small-scale projects, operations and maintenance, and large-scale renovation projects such as the Government Office Center modernization project. The guide demonstrates that GSA sees some of the same benefits in BIM for Facilities Management as previously described in this analysis, explaining that there is a business need for BIM for Facilities Management in order to support GSA maintenance workers, building operators, spatial data managers, and building tenants.

5.7 Proposed BIM Implementation Strategies

To benefit the Government Office Center, BIM for facilities management efforts should focus on the management of information included in a model. Although part of the BIM acronym, "Information" beyond the size and shapes of a set of building components is often not the primary focus of modeling teams. However, information and the ability to access it quickly when needed are both incredibly valuable to designers, builders, and owners alike. Therefore, modeled content of the Government Office Center as-built should be populated with information in order to support future operations and maintenance needs for the facilities management staff.

5.7.1 Ideate BIMLink

Two particular methods will be examined for the purposes of this analysis. First, the existing Autodesk Revit model will be populated with data with support from programs like Ideate BIMLink. This type of software creates a more manageable interface between Revit schedules and Microsoft Excel, and allows users to transfer data from Revit to Excel and from Excel into Revit. By improving this process, project team members can update product and equipment information with minimal effort, which in turn provides tremendous value to the owner.

Several benefits to using this software can be identified. For example, because a large number of contributors to design and construction efforts for a project do not use Revit, software like Ideate BIMLink allows the skills and expertise of these project contributors to be easily included within modeled content.[6] In addition, by enabling access to this information without access to the model, the project team does not need to risk the development of errors within the model,

[5] *BIM Guide for Facility Management*. GSA. PDF.
[6] *Top Ways Ideate BIMLink Saves Hours, Days – Even Weeks.* Ideate. PDF.

accidental or otherwise, that can result from providing access to the Revit model to too many parties.

Ideate BIMLink creates an easier to use workflow than previously available processes, such as Autodesk dB Link, which connects with Microsoft Access and reputedly has a somewhat difficult learning curve. Because Ideate BIMLink connects Revit files to Microsoft Excel, only a basic operating ability is needed, and the process of populating and accessing data is streamlined by Excel functions.

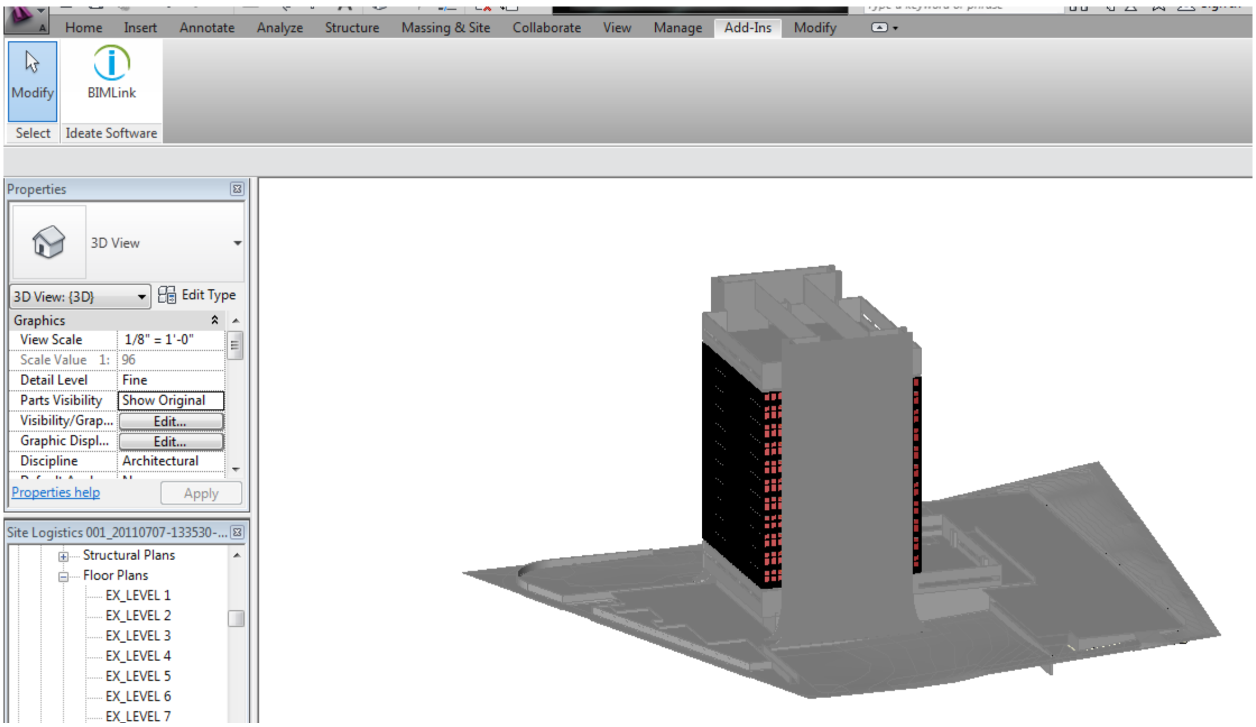


Figure 10: Screenshot of Government Office Center on Autodesk Revit Architecture 2012

In a test run of this process, both Autodesk Revit Architecture 2012 and Ideate BIMLink were installed. Existing models of the Government Office Center were loaded in Revit. The model shown in Figure 10 above contains substantial content, including lighting fixtures, mechanical equipment, and much more.

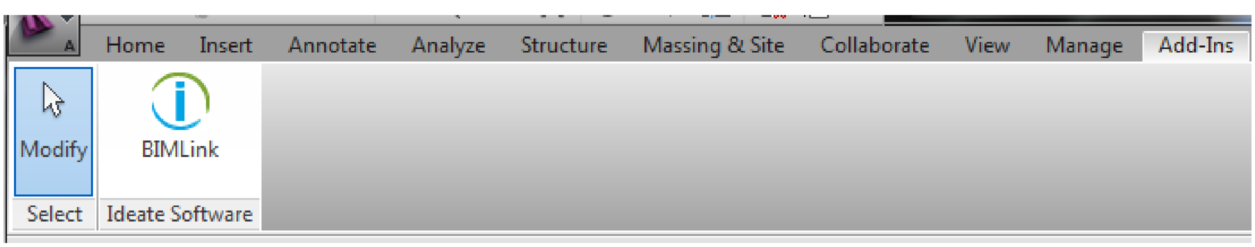


Figure 11: Screenshot of toolbar ribbon with view of Add-Ins, including Ideate BIMLink

As shown in Figure 11 above, the Revit toolbar ribbon displays a button to access Ideate BIMLink features within the “Add-Ins” section. Because Autodesk allows for third party programmers to create functions like these, software like Ideate BIMLink is very simple to access.

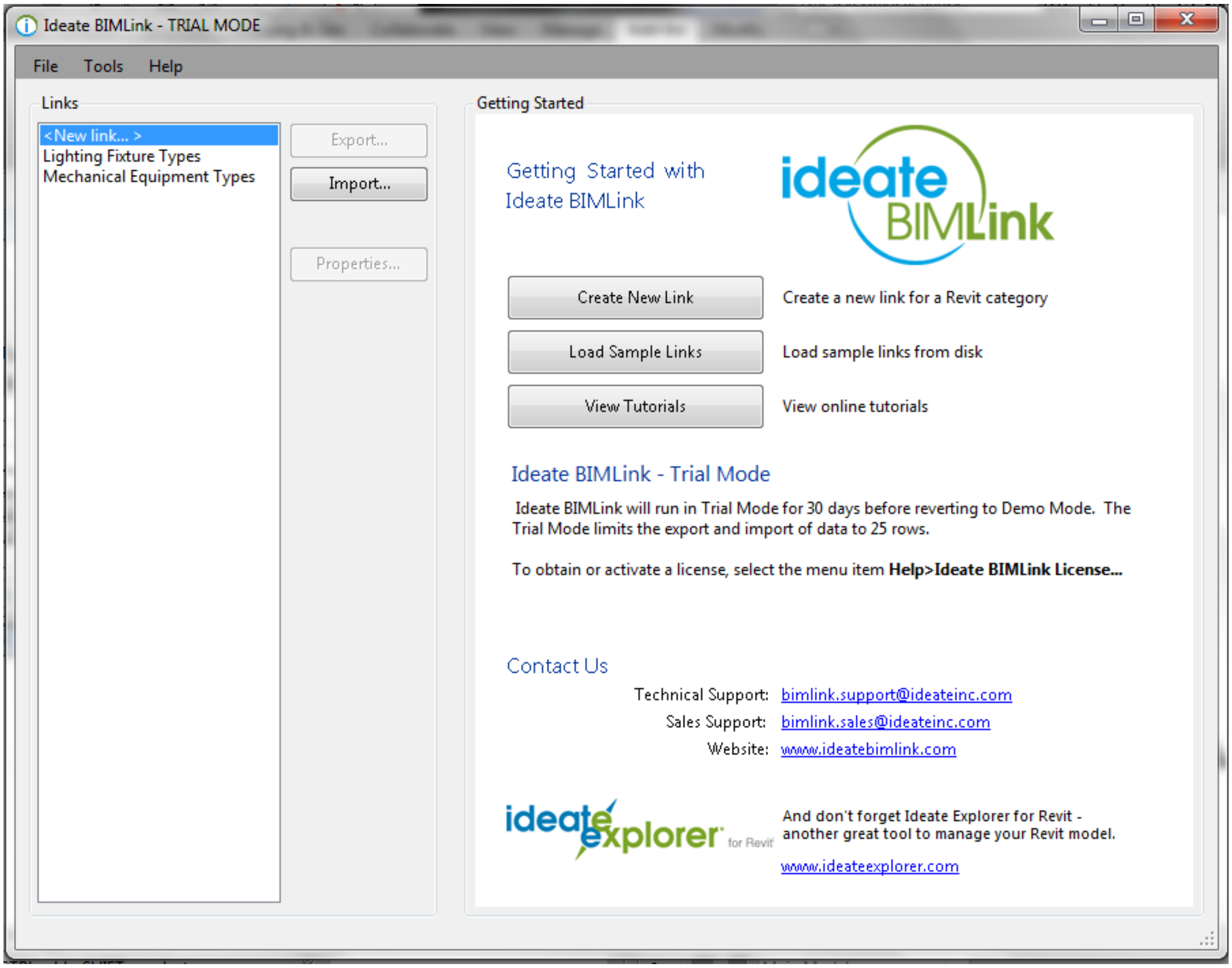
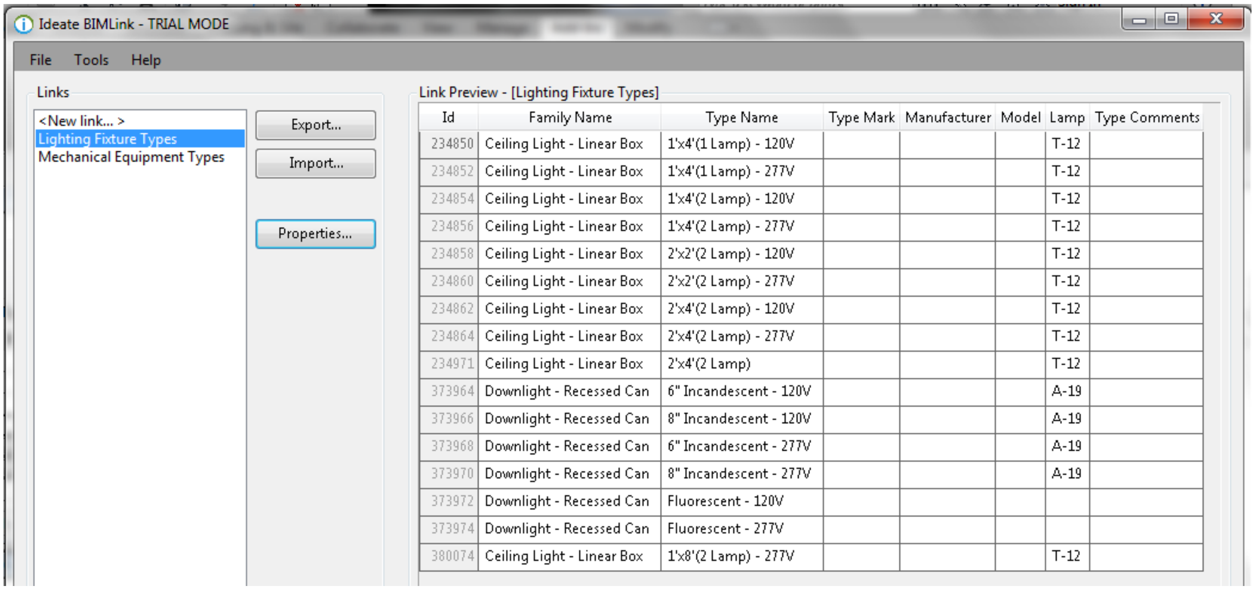


Figure 11: Screenshot of Ideate BIMLink opening screen

After clicking the BIMLink button within the Revit Add-Ins toolbar ribbon, the opening screen, as shown in Figure 11 above, launches to display options for the user. At this stage, the user can access sample links, such as lighting fixture or mechanical equipment types. While the Ideate BIMLink software comes with a great variety of these samples, the user has the option to create new links as needed, allowing for a great deal of customization for unique project or owner needs.



Id	Family Name	Type Name	Type Mark	Manufacturer	Model	Lamp	Type Comments
234850	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 120V				T-12	
234852	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 277V				T-12	
234854	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 120V				T-12	
234856	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 277V				T-12	
234858	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 120V				T-12	
234860	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 277V				T-12	
234862	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 120V				T-12	
234864	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 277V				T-12	
234971	Ceiling Light - Linear Box	2'x4'(2 Lamp)				T-12	
373964	Downlight - Recessed Can	6" Incandescent - 120V				A-19	
373966	Downlight - Recessed Can	8" Incandescent - 120V				A-19	
373968	Downlight - Recessed Can	6" Incandescent - 277V				A-19	
373970	Downlight - Recessed Can	8" Incandescent - 277V				A-19	
373972	Downlight - Recessed Can	Fluorescent - 120V					
373974	Downlight - Recessed Can	Fluorescent - 277V					
380074	Ceiling Light - Linear Box	1'x8'(2 Lamp) - 277V				T-12	

Figure 12: Screenshot of a link preview in Ideate BIMLink

When a new link is created, whether from sample or from scratch, a preview is displayed showing the basic information that will be organized. As shown in Figure 12 above, this preview is very useful to the user, especially when the user is unsure of which sample link template is appropriate for the need at hand. In this example, data columns for lighting fixture types include identification number, family name, type name, type mark, manufacturer, model, lamp, and type comments.

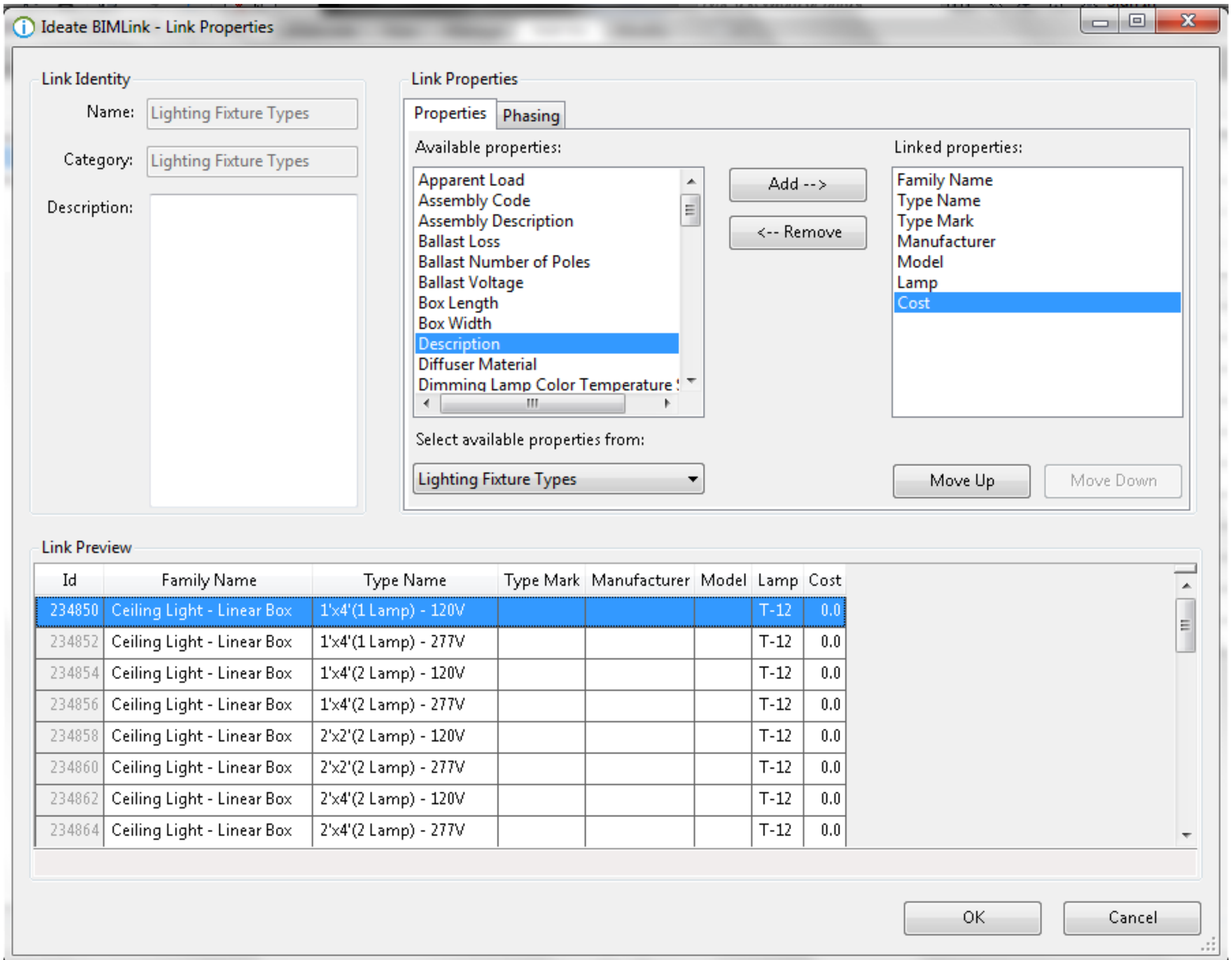


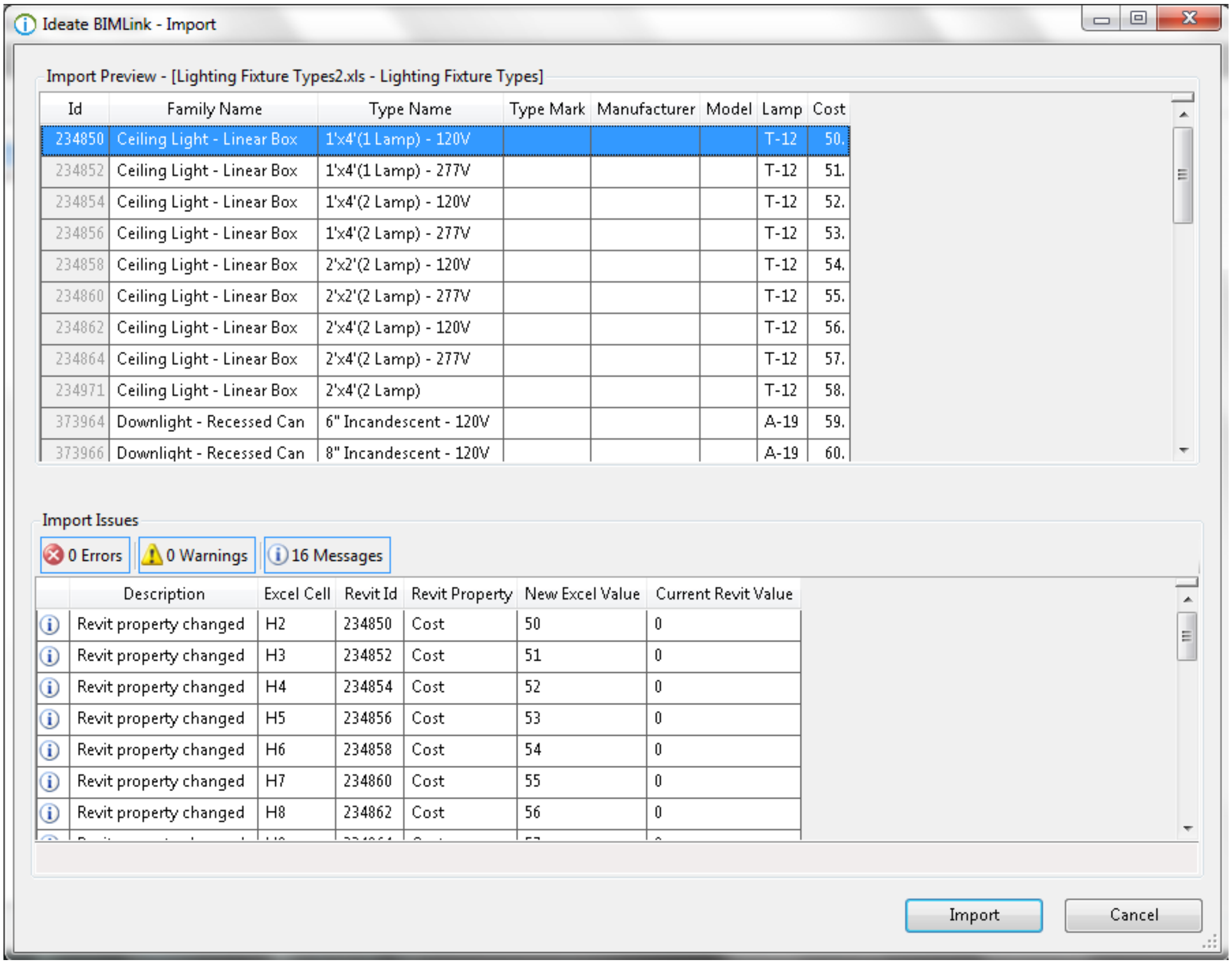
Figure 13: Screenshot of Link Properties page in Ideate BIMLink

In the example shown in Figure 13 above, link properties can be adjusted such that data sets include desired properties. As shown, the type comments column has been removed, while a cost column has been added. A large number of properties are available for use. Additionally, Ideate BIMLink can distinguish between construction phases within a model. In the case of the Government Office Center renovation project, existing and new construction phases are included within the model and are therefore relevant for consideration.

	A	B	C	D	E	F	G	H
1	Id	Family Name	Type Name	Type Mark	Manufacturer	Model	Lamp	Cost
2	234850	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 120V				T-12	50.00
3	234852	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 277V				T-12	51.00
4	234854	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 120V				T-12	52.00
5	234856	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 277V				T-12	53.00
6	234858	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 120V				T-12	54.00
7	234860	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 277V				T-12	55.00
8	234862	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 120V				T-12	56.00
9	234864	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 277V				T-12	57.00
10	234971	Ceiling Light - Linear Box	2'x4'(2 Lamp)				T-12	58.00
11	373964	Downlight - Recessed Can	6" Incandescent - 120V				A-19	59.00
12	373966	Downlight - Recessed Can	8" Incandescent - 120V				A-19	60.00
13	373968	Downlight - Recessed Can	6" Incandescent - 277V				A-19	61.00
14	373970	Downlight - Recessed Can	8" Incandescent - 277V				A-19	62.00
15	373972	Downlight - Recessed Can	Fluorescent - 120V					63.00
16	373974	Downlight - Recessed Can	Fluorescent - 277V					64.00
17	380074	Ceiling Light - Linear Box	1'x8'(2 Lamp) - 277V				T-12	65.00

Figure 14: Screenshot of data imported into Microsoft Excel

After data has been exported from Autodesk Revit Architecture 2012 to Microsoft Excel format through Ideate BIMLink, the newly created Excel workbook can be viewed, examined, and edited with ease. In this example process, arbitrary costs were applied to lighting fixture types in Excel, as shown in Column H of the Figure 14 above. These values were each initially set to 0.0, as shown in Figure 13. Each was set to a different value for demonstration purposes within this analysis.


Ideate BIMLink - Import

Import Preview - [Lighting Fixture Types2.xls - Lighting Fixture Types]

Id	Family Name	Type Name	Type Mark	Manufacturer	Model	Lamp	Cost
234850	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 120V				T-12	50.
234852	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 277V				T-12	51.
234854	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 120V				T-12	52.
234856	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 277V				T-12	53.
234858	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 120V				T-12	54.
234860	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 277V				T-12	55.
234862	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 120V				T-12	56.
234864	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 277V				T-12	57.
234971	Ceiling Light - Linear Box	2'x4'(2 Lamp)				T-12	58.
373964	Downlight - Recessed Can	6" Incandescent - 120V				A-19	59.
373966	Downlight - Recessed Can	8" Incandescent - 120V				A-19	60.

Import Issues

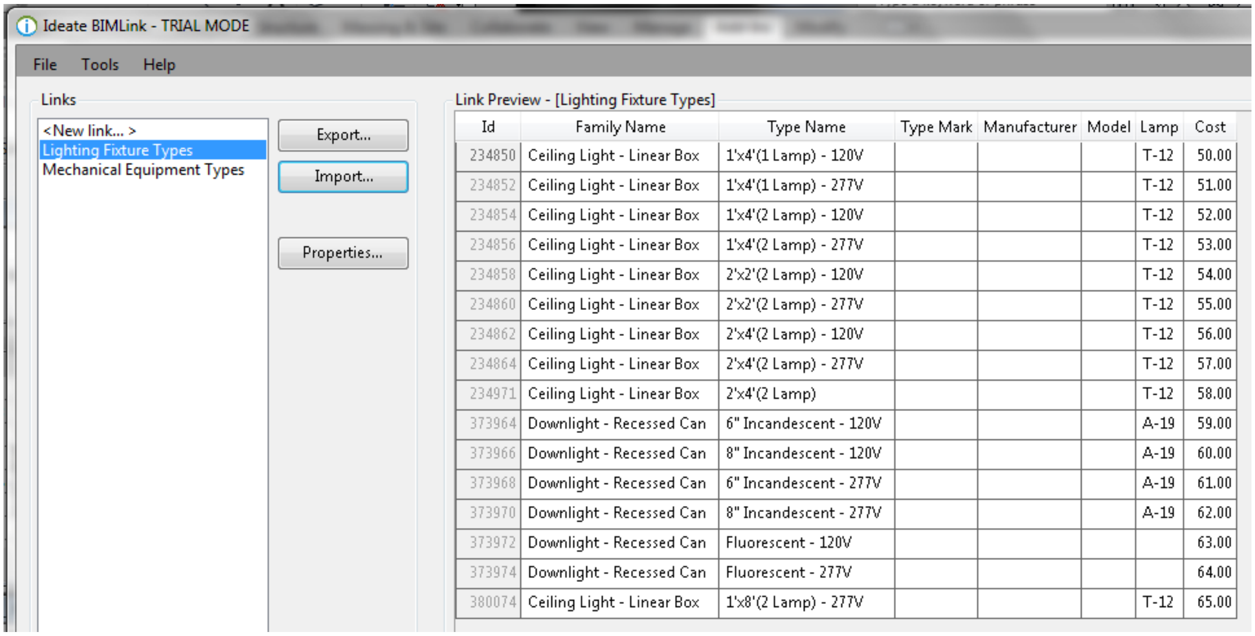
0 Errors | 0 Warnings | 16 Messages

Description	Excel Cell	Revit Id	Revit Property	New Excel Value	Current Revit Value
Revit property changed	H2	234850	Cost	50	0
Revit property changed	H3	234852	Cost	51	0
Revit property changed	H4	234854	Cost	52	0
Revit property changed	H5	234856	Cost	53	0
Revit property changed	H6	234858	Cost	54	0
Revit property changed	H7	234860	Cost	55	0
Revit property changed	H8	234862	Cost	56	0

Import | Cancel

Figure 15: Screenshot of data imported into Revit from Excel through Ideate BIMLink

After changes have been made to the data in Microsoft Excel, Ideate BIMLink allows for easy import of the data back into Revit. In the import preview screen, as shown in Figure 15 above, Ideate BIMLink informs the user of the changes being made, as well as any errors or warnings resulting from the changes made. For this example, the import preview screen illustrates how costs were changed from 0 to values from 50 to 65 in the bottom table, where current Revit values are compared to new Excel values.



Id	Family Name	Type Name	Type Mark	Manufacturer	Model	Lamp	Cost
234850	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 120V				T-12	50.00
234852	Ceiling Light - Linear Box	1'x4'(1 Lamp) - 277V				T-12	51.00
234854	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 120V				T-12	52.00
234856	Ceiling Light - Linear Box	1'x4'(2 Lamp) - 277V				T-12	53.00
234858	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 120V				T-12	54.00
234860	Ceiling Light - Linear Box	2'x2'(2 Lamp) - 277V				T-12	55.00
234862	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 120V				T-12	56.00
234864	Ceiling Light - Linear Box	2'x4'(2 Lamp) - 277V				T-12	57.00
234971	Ceiling Light - Linear Box	2'x4'(2 Lamp)				T-12	58.00
373964	Downlight - Recessed Can	6" Incandescent - 120V				A-19	59.00
373966	Downlight - Recessed Can	8" Incandescent - 120V				A-19	60.00
373968	Downlight - Recessed Can	6" Incandescent - 277V				A-19	61.00
373970	Downlight - Recessed Can	8" Incandescent - 277V				A-19	62.00
373972	Downlight - Recessed Can	Fluorescent - 120V					63.00
373974	Downlight - Recessed Can	Fluorescent - 277V					64.00
380074	Ceiling Light - Linear Box	1'x8'(2 Lamp) - 277V				T-12	65.00

Figure 16: Screenshot of Ideate BIMLink after data has been updated

After importing the data into Revit from Excel, changed values are now stored within the modeled content. As shown in Figure 16 above, lighting fixture types have officially been assigned new cost values, which are observable within the Revit model as well. Storing information like cost, planned performance, actual performance, maintenance records, and other data within the Revit model allows for a single point of access, simplifying future data searches.

While Ideate BIMLink is not a free program, users can try the program during a free trial period. Additionally, although the software is already quite simple to use, Ideate offers a veritable wealth of tutorials on their Youtube channel, allowing for a more rapid mastery of their software package.

5.7.2 Unity

The second method involves the development of an interactive model for use by facilities management personnel. In this analysis, a gaming engine called Unity will be used to develop this prototype. Because of the functions of Unity, almost any interaction imaginable can be created. By writing and applying program scripts, the Revit model can become an environment that can be walked through and interacted with. These interactions can allow a user to pull up product data for a piece of equipment or act as a guide to show maintenance staff where to find shut-off valves, and even demonstrate how to operate equipment.

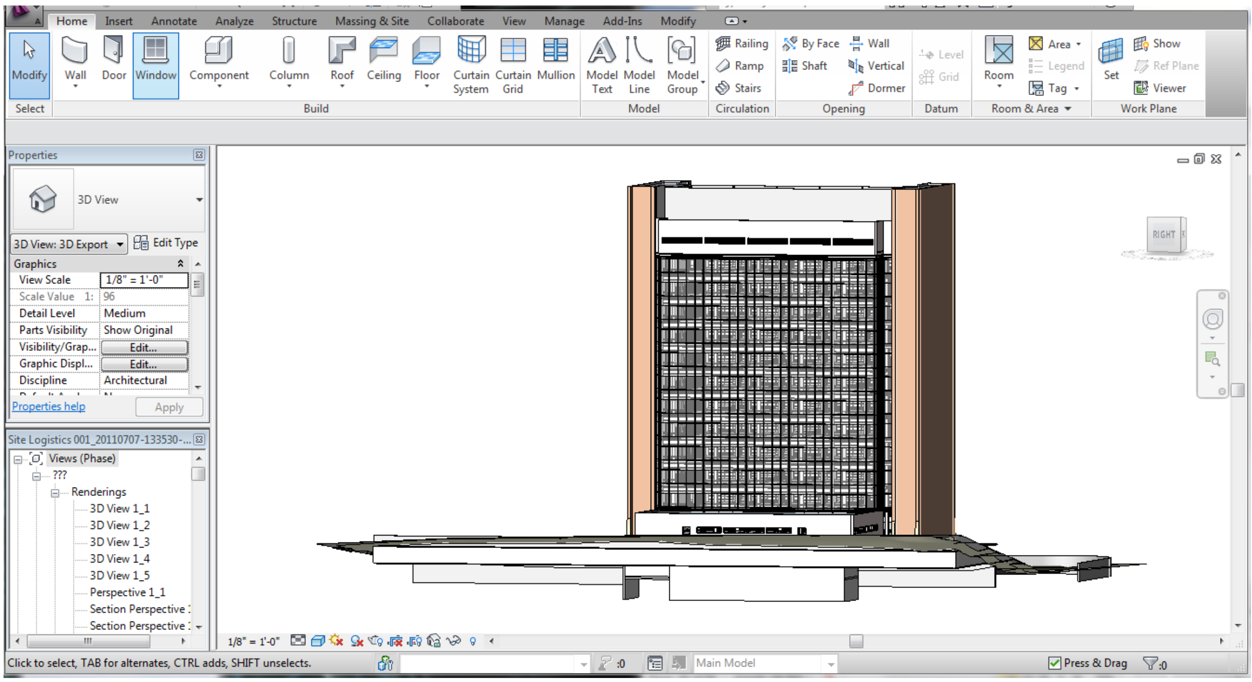


Figure 17: Screenshot of Revit model of Government Office Center

The first step of this process is to develop a model of the project in Autodesk Revit. Once this has been completed, the user must open a 3D view of the model, as shown in Figure 17 above, and select which modeled components should be included within the interactive Unity environment. This can be accomplished by accessing the visibility and graphics display properties, which allow a user to hide or show content by type, such as structural components, doors, or electrical components.

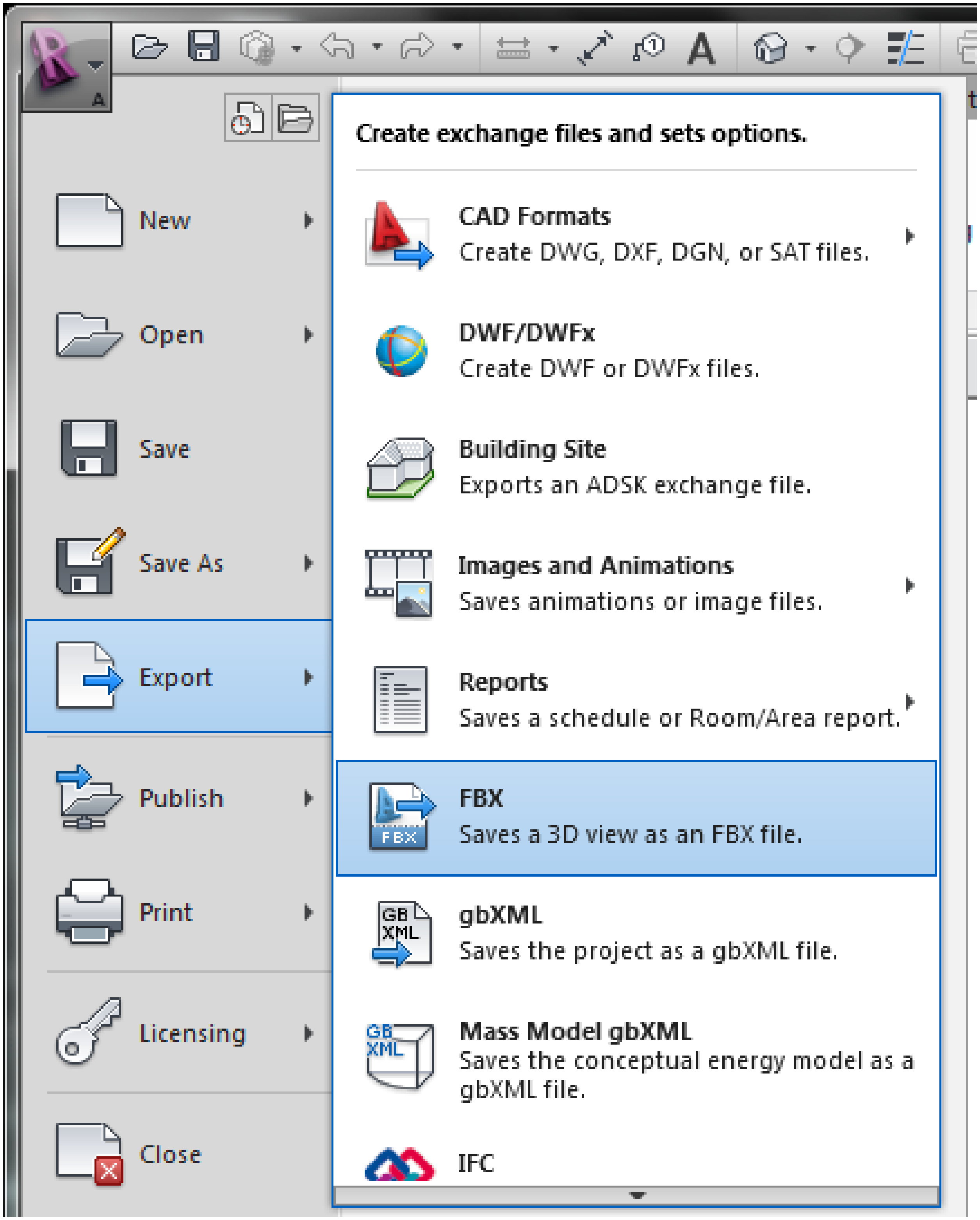


Figure 18: Screenshot of export method used

Once the user has made only the desired components visible in the 3D model, the model should be exported as an FBX file, as demonstrated in Figure 18 above. This will convert the 3D model into a file format that is readable by Unity.

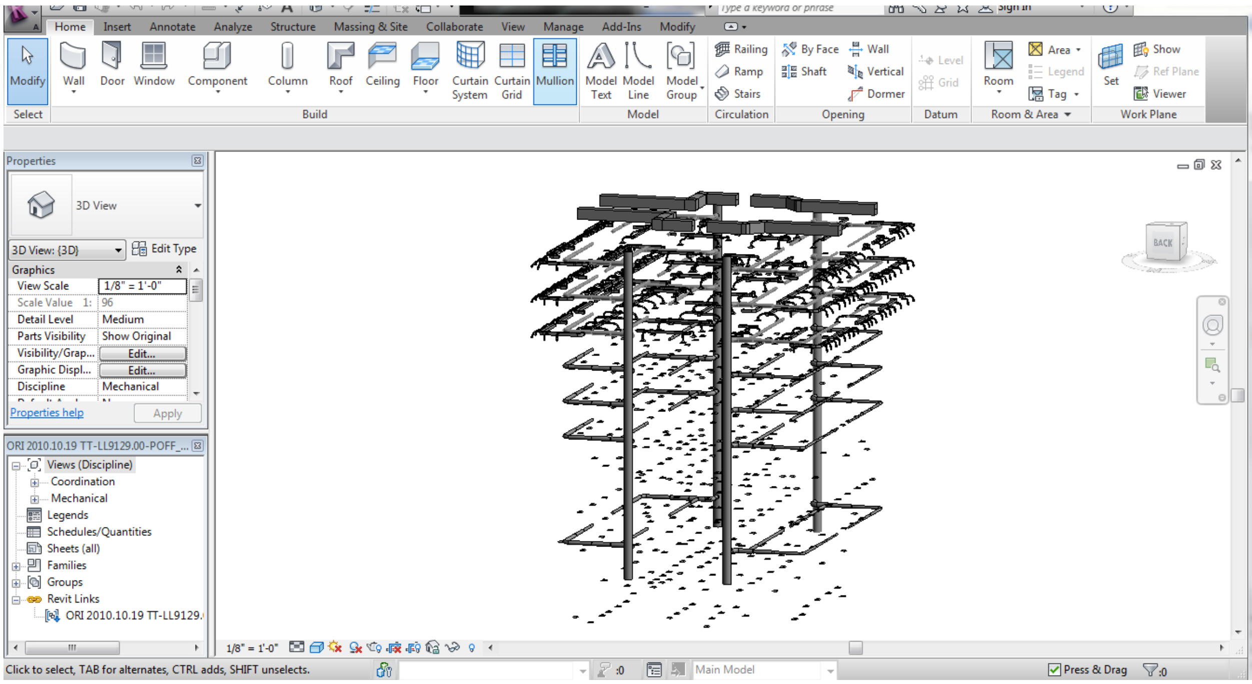


Figure 19: Screenshot of additional content modeled in Revit

For some projects, particularly larger projects with substantial modeled content, Revit modelers break the total project down into a set of smaller Revit files that are linked together. For large project models, it is beneficial to export the modeled content to FBX in smaller chunks as well. In this way, there are fewer software crashes and greater production rates. Therefore, the Government Office Center model was exported in three separate pieces. These parts include the envelope, the structural components and ceilings, and the mechanical system, which is shown in Figure 19 above.

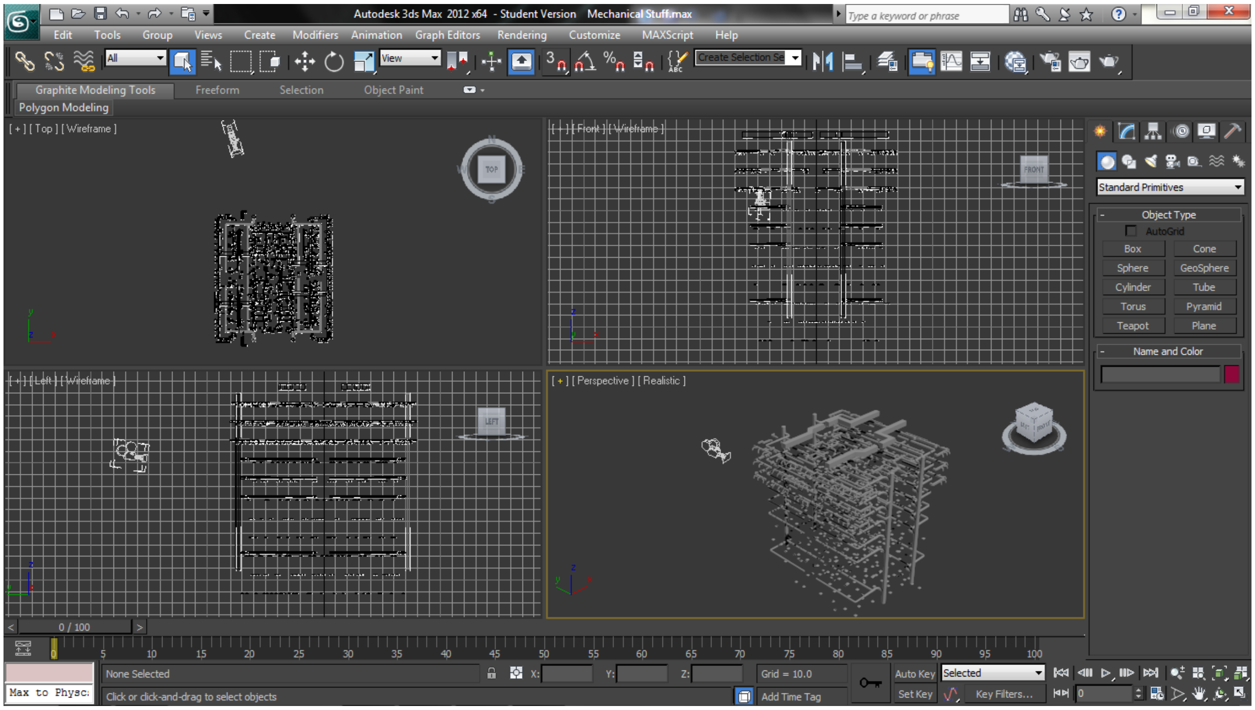


Figure 20: Screenshot of FBX file imported into Autodesk 3DS Max

Once the FBX files have been exported from Autodesk Revit, an interesting issue arises. For some reason, the FBX files exported from Revit do not directly store all of the information that they could, such as texture and color properties of each object. The solution to this issue is to import the FBX files into Autodesk 3DS Max, as shown in Figure 20 above, and then export the files again as FBX files. For insurance against occasional failed exports at this stage, the user should save the imported file as a MAX file prior to exporting again. After the file has been exported as an FBX from 3DS Max, it now contains substantially more information. It is not uncommon for the FBX exported from 3DS Max to be nearly five times the size of the FBX exported from Revit.

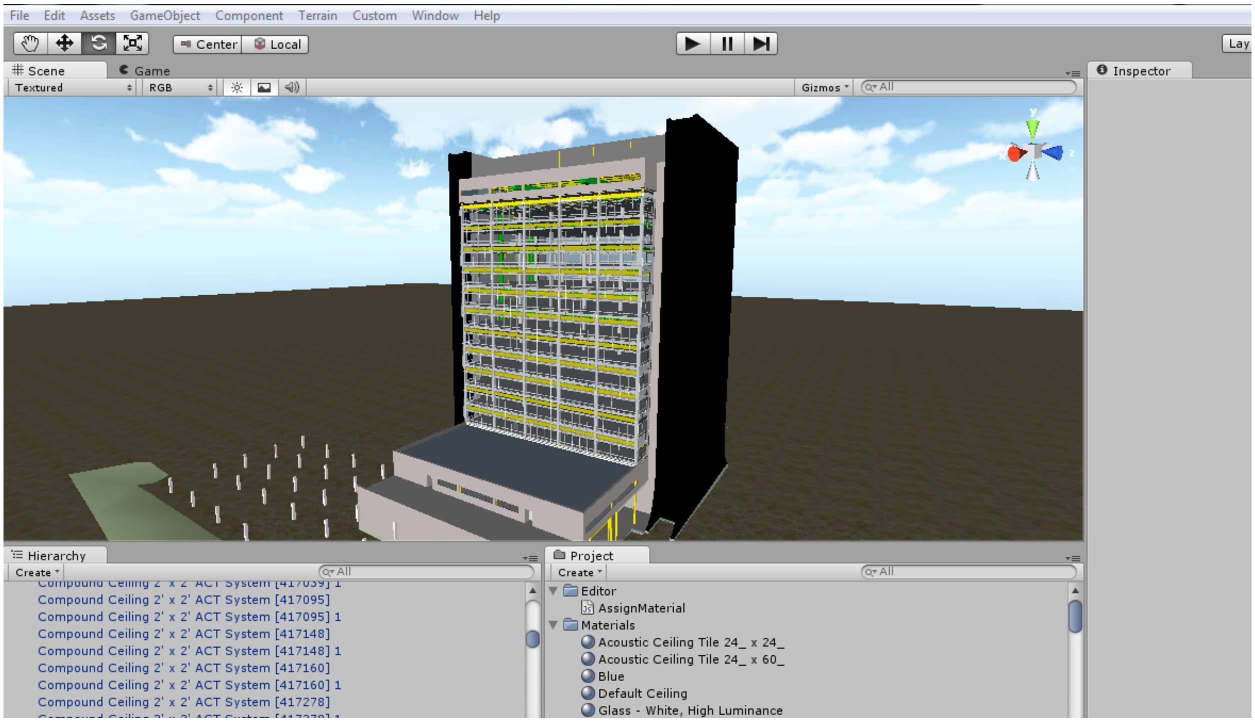


Figure 21: Screenshot of modeled content after being imported into Unity

Once the FBX files have been exported from Autodesk 3DS Max, they are ready to be imported into Unity, as shown in Figure 21 above. Because Unity is designed to create and support video games, all Unity projects begin by selecting asset packages to start with. In this example, a basic, flat terrain and a skybox were created to provide some of the realistic feel that would be expected by a user of the end product. Unity is also capable of importing terrain data from Google Earth, but this process is not critical to the goals of this analysis and therefore will not be discussed. Once the Unity project has land and sky created, the FBX files can be imported.

A common issue that arises at this step is a scale factor discrepancy. In this example, Autodesk 3DS Max was set to units of feet, while Unity defaults to meters. Imported modeled content can be easily scaled for unit conversion. Because the model was divided into three parts, the pieces also had to be lined up with each other. This process is extremely easy for models imported piece by piece from the same Revit file (or from linked files): simply copy and paste coordinates from one piece to the rest.

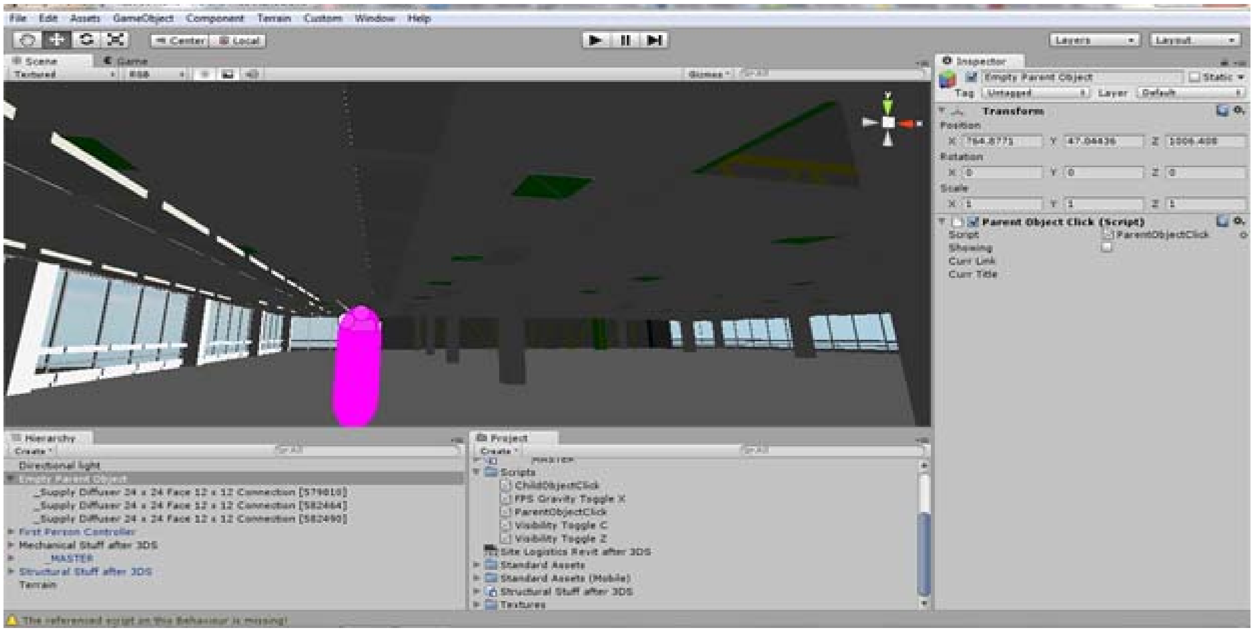


Figure 22: Screenshot of Unity during game development

At this stage, the user must develop the interactions desired for the end product to be delivered to the owner. As shown in Figure 22 above, Unity displays a view of the modeled environment, as well as a set of tabs that contain object properties, scene or level objects, and project assets. In this example, the first person controller is shown in pink.

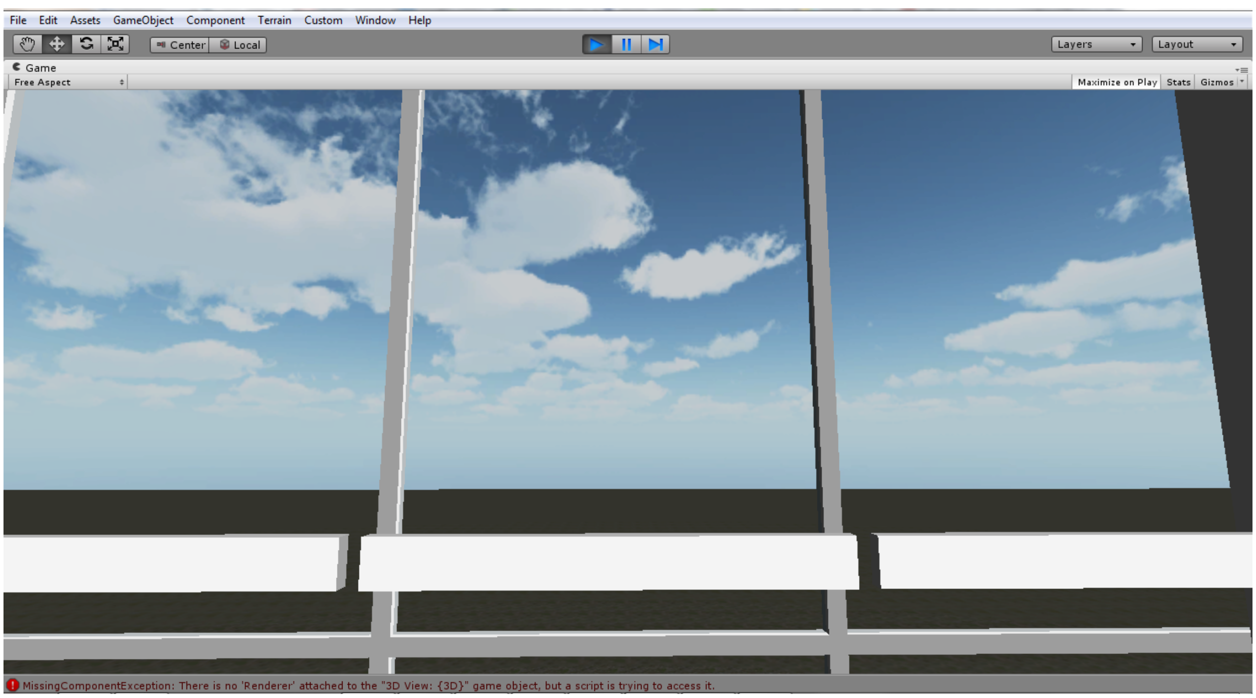


Figure 23: Screenshot of view through curtain wall in Unity

By applying textures and other material properties, objects that were once opaque can become transparent, as in the case of the glass curtain wall shown in Figure 23 above. This allows for more realistic views out of windows to perceive the surrounding environment, which can also be included in Unity.

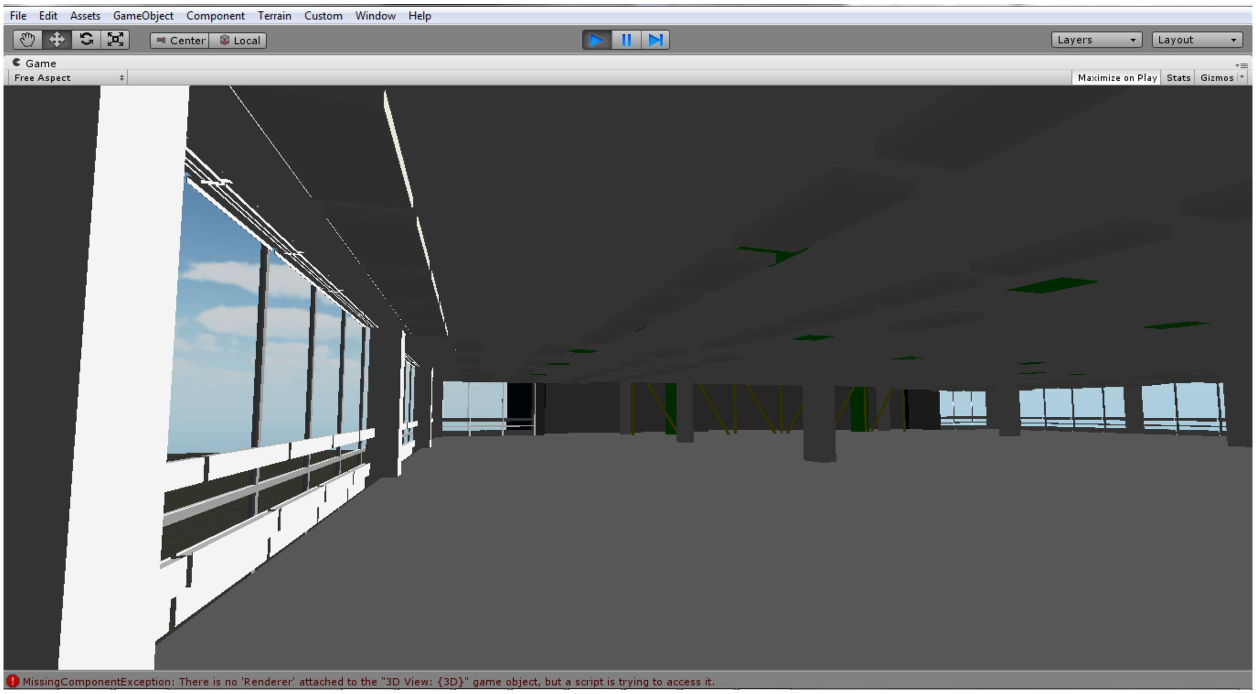


Figure 24: Screenshot of bare floorplan within Unity

While the floorplan shown in Figure 24 above is very plain, textures were not applied to place more attention on other efforts, since it has been demonstrated previously. During "gameplay," the user can walk around this environment and interact with objects through the use of scripts. These scripts can animate objects, such as a door opening and closing, or any number of other desired effects.

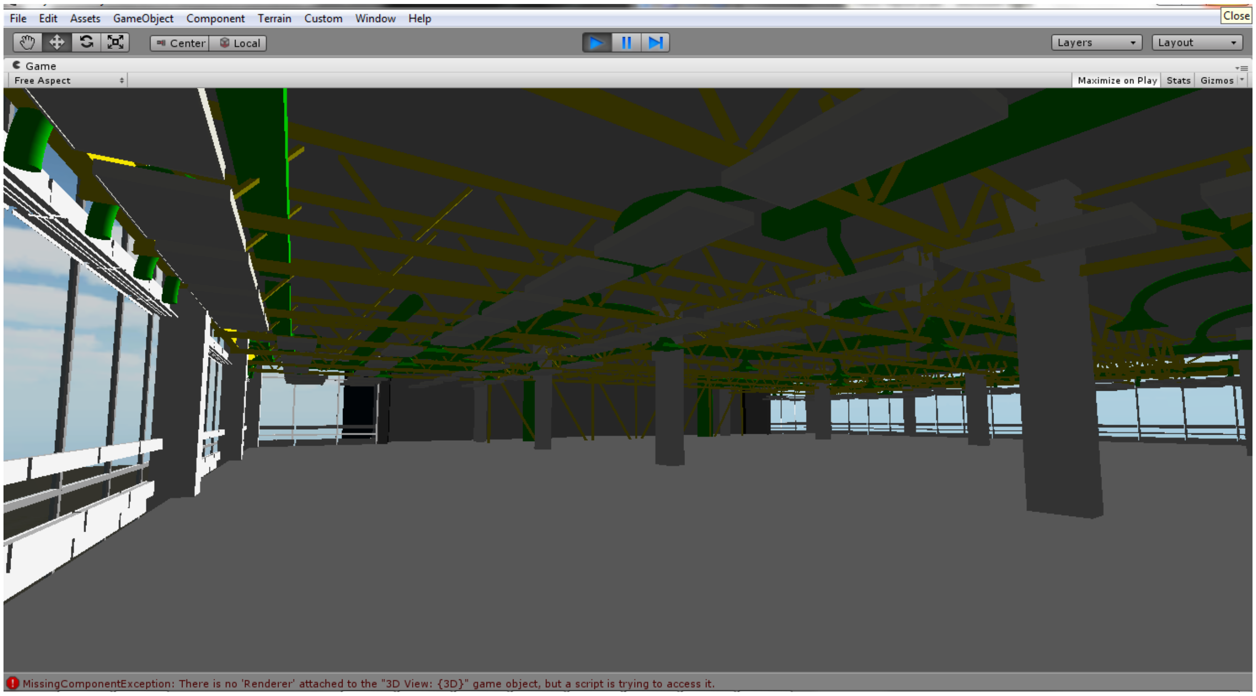


Figure 25: Screenshot of bare floorplan with ceilings toggled off

One such script is a visibility toggle, which turns the visibility of any object on or off instantly at the press of a button. In this example, the ceilings within the Government Office Center model have been hidden by pressing the 'C' key. This function may prove to be extremely useful to facilities management personnel who need to locate junction boxes or other equipment and want to minimize the number of ceiling tiles that they need to remove. As shown in Figure 25 above, structural trusses have been given a yellow texture, while mechanical equipment and ductwork has been given a green texture. In a real world application, this can provide quick distinction for a user of the model, as is commonly seen in Autodesk Navisworks files.

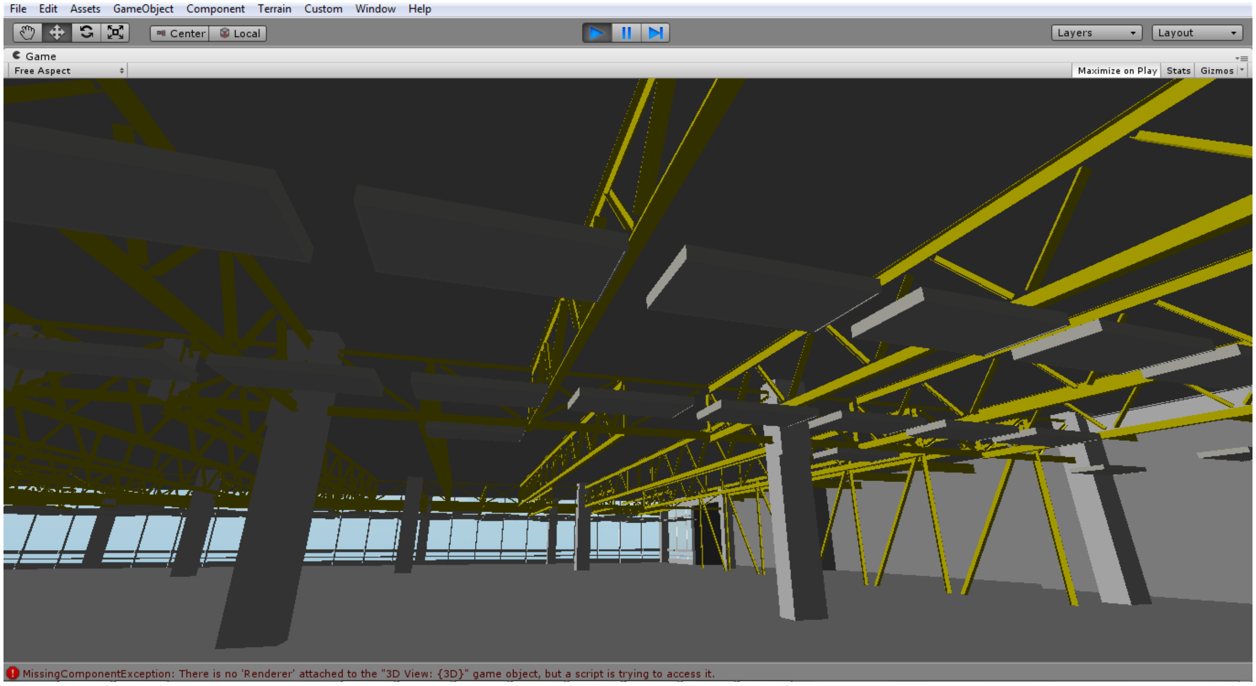


Figure 26: Screenshot of bare floorplan with ceilings and mechanical system toggled off

Continuing with this example, Figure 26 above shows both the ceiling and the mechanical systems hidden through a visibility toggle script. Depending on the needs of the user of this virtual mockup, the ability to hide parts of the building may support planning demands by allowing the user to focus on a specific set of building objects, such as the structural system. In the case of the Government Office Center, some of the trusses shown in yellow must be reinforced to support added loads during the construction process, when a large number of filing cabinets will be relocated into more centralized areas of the building.

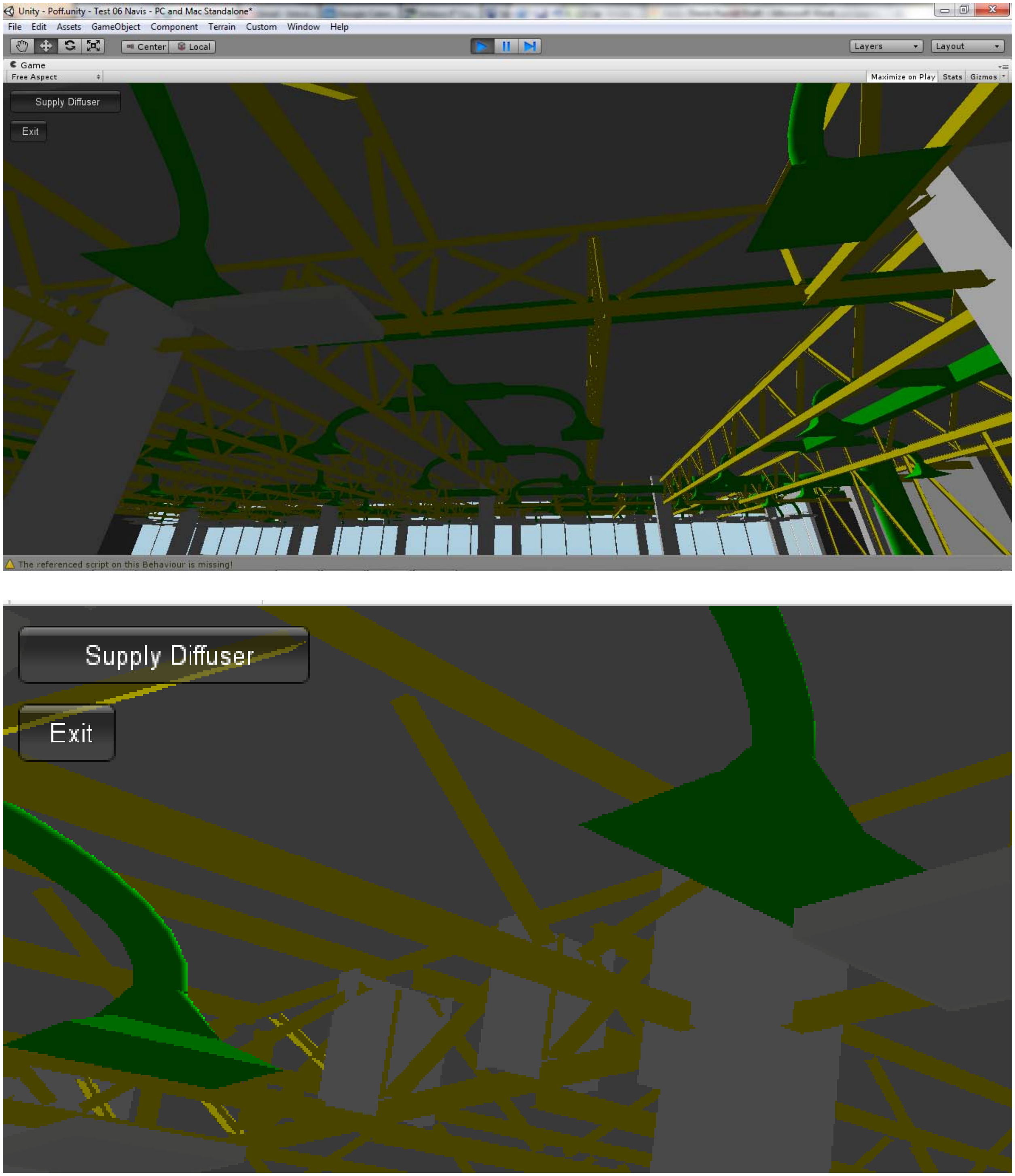


Figure 27: Screenshot of revealed ceiling with enlarged view below

Another beneficial function for facilities management personnel is the ability to access data associated with a specific piece of equipment, particularly when this data is stored outside of the Unity model. In this example, a supply diffuser has been equipped with a script that displays a menu when the diffuser is clicked on, as shown in Figure 27 above. This menu can provide any number of resources to the user of the model.

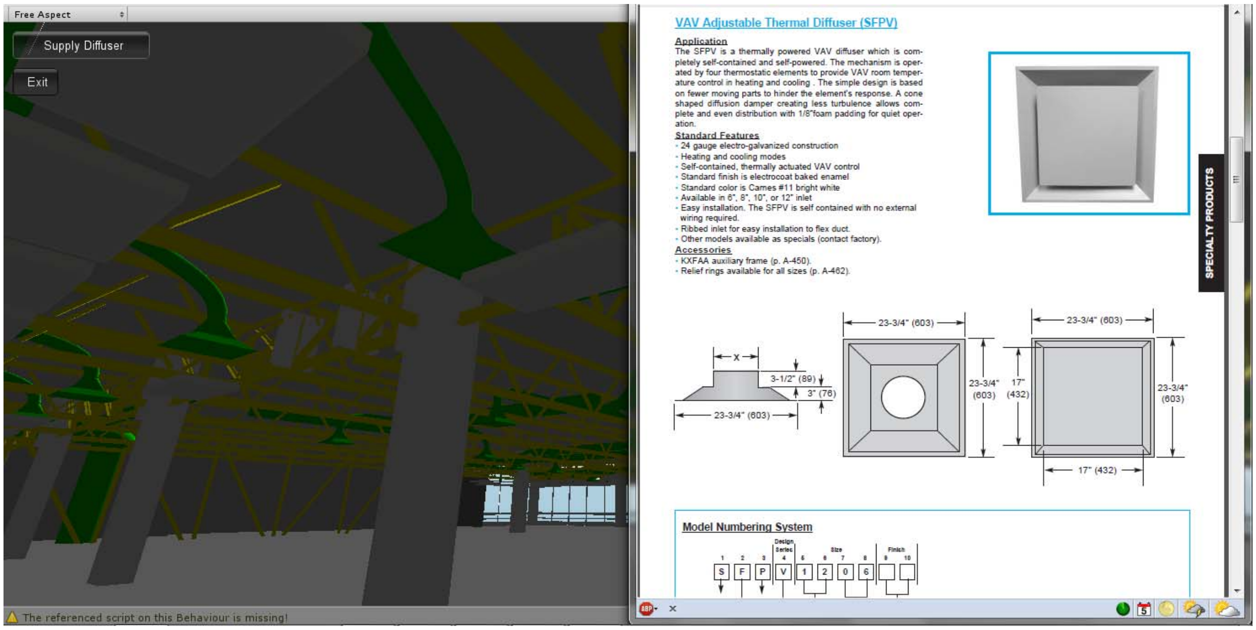


Figure 28: Screenshot of Unity and Supply Diffuser specification sheet

For example, by clicking on a button in this menu, a PDF file that contains product information about the supply diffuser and is stored on the internet opens for viewing, as shown in Figure 28 above. Similarly, any desired link can be attached to any object within the building. These links can be to sites restricted to company access, or to energy dashboards and other emerging technologies. Owners and builders alike are increasingly seeing the benefits of energy management, and interactive virtual mockups like these may provide added functionality and value to an energy management system.

*Coding for the scripts used in this example can be found in Appendix G.

5.8 Field Impact

There will be minimal impact to the field team for either of the proposed strategies. In the first strategy, field staff will input product and equipment data into pre-made templates in Excel. Whenever a pump is installed or a door is hung, important data on pump capacity or door hardware can be recorded and attached to the Revit model. In the second strategy, the field staff will most likely not be responsible for this effort. Early efforts will have significant impact on the BIM staff in the office. However, once scripts have been written, they can be applied repeatedly from project to project, which results in a more streamlined process after a few projects have been completed. The largest impact to the field team in the second strategy will come as a result of verification efforts to ensure that the interactive model delivered to the owner at the end of the project is as accurate and complete as possible.

5.9 Recommendation and Conclusion

There are positives and negatives associated with both concepts illustrated and described above. For software processes like Ideate BIMLink, discussed in section 5.7.1, the learning curve is extremely short. Users are fully capable of mastering this software within a day or two, especially with the support of tutorial videos online. However, most owners do not have Autodesk Revit, and therefore may have no use for information stored within a Revit file. In that case, the information collected within the model would need to be exported entirely at the conclusion of a project, such that the facilities management staff can incorporate the data into their systems.

For software processes like Unity, discussed in section 5.7.2, the learning curve is much longer. A virtual mockup developer needs some familiarity with modeling, the file export process, and code scripting. Because Unity is a gaming engine, almost all tutorials available are geared towards producing gaming effects, such as explosions and other events that an owner would certainly prefer to keep away from their new building. However, Unity is nearly limitless in terms of possible functions and interactions between a user and the virtual mockup. End users can do realistic walkthroughs of designed spaces, owners can see what their new building will look like next to neighboring properties, and facilities management staff can locate system components and access important maintenance, service, and performance history. Once the initial hurdles of the learning curve have been overcome, project teams may be able to deliver valuable products to owners throughout the construction process with the help of Unity.

Both processes are strongly recommended for future use in the industry. Project teams should pay close attention to the needs of the owner in order to determine if either or both methods may provide desired value.

5.10 MAE Requirement

The integrated undergraduate and graduate requirement for the senior thesis was met in part by utilizing skills developed in AE 597F: Virtual Facilities Prototyping for this analysis. Specifically, the fundamental understanding of the Unity gaming engine and the workflow to bring modeled content from Autodesk Revit Architecture 2012 into a Unity project were critical for the completion of this analysis.

6.0 Analysis #2: SIPS Study for Curtain Wall Activities

6.1 Problem Identification

The replacement of the North and South curtain wall systems constitute a substantial portion of the scope of this project and fall on the critical path of the schedule. Because of the highly repetitive nature of the construction activities relating to the curtain wall replacement, the project schedule could benefit from the implementation of a production management technique such as Short Interval Production Scheduling (SIPS). Additionally, the replacement of the South-facing curtain wall provides an excellent opportunity to incorporate a building-integrated photovoltaic system into the scope of this project. In this case, the owner would stand to benefit by challenging the project team to increase the value of the project without increasing cost or duration.

6.2 Research Goal

The purpose of this analysis is to evaluate the benefits of incorporating SIPS for a substantial portion of the project scope and to evaluate the feasibility of an alternate building-integrated photovoltaic curtain wall system.

6.3 Methodology

- Identify key activities that relate to the demolition and replacement of the curtain walls
- Interview construction team for an understanding of activity durations and other details
- Interview PV glazing manufacturers and installers for details regarding cost, schedule, and performance of the proposed alternate system
- Develop SIPS model based on insight gained from interview process
- Analyze feasibility and constructability of alternate PV curtain wall system
- Draw conclusions based on whether implementation of SIPS for curtain wall activities would benefit the project
- Draw conclusions based on whether the proposed alternate PV glazing system is financially feasible and whether it impacts the planned construction sequence
- Develop a summary of findings illustrating the benefits of SIPS and PV glazing compared to necessary effort involved

6.4 Background Information

Short Interval Production Scheduling allows for a detailed breakdown of construction activities to improve productivity on site. Crews are given early forecasts of the work they must complete in the future, helping to mitigate any potential confusion during construction. SIPS is especially applicable to projects with highly repetitive tasks or a series of similar spaces, such as hotels, dormitories, prisons, and school buildings.

For the Government Office Center renovation project, the curtain wall demolition, replacement, and related activities constitute a significant portion of the scope of work. In addition, the work is highly repetitive for both the North and South curtain wall facades, each with eleven floors of nearly identical construction activities being performed on each floor. Since the curtain wall activities fall on the critical path of this renovation project, the use of SIPS will allow for a slightly accelerated schedule.

In fact, this time savings has quantifiable value, and can be used by the project team to increase the value of the project at no added cost to the owner. Though commonly misunderstood to simply mean the removal of something valuable from a project in order to save money for the owner, 'value engineering' also refers to the addition of value to a project at little or no cost to the owner. For this analysis, the time savings created by implementing SIPS for the curtain wall activities will be repurposed to justify replacing the planned South-facing curtain wall with a building integrated translucent photovoltaic curtain wall system.

The following individual has earned great appreciation for his instrumental role in the completion of this analysis:

David Bolt……………... Balfour Beatty Construction

6.5 SIPS Model Development

6.5.1 Traditional SIPS

Although the traditional SIPS method can be used for any work activity, it is usually focused on one work process. This method breaks down time intervals into one-hour, fifteen-minute, or smaller increments and is used to assist project management teams in leveling the manpower and material usage for a particular process. As shown in Figure 29 below, the time intervals can be broken down into very small increments, but there is no consistency with the number of time intervals required to complete a given activity. This contrasts greatly with the non-traditional SIPS method, which is described in the following section.

Unfortunately, this method is more concerned with detailed planning of process than with the leveling of manpower and material usage. As a result, the SIPS produced by this method does not necessarily produce the schedule savings desired, and will therefore not be used in this analysis.

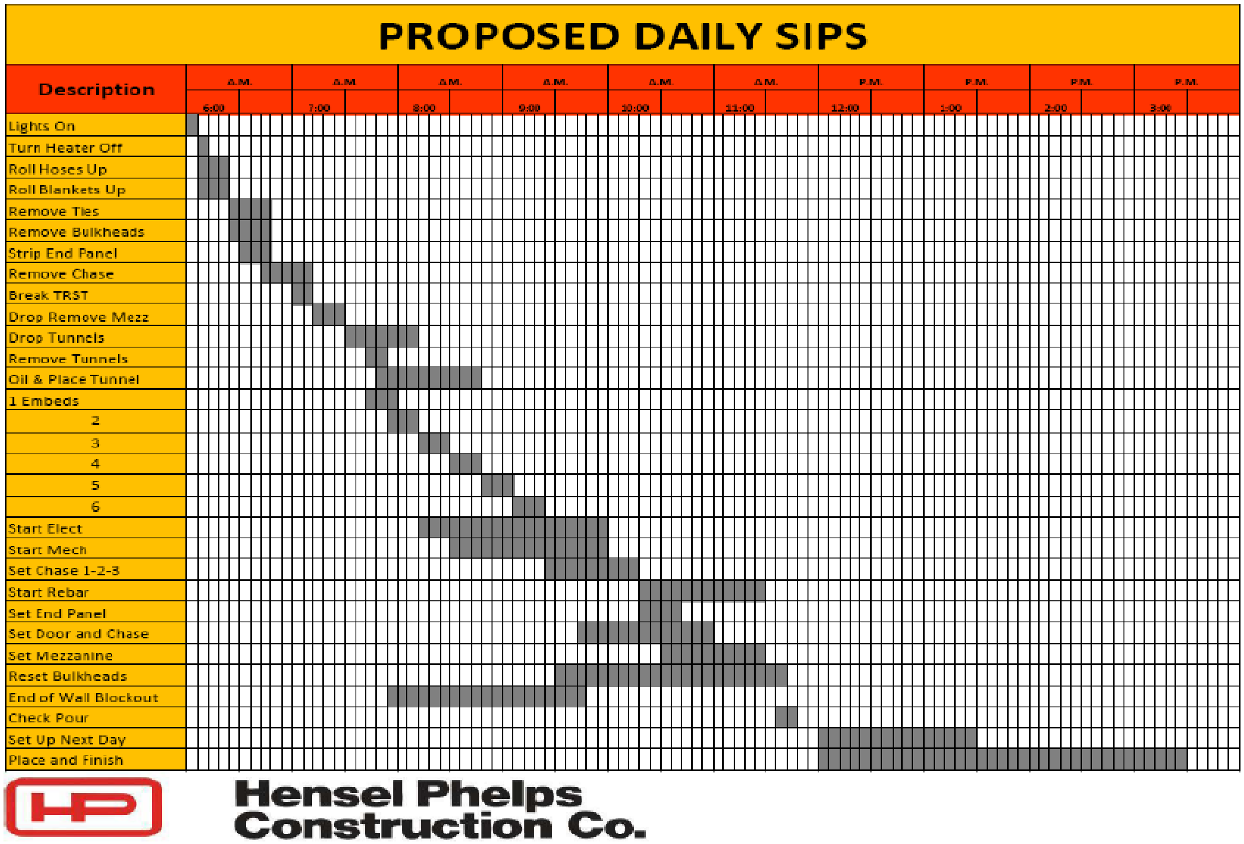


Figure 29: Traditional SIPS from Hensel Phelps presentation

6.5.2 Non-Traditional SIPS

Unlike the traditional SIPS method, the non-traditional SIPS method focuses on many construction activities that take place in a given area. This method breaks down time intervals into larger increments than in the traditional method, ranging from a number of days to a week or more. Building areas are broken up such that work activities can be completed in one time interval, with successive activities being completed in the same building area during the next time interval, as shown in Figure 30 below.

Because the goal of the non-traditional SIPS approach is to plan and evenly distribute manpower on a jobsite, it is especially applicable on projects with highly repetitive areas or work activities. Therefore, this production management method was selected for the purposes of this analysis. With a very repetitive work area and construction process defining the curtain wall replacement efforts, which fall on the critical path of the project schedule, this analysis applies the non-traditional SIPS method to the activities that impact the curtain wall scope of work.

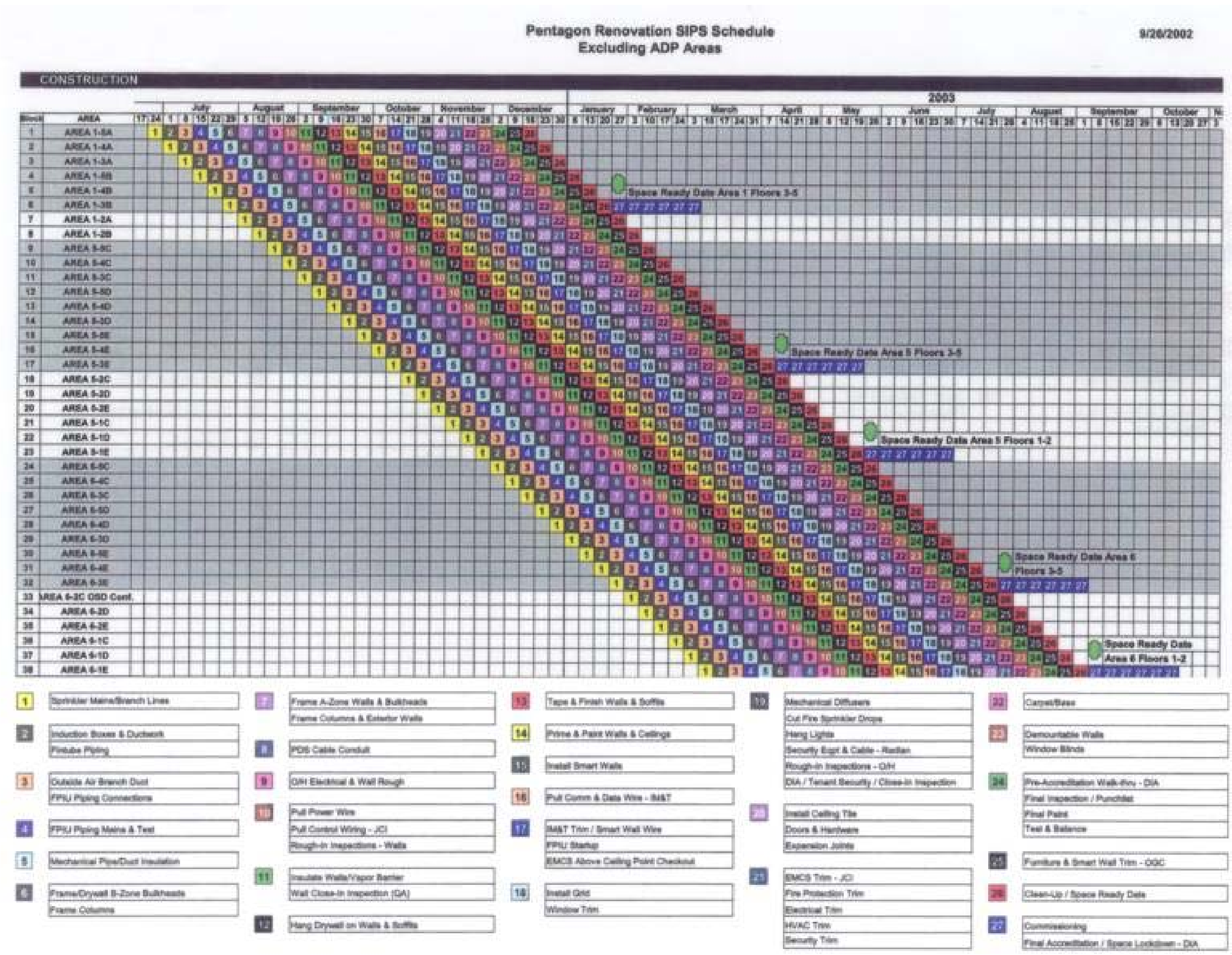


Figure 30: Pentagon Renovation Non-Traditional SIPS by Hensel Phelps and Washington Headquarters Service[7]

6.5.3 Activity Identification

In order to maximize the amount of time saved by implementing SIPS, the activities related to the curtain wall demolition and replacement must be identified. For this analysis, the sequence of activities will proceed as follows:

- Weather wall installation and curtain wall bracing
- Demolition of existing curtain wall
- Installation of new structural steel supports
- Installation of new curtain wall system
- Demolition of weather wall
- Frame and rough-in
- Restoration of finishes[8]

These activities will be carried out in two-week intervals over the eleven stories of curtain wall system for both the North and South facades.

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[7] "Short Interval Production Schedule (SIPS)." *Pentagon Renovation Program*. Web. 19 Jan. 2012. <http://renovation.pentagon.mil/wedge2-5/sips.htm>.

[8] Bolt, David. (10 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

6.5.4 Building Areas

Work will flow from the thirteenth floor on the North curtain wall down to the third floor, and then again on the South curtain wall. The area pertinent to this effort is highlighted on Figure 31 below, which illustrates a typical floor for this construction process.

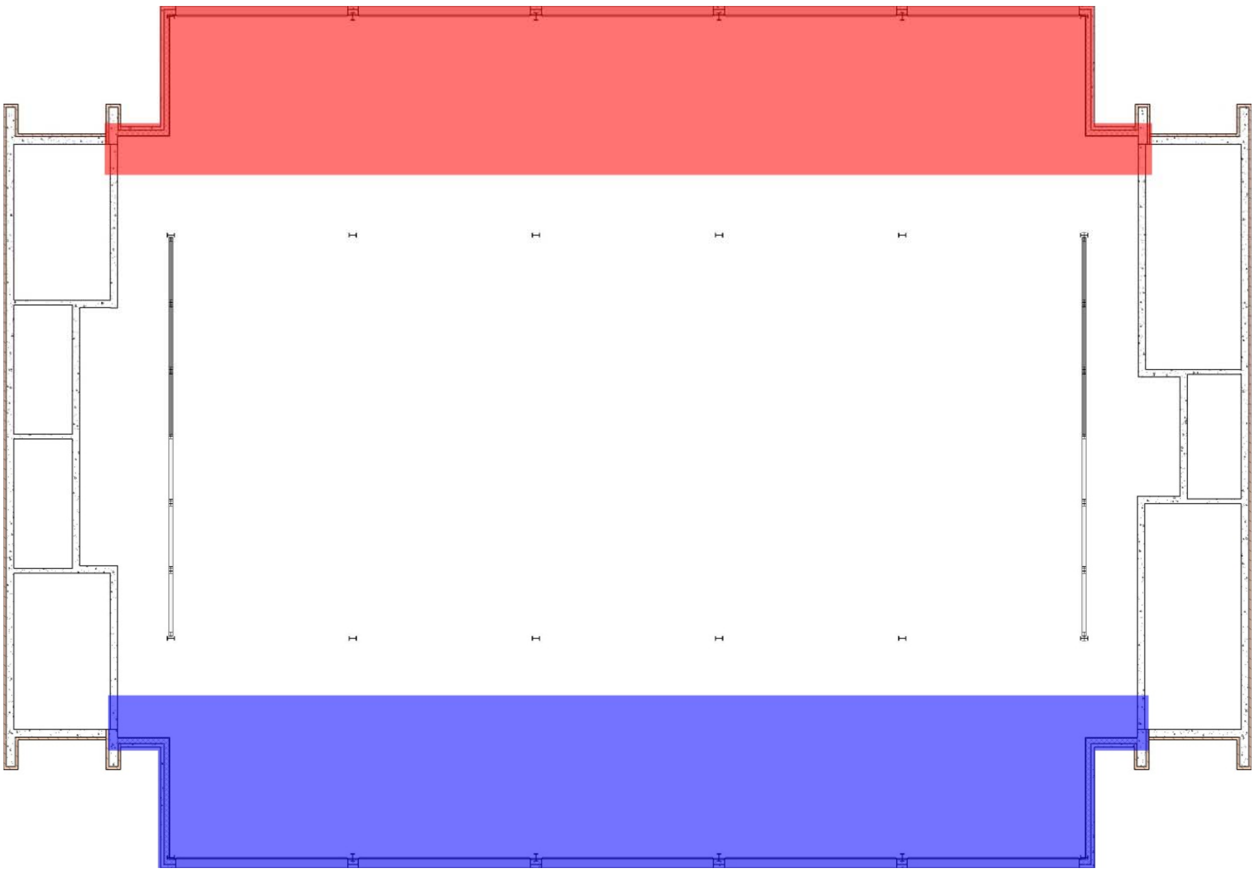

Figure 31: Work areas involved in proposed SIPS

As shown in the typical floor plan above, the building areas that will be involved in this SIPS method include the area around the North curtain wall (in red) and the area around the South curtain wall (in blue) for each floor from the third to thirteenth floor. The interior boundary of these areas will become a physical reality after the completion of the temporary weather wall.

6.5.5 Existing Schedule

Under the existing project schedule, the process outlined above begins with the installation of the North weather wall on October 11, 2011 and ends with the completion of interior finishes on the South side on September 16, 2013. However, the phasing of this project creates a schedule gap between the North and South activities, starting September 12, 2012 with the completion of interior finishes on the North side of the Government Office Center and ending November 8, 2012 with the installation of the South weather wall. This delay is conservatively included in the analysis. Therefore, the total required schedule time as planned is approximately 101 weeks, including the 8 week break for other construction activities.

6.5.6 Short Interval Production Schedule

To determine an appropriate time interval duration, the original durations relevant activities were each identified. Because the longest activity is the restoration of finishes (100 work days planned for the North side), intervals were set to two-week durations, providing workers with 110 work days to complete the activity (eleven floors, two-week intervals, and five work days per week). Additionally, the eight-week break between the completion of these activities on the North side of the building and the start of these activities on the South side of the building was included in the development of the SIPS to allow other activities to continue as planned.

Maintaining the same October 11, 2011 start date, this SIPS allows for a completion of the described activities by March 25, 2013, as shown in Figure 32 below. Therefore, by scheduling activities in this manner, which actually allows more time for crews to complete their work than in the existing schedule, a direct schedule savings of 25 weeks can be achieved.

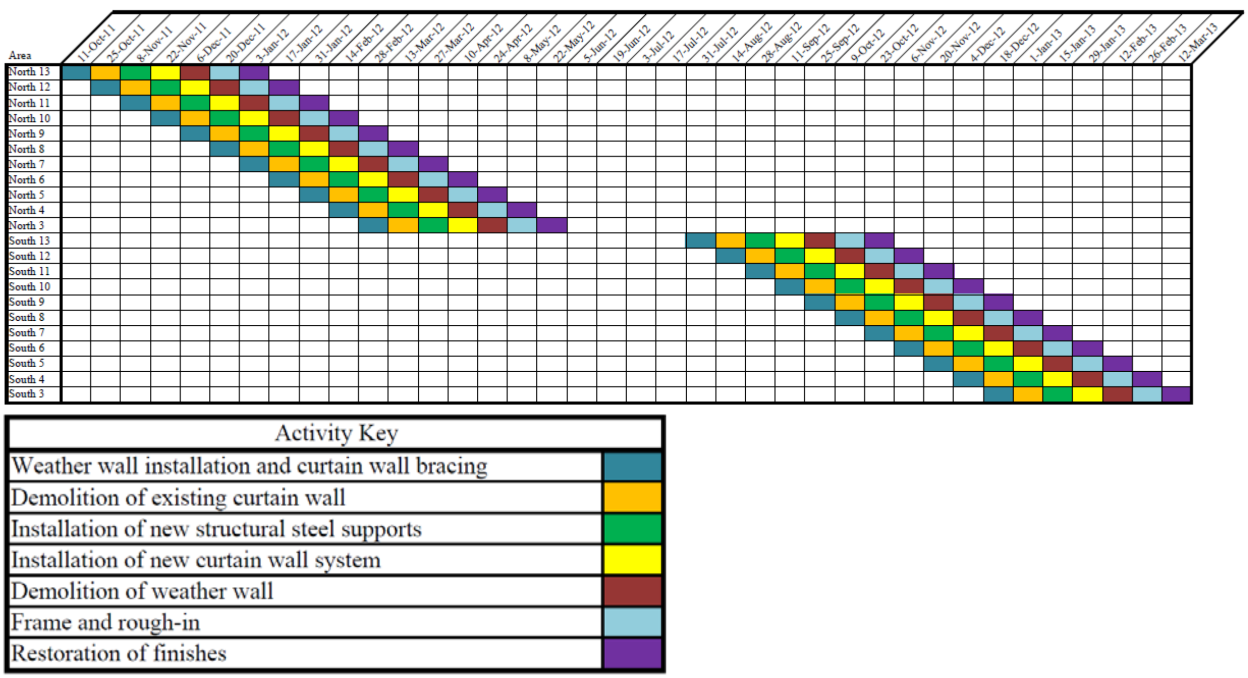

Figure 32: Proposed SIPS for curtain wall activities

The image above illustrates how the work is broken down into seven different activities which must be completed in twenty-two areas during a series of two-week intervals. See Appendix H for a larger representation of this chart.

6.5.7 Savings

Conservatively, labor costs are assumed to remain constant, as subcontractors will still be completing the same scope of work. Therefore, implementation of SIPS for these activities will not generate a labor cost savings for the Government Office Center project team. However, because these activities fall on the critical path of the project schedule, there is a direct savings of twenty-five weeks of schedule time. With approximately $17,000 of general conditions costs per week, this SIPS implementation plan can provide $425,000 in general conditions cost savings for the project. Also, completing the project early provides quantifiable value to the owner of the Government Office Center. This daily value should be approximately equal to the liquidated damages for this renovation, which are $7,000 per calendar day (rounded and altered slightly). Therefore, completion of the project twenty-five weeks early is worth nearly $1.225 million. As a result, implementation of this SIPS method generates a value of $1.65 million for the owner.

6.6 Preliminary PV Curtain Wall Design – Renewable Energy/Electrical (Breadth Topic 1)

6.6.1 System Selection

A variety of issues must be considered when selecting a photovoltaic array system. For the Government Office Center to reduce its electricity demand and dependence on rising energy prices, on-site power generation options such as photovoltaic electricity generation systems should be considered. However, because this renovation project is already adding solar panels to its roof, a more unique application of this technology presents itself. Since the Government Office Center renovation project is removing and replacing glass curtain wall systems on its North and South facades, a building integrated photovoltaic glazing system can provide added value to the owner over the designed replacement for the South façade.

While typical solar panels are opaque, this property would block the view to the south for building occupants who have been used to floor to ceiling glazing. Since there is true value in maintaining this view, a semi-transparent solar glazing panel, such as amorphous silicon panels, would be necessary to allow between ten and thirty percent of light to pass through. The opacity of such a system would eliminate the need for the sunshades, shown in Figure 33 below, that are currently included in the curtain wall scope of work, and this immediate savings can help to support the marginal cost of the photovoltaic system.

Semi-transparent amorphous silicon photovoltaic glazing for curtain wall systems is becoming more readily available. In fact, nearly the same glazing design as used in the new GOC curtain wall can be found with amorphous silicon photovoltaic technology. This technology is also much lighter than crystalline panels, which means there will be no impact to the structural system beyond what is currently designed for the replacement system.

For the Government Office Center project, there is 25,320 square feet of curtain wall on the South façade, reduced by five percent to 24,054 square feet to account for mullions and other issues that detract from the possibility of 100% photovoltaic glazing on the surface. A common energy output of 8.4 W per square foot will be assumed for an amorphous silicon array that allows ten percent of outside light to pass through.[9] Thus, the proposed alternate system is rated to produce 202.1 kW (DC).

[9] *Building Integrated Photovoltaics*. Onyx Solar. PDF.

Figure 33: Photo of the curtain wall mockup at the GOC

6.6.2 Orientation and Shading Analysis

The portion of the curtain wall being replaced that is relevant for the purposes of implementing a building-integrated photovoltaic curtain wall system is on the south side of the Government Office Center. Based on the original layout of the building, this system will replace the existing South-facing curtain wall. In other words, the array will be vertical and face directly south. This tilt is certainly not optimal for solar power generation. However, amorphous silicon technology has been shown to collect diffuse radiation much more effectively that crystalline panels, allowing for greater performance over the year due to continued electricity generation even during cloudy days.

As shown in Figures 34 and 35 below, the eleven stories of South-facing glass curtain wall are not shaded by any neighboring buildings, trees, or other objects. Therefore, there are no losses due to shading for this configuration. This will help to optimize the electricity generation of the proposed alternate building integrated photovoltaic curtain wall system.

Figure 34: Photo from the South-facing existing curtain wall

Figure 35: Photo of South-facing façade of the Government Office Center

6.6.3 Energy Production

Before this proposed system can be analyzed for financial feasibility, electricity generation must be calculated. This process is simplified by tools like PVWatts, which was developed by researchers at the National Renewable Energy Laboratory (NREL). This tool is limited by locations available, but a newer version of this tool is currently being developed to allow for more site-specific analysis. For this analysis, Richmond, Virginia was assumed to reasonably approximate the conditions found at the site of the Government Office Center. As shown in Figure 36 below, this array will produce 163,928 kWh in AC energy in the first year. However, this tool is geared towards more typical crystalline photovoltaic technologies, which would not perform as well as the proposed amorphous silicon system under diffuse conditions. Therefore, these results are conservatively low.

Station Identification	
City:	Richmond
State:	Virginia
Latitude:	37.50° N
Longitude:	77.33° W
Elevation:	50 m
PV System Specifications	
DC Rating:	202.1 kW
DC to AC Derate Factor:	0.770
AC Rating:	155.6 kW
Array Type:	Fixed Tilt
Array Tilt:	90.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.92	19014	1521.12
2	3.72	16063	1285.04
3	3.53	16039	1283.12
4	3.00	11904	952.32
5	2.55	9729	778.32
6	2.33	7991	639.28
7	2.44	8685	694.80
8	2.77	10614	849.12
9	3.47	13977	1118.16
10	3.76	16716	1337.28
11	3.68	16705	1336.40
12	3.45	16491	1319.28
Year	3.21	163928	13114.24

Figure 36: Screenshot of PVWatts results

6.6.4 Electrical Components and System Tie-In

The Government Office Center has an existing electrical infrastructure that will be able to handle this system through a typical supply side interconnection. The specifications for this project call for an isolation transformer for the photovoltaic array being installed on the roof. It can be reasonably inferred that this requirement will also apply to this proposed system. Therefore, the isolation transformer will either need to be sized up to handle additional loading or an additional isolation transformer will need to be added to the proposed package. Similarly, DC disconnects will be required for this system prior to the invertors, AC disconnects will be required after the invertors, and a service tap connection will be required at the meter. Because the Government Office Center renovation project is using the Sunny Tower invertor system by SMA Solar Technology for the rooftop photovoltaic array, this system should also be used for this photovoltaic curtain wall. The proposed system is rated at 202.1 kW DC, and would therefore need four Sunny Tower ST42 units equipped with six Sunny Boy SB 7000US each, with each of these towers rated at 52.5 kW DC for a total maximum capacity of 210 kW DC.[10]

*See Appendix I for Sunny Tower ST42 Technical Data

6.6.5 Feasibility Analysis

Because the Government Office Center renovation is a federal project, rebates and other incentives are not applicable. However, because this is a building integrated photovoltaic system that also provides curtain wall functionality, only the marginal added cost is relevant for consideration. With amorphous silicon photovoltaic panels prices dropping as low as $1.00 per Watt, it is safe to assume that the marginal cost for this system will be somewhere between $1 and $2 per Watt, since the cost of adding the amorphous silicon to a substrate must be less than $1.00 per Watt to account for the cost of the substrate. Therefore, the marginal cost for this system should be approximately $404,107.20 at a rate of $2.00 per Watt.

This cost is immediately and significantly reduced by the removal of the sunshades from the scope of curtain wall work. These sunshades account for approximately 5% of the curtain wall package, placing their value at $382,500. Therefore, by removing them from the scope of work for the Government Office Center renovation project, the immediate marginal cost for this proposed system is reduced to $21,607.20. Assuming an average electricity cost of $0.08 per kWh, the yearly production is worth $13,114.24. Consequently, the proposed system will pay for itself within two years of installation, and produce continuing profits beyond this point. If, however, the value of the sunshades is significantly lower, or the cost of the proposed system is significantly higher, the payback period rises quickly. It is therefore critical that issues such as mechanical load impact, changes in lighting demand, dependence on rising energy costs, and even public opinion be considered in a more detailed feasibility analysis.

6.7 Recommendation and Conclusion

When presented with an opportunity to accelerate the project schedule by 25 weeks as shown in section 6.5.6, a feat worth $1.65 million to the owner as explained in section 6.5.7, it is clear that this opportunity should be examined for implementation on the Government Office Center project. Unfortunately, with little to no incentive for the construction management team due to the contracting arrangement, this SIPS method was likely never considered. The risk involved accompanied by the lack of reward also makes it impossible to gain subcontractor buy-in into the process, as they would rather stand by their inflated schedule projections. Based on the results of

[10] *Mounting Rack: Sunny Tower-US ST6US/ST36/ST42/ST48 Installation Guide.* SMA. PDF.

this analysis, the implementation of this proposed SIPS strategy is highly recommended for the Government Office Center renovation project.

Similarly, the opportunity to reduce dependence on rising energy costs with a building integrated photovoltaic curtain wall could have been successfully made a reality with greater support from the owner. As demonstrated in section 6.6.5, the immediate marginal cost of a building integrated semi-transparent photovoltaic curtain wall system that maintains the view from the building for its occupants while generating a substantial amount of electricity is under $22,000 after the sunshades have been removed from the scope of work. This translates to a payback period under two years, making it an incredibly smart financial investment. Furthermore, the inclusion of such a system would help to set a trend of optimizing projects as a whole, rather than system by system, for future public and private projects. Because this system pays for itself so quickly, it is recommended that this amorphous silicon photovoltaic curtain wall system be implemented for the project, and that the savings from the previously discussed SIPS strategy be reinvested into the project for added value. Potential areas for this reinvestment include a progressive collapse prevention system, such as the one discussed in Analysis #4.

6.8 MAE Requirement

The integrated undergraduate and graduate requirement for the senior thesis was met in part by utilizing course material covered in AE 570: Production Management in Construction and AE 897A: Solar Project Development for this analysis. The concepts in AE 570 provided the background necessary to develop the short interval production scheduling system for the curtain wall demolition and replacement activities, while concepts from AE 897A provided the basic skills needed to perform a preliminary photovoltaic feasibility analysis.

7.0 ANALYSIS #3: INTEGRATED PROCESSES

7.1 Problem Identification

The construction industry is slowly beginning to trend toward more integrated solutions to project delivery challenges. Designers, contractors, and owners are forming teams in order to improve value while reducing wasted time and money along the way. For the greatest chance of success, owners must be fully engaged in the process from concept to turnover. Integrated teams would benefit from the identification of the benefits of an engaged owner that positively contributes to integrated team efforts, as well as the identification of the process and integration failures that can be encountered on this type of project.

7.2 Research Goal

The purpose of this analysis is to evaluate process and integration failures associated with disciplines like envelope and mechanical systems that are critical to the success of high performance retrofit projects.

7.3 Methodology

- Interview industry professionals regarding the benefits of an engaged owner
- Evaluate themes and identify key traits of engaged owners who positively contribute to integrated team efforts
- Interview project team members to gain an understanding of the management of the design and procurement process
- Interview industry professionals regarding envelope and mechanical systems in high performance retrofit projects
- Evaluate themes and identify specific causes of failures associated with the critical systems in high performance retrofit projects
- Draw conclusions based on the benefits of an engaged owner on the delivery of envelope and mechanical systems in high performance retrofit projects
- Analyze how these conclusions could apply to the Government Office Center in terms of accelerating the design schedule, improving constructability of the curtain wall and mechanical equipment, and ensuring that the needs of the owner are met

7.4 Background Information

Owner involvement is critical to the success of a construction project. With the rising popularity of more collaborative, integrated project teams, this argument has never been more valid. In fact, the way in which an owner interacts with the project team can make or break the construction project. A project with great potential, such as a high performance retrofit project, will likely never realize this potential without an engaged owner who consistently plays a positive, contributing role in the planning, design, and construction process.

The following individuals have earned great appreciation for their instrumental roles in the completion of this analysis:

Mark Konchar…………. Balfour Beatty Construction
Tim Carr………......... Heery International
Andreas Phelps…………Balfour Beatty Construction
Bevan Mace…………….Balfour Beatty Construction

7.5 Engaged Owner

An engaged owner provides a construction project with many benefits. Especially on projects with highly integrated teams, an engaged owner is actively involved in the process and shares in the ownership and accountability for the success of the project with all major parties involved. Based on interviews with several industry professionals, this analysis discusses some of the key advantages to having an engaged owner on a construction project.

7.5.1 Decision Making

In all phases of a project, an engaged owner enables faster and more refined decision making.[11] This benefit is especially important when the amount or source of funding is changing, since an engaged owner will help to accelerate the decision-making process.

An engaged owner is more informed of options being considered by the project team, and is familiar with the consequences of each of these options. For example, in an energy efficiency retrofit that focuses on the performance of the building envelope and mechanical system, a truly engaged owner is actively involved in the decision making process in order to ensure that the end product is optimal. Passive and active energy efficiency strategies can be employed, and each has positives and negatives. Passive strategies, such as decreasing air infiltration, adding insulation or thermal mass, and using shading devices designed to meet the unique situation of a building, require no effort on the part of the owner or facilities management staff to maintain or control them. Although they may add to the initial cost of the project, financial benefits can be observed immediately through downsizing mechanical equipment in addition to the value of long-term energy savings. Active strategies, such as energy efficient mechanical systems and photovoltaic power generation, require careful implementation and users who are properly educated to monitor and control them. Active strategies almost always will add to the up-front cost of a project, but these costs are expected to be recovered through long term energy savings. An engaged owner is conscious of factors like these, and takes an active role in the decision making process to choose systems appropriate to the needs of the project, consequently improving the handover process and overall project value.[12]

Many cases which demonstrate noticeably faster and more refined decision making as a result of having an engaged owner can be identified and explored. Three of these projects, including a middle school renovation and the new construction of an elementary school and a middle school, display these improvements to the decision making process most significantly during the

[11] Carr, Tim. (23 January 2012). Heery International. (A. Ward, Interviewer)
[12] Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

development of design documents. It is important to note that these benefits can impact both renovations and new construction projects alike.

For the renovation project, an existing YMCA facility was repurposed as a public middle school. The 55,000 SF building was expanded to 71,000 SF with the addition of two infill areas, the entire roofing system was replaced, all new windows were installed, and a new central station mechanical system replaced the existing HVAC system to improve energy performance in the building. By having all stakeholders actively involved in each design review meeting, decisions for the project were measurably expedited. This collaborative effort carried into the construction phase, where the owner, architect, and contractor worked as a team to handle unforeseen conditions as they were discovered and keep the project on its planned schedule. Ultimately, this project achieved a LEED Gold rating with Enhanced Commissioning credits, and the active involvement of the owner in the project process was critical to this success.

Although the other two projects examined were distinct projects, their similarities allow them to be grouped for analysis purposes. While one is a 98,000 SF elementary school and the other is a 151,000 SF middle school, both are new construction projects for the same owner and are designed by the same architect. The unique challenge faced by these projects was the development of accurate energy models that could be incorporated into a centralized building energy monitoring and control system run by the school district. In both cases, project decisions were greatly expedited thanks to the owner being engaged in the design review meetings and as needed during the construction process. In fact, the active involvement of the owner enabled facilities management staff to have adequate training time scheduled prior to the opening of the schools in the fall. Once again, an engaged owner supported project decisions and helped both projects achieve LEED Silver ratings with Enhanced Commissioning credits.

7.5.2 Changes

Changes to the scope of work are more clearly understood when an owner is actively involved in defining what the change will accomplish and why it is needed.[13] In addition, changes in general occur less frequently, due to the fact that an actively involved owner clarifies project needs earlier in the project development process.

Projects with more actively engaged owners see benefits in the design phase of a project as it relates to changes. In a large number of projects, there are inevitably some changes, administrative or otherwise, that impact the program of requirements before a project is completed. While these changes primarily depend on the type of client, an engaged owner will help to improve coordination in the design process for their projects, while an owner who is less involved may face changes that have a greater, and usually negative, impact on their projects.

When a project team is aware of the fact that the owner is not satisfactorily engaged in the process, the team must follow a less-than-optimal strategy, especially during earlier phases of the project. For example, the project team is more careful and methodical about keeping the owner informed. The team must guide the owner through the design development process, and must constantly relate every decision back to the program of requirements for the project, helping to

[13] Carr, Tim. (23 January 2012). Heery International. (A. Ward, Interviewer)

assure the owner and the team that the purpose planned for the project will be achieved. Without an engaged owner during this project phase, there is a greater likelihood of major changes occurring as the design is developed. Consequently, the degree of change is reduced with the support of an engaged owner.

7.5.3 Communication

With an owner who is actively involved in the project process, communication between team members improves noticeably. In regards to subjects such as funding, program objectives, and "big picture" issues that may directly impact the project outcome, an improved level of communication between project team members and the owner give the project a greater chance of reaching optimal value.[14]

Because an engaged owner generally has more knowledge about the design and construction process than an owner who is less involved, they tend to be more involved in the process and offer stronger communication skills. These engaged owners do not need to rely so heavily on the expertise of the project team, and as a result bring more to the table during discussions. However, while the project team can benefit from the communication improvements seen with engaged owners, the enthusiasm of the team depends more on the personality and ability to manage scope, time, and budget of the project manager than on an owner. In other words, an engaged owner brings improved communication between the owner and other team members, but maintaining active communication channels between project team members is more reliant on the project manager.

7.5.4 Schedule Acceleration

An engaged owner can help to accelerate the project schedule through a variety of methods. In particular, active owner involvement during the design review process can minimize typical delays and allow design packages to be developed and put out for bid much more quickly. For one project, which consisted of the addition of an eight-classroom space to an operational elementary school, the work needed to be completed one year earlier than originally planned. The school district was willing to pursue an atypical project delivery method, CM in a Design Build arrangement, in order to accelerate the design and construction process. On another project, a large pharmaceutical company needed to consolidate almost 1,000 employees in a given office space, requiring over twenty consecutive interior renovation projects in a given six-month window. In this case, the owner supported the construction efforts by keeping maintenance and facilities management staff actively involved. Without an engaged owner, it is likely that these project teams would not have had these schedule acceleration options available to them.

7.5.5 Relationship Building

By the end of a project, a project team with an engaged owner generally has developed a greater relationship with the end user than teams with an inactive owner would. The development of a stronger bond between the project team and the owner has benefits for all parties. Builders can

[14] Carr, Tim. (23 January 2012). Heery International. (A. Ward, Interviewer)

leverage this relationship to negotiate future work, and owners have the benefit of being familiar with a particular team and its process.

In the architecture, engineering, and construction (AEC) industry, relationships are critical. By being actively involved in the design and construction process, an engaged owner sees several benefits that a typical owner may not see. Perhaps the greatest benefit is the knowledge of the process that an engaged owner gains, which is an advantage that can be directly applied to similar tasks in the future.

Because of the importance of relationships in the AEC industry, project team members must use carefully planned and executed strategies to ensure that a strong positive relationship with the owner has been established by the conclusion of a project. Many of these strategies revolve around maintaining regular communication with the owner. Building on a foundation of a strong communication and project management process, a project team should continue to develop the confidence of the owner in the abilities of the team and its members. Regular and accurate reporting of project progress and observable management of scope, schedule, and budget help to provide constant assurance to the owner that the project is on course to be successful. Creating a clear pathway for the project to follow as part of early planning phases is a powerful tool for fostering owner confidence in the project team for future work, provided that the team can follow this road map.

7.6 Integration Failures

In relation to disciplines such as building envelope and mechanical systems that are critical to the success of high performance retrofit projects, there are several significant problems that can occur during design and construction that can have significant negative impacts on the final product delivered to the owner. Breakdowns in process, communication, or integration efforts on these highly integrated projects, as well as lack of forethought in the initial project design, can ultimately lead to a less-than-optimal project value, and must therefore be identified and avoided by project teams.

7.6.1 Communication

In some cases, owners seek the advice of builders or commissioning agents to analyze building envelope and mechanical systems in existing property and recommend a course of action for retrofit, but are unprepared for the cost and schedule impacts of these recommendations. Although the blame for this lack of preparation largely falls with the owner, the contractor or commissioning agent should take the time to familiarize the owner with some of the potential retrofit work that may be required prior to beginning building analysis efforts.[15]

7.6.2 Integration

For retrofit projects focused on optimizing energy performance in an existing building, the owner must be fully integrated into the process from the beginning. Without strong support from the owner, projects like this often face greater challenges that limit the final product. For example,

[15] Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

an owner who is not integrated into the process may not be willing to pay higher up-front costs for building envelope or mechanical systems that provide the best energy performance, especially when portions of the existing building envelope or mechanical systems are still operating at an "acceptable" level. Renovation projects like this also face occupancy and staging issues, due to the fact that the majority of these buildings must remain occupied while components or entire systems are replaced or upgraded extensively.

7.6.3 Initial Design and Construction

Retrofits, especially those with the intent to provide drastic improvement to the overall energy performance of a building, are limited substantially by the initial design and construction of the building. If the original owner, who may or may not still own the property at the time of the retrofit project, did not have the forethought to include passive energy efficiency features or a "Design for Flexibility" (DfF) methodology, the number of cost-effective retrofit options can be significantly reduced. Examples of these DfF strategies include placing major equipment in locations where they can be easily accessed, removed, and replaced, rather than trapping a large piece of equipment in the basement of the building; placing MEP and data pathways such that they can be easily accessed, rerouted, and upgraded; designing roof systems to allow for future photovoltaic arrays or easy re-roofing.[16] If an owner does not plan for scenarios like these, a retrofit project aimed at improving the energy performance of the building will be limited and may become too expensive to be feasible.

Owner education in regards to the long-term effects of early decisions is critical. Passive energy efficiency features, including site orientation, taking advantage of thermal mass, and laying out spaces to enable natural ventilation, are all but impossible to change after the initial design and construction of a building. Passive features such as shading devices and light shelves are easier to add to an existing building, but are not as beneficial as previously mentioned features. The owner must be fully educated on the long-term effects of decisions made early in the design process, and must also maintain active involvement in this phase of the process to facilitate optimal results.

Unfortunately, most owners have a relatively limited and basic understanding of building systems and their interactions with one another. These owners tend to think only of the relative costs of each building system. Additionally, each design professional and trade is concerned only with the systems they are responsible for, resulting in efforts to preserve or even expand their scope of work, rather than efforts to improve the project as a whole. For example, the owner (or even project team) may not realize that an increase of $10 per square foot to upgrade to a more efficient skin can result in significant MEP and structural cost savings by decreasing the mechanical loads, allowing for equipment to be downsized (generating a MEP cost savings), which in turn reduces the load of the mechanical equipment on the structural system, allowing for structural members to be downsized as well (generating a structural cost savings).[17]

Continuing with this example, it is possible that a high-performance building envelope can allow for the mechanical system to not only be downsized, but also be decentralized. Placing smaller

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[16] Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)
[17] Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

units throughout the building rather than a few large, centrally located units may further decrease mechanical and structural system costs while allowing for improved future flexibility within the building spaces. If the original mechanical equipment were to be placed on the roof, this change would offer the owner essentially an extra floor for rooftop gardens and other features at no additional cost (arguably at a cost savings).

The construction industry is coming to realize that this style of thinking to optimize the project as a whole, rather than simply optimizing its pieces, is a much needed step in the right direction. Some project teams are beginning to pursue Integrated Project Delivery (IPD) as a preferred delivery method (over Design-Build, CM-at-Risk, etc.). These IPD projects are supported by unique contracting in which all major players, including subcontractors, sign a single contract and agree to share in the risk and reward of the success of the project. This contracting method helps to encourage all parties to generate project savings by rewarding them with a share of the savings. For example, if a mechanical contractor can reduce their scope and save the project hundreds of thousands or even millions of dollars, the mechanical contractor would be entitled to a proportionate share of that savings without actually performing any work. IPD is sometimes described as the next step after Design-Build, primarily because the owner must be a team player and be actively involved in the design and construction phases, rather than act as an entirely detached entity who has little or no incentive to be an active team player.

Aside from the owner, the architect is one of the most influential people on a project team, and must therefore act in accordance with the critical nature of his or her decisions. In one example, a community college in California had developed programming requirements, such as types of spaces, desired square footage, etc., for a new athletic building to be built on their campus. Additionally, the college wanted this new athletic building to be a net-zero energy building, meaning that the total energy used by the building would be no more than the total energy produced by the building. One major key for successfully delivering a net-zero energy building is to minimize energy demands by leveraging thermal mass and daylighting, in addition to other strategies. Early in the project, the architect developed three different layouts to present to the owner, each of which addressed space types, square footage requirements, relationships to an adjacent plaza, how the architect envisioned the building being used, and other goals that were important to the architect. As part of the effort to achieve net-zero, a daylighting consultant was brought in early on in the project to provide numerous guidelines to the architect. These guidelines generally described how the building spaces should be laid out to optimize daylighting performance, but were ignored almost entirely in favor of the previously described goals of the architect.[18]

In this example, the project team developed energy models after the architect had finished the three layouts. This analysis, which was based on building layout and orientation only, demonstrated an $800,000 range for the three scenarios over the planned thirty-year lifespan period. The best of these three options could have been further improved through consideration of the daylighting guidelines, resulting in significant energy savings. In other words, if the project team used the least energy efficient building layout, which added an extra $800,000 in energy costs over thirty years, even the best available and most energy efficient building enclosure systems would only reduce that added cost by $200,000. Clearly, energy performance

[18] Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

in this athletic building would have been improved tremendously if proper consideration had been given to the guidelines presented by the daylighting consultant. It is critical to understand that changing the footprint or layout of the building can produce benefits far greater than the benefits of advanced building envelope and mechanical system technologies.

7.7 Applicability to GOC

Like most projects, the Government Office Center renovation project would stand to benefit from a more actively engaged owner. An engaged owner would have improved decision making for the project through faster turnaround time and a stronger push for lifecycle systems optimization. Changes to project scope based on funding or other concerns would occur less frequently and would be smaller in magnitude if the owner were more actively involved in the step by step planning and design process from start to finish. Additionally, opportunities for schedule acceleration could have been explored more thoroughly and perhaps implemented on the Government Office Center project, which in turn would deliver a completed product to GSA much sooner, and may additionally reduce costs. This schedule and project savings could have then been reinvested into the project to add more value to the project, such as through building integrated photovoltaics as discussed in the previous analysis or through progressive collapse prevention systems as discussed in the analysis to follow.

7.8 Recommendation and Conclusion

Active owner involvement throughout the design and construction process is critical to the successful delivery of high performance retrofit projects. Because owners are not always able to provide space as a temporary substitute, demolition and construction work must be phased, as seen on the Government Office Center project. Phasing the work increases the complexity of the project, resulting in adding cost and schedule requirements for the owner. Therefore, it is important that the owner be actively involved in the entire process in order to support decision making for the project team and to minimize the disruptions impacting the building occupants.

The Government Office Center would have gained substantial benefits from having an owner who was more actively engaged throughout the design and planning process, as described in section 7.5. This project most likely had tremendous opportunity to be a model for future high performance renovation projects, especially with a large number of projects similar to the Government Office Center renovation coming up in the near future. Some missed opportunities that would have added tremendous value to the project were highlighted in Analysis #2 and would have been within reach for the project team had the owner been more actively involved.

7.9 MAE Requirement

The integrated undergraduate and graduate requirement for the senior thesis was met in part by utilizing course material covered in AE 572: Project Development and Delivery Planning for this analysis. Specifically, an understanding of Integrated Project Delivery and the importance of relationships and collaboration in the successful delivery of complex projects provided the foundation that acted as a driving force for this analysis.

8.0 ANALYSIS #4: PROGRESSIVE COLLAPSE

8.1 Problem Identification

The federal government implemented progressive collapse prevention requirements for government buildings decades after the original construction of the Government Office Center. As a result, the building will eventually require structural upgrades to meet these regulations. Considering the need to maintain continuous occupancy during the current renovation project, it can be assumed that the installation of the progressive collapse prevention mechanisms will face the same constraints. Although these constraints would likely impact the cost and time needed to complete the work, the impact could perhaps be mitigated if this system is installed as part of the scope of the current renovation project.

8.2 Research Goal

The purpose of this analysis is to analyze the cost and schedule impacts of adding a progressive collapse system to the scope of this renovation project as compared to incorporating this system into a future project.

8.3 Methodology

- Develop a working knowledge of the basics of progressive collapse prevention methods used in retrofit projects
- Design a theoretical section, such as a column or bay
- Determine total material and labor requirements by extrapolating the designed theoretical section as necessary across the building
- Analyze the cost and schedule impacts of installing this system separately, during the current renovation project, or during a future renovation project, as well as the implications of each choice
- Determine the value of having this system

8.4 Background Information

Progressive collapse can be defined as an incident where a specific, localized failure of a structural component results in the collapse of additional adjacent building elements, causing a disproportionate amount of total damage in comparison to the initial failure event. Progressive collapse prevention measures have become increasingly commonplace in the construction industry. Structural engineers for new construction projects can account for recent federal guidelines and requirements in their designs. However, older buildings that were built prior to the implementation of federal progressive collapse prevention requirements will eventually need to upgrade their structural systems to comply with these regulations. These existing buildings are conducive to the use of the Tie Force method outlined in the *Unified Facilities Criteria (UFC): Design of Buildings to Resist Progressive Collapse*. Using this method, structural elements are tied together, most commonly with cable systems, to provide the necessary support in the event of a localized structural failure.

Quantifiable benefits can be observed when considering the implementation of progressive collapse prevention measures as part of the scope of the current Government Office Center renovation project as compared to the next major renovation and modernization of the building. However, inclusion of a progressive collapse prevention upgrade to the existing structural system will unquestionably increase the cost and construction duration beyond what is planned for the current renovation project.

The following individuals have earned great appreciation for their instrumental roles in the completion of this analysis:

Ryan Solnosky………… AE Graduate Student
Mark Taylor…………... Nitterhouse Concrete Products, Inc.

8.5 Preliminary Progressive Collapse Prevention System Design - Structural (Breadth Topic 2)

*See Appendix J for additional notes and calculations

Because the Government Office Center project is a major renovation of an existing building, post-tensioning (PT) cables will be used to resist progressive collapse through the Tie Force method. These tendons will be comprised of 0.6" seven-wire strands of 270ksi (thousand pounds per square inch) capacity that are rated for low-relaxation.[14] Due to building symmetry, two areas were analyzed from the second floor to the roof, as shown in Figure 37 below, in order to determine the loads that would be applied to this cable system. The results of this part of the analysis were extrapolated across each floor. The first floor is a slab on grade, and therefore does not need to be supported by a supplementary progressive collapse prevention mechanism.

[14] *DYWIDAG Strand Anchor Systems.* DYWIDAG-Systems International. PDF.

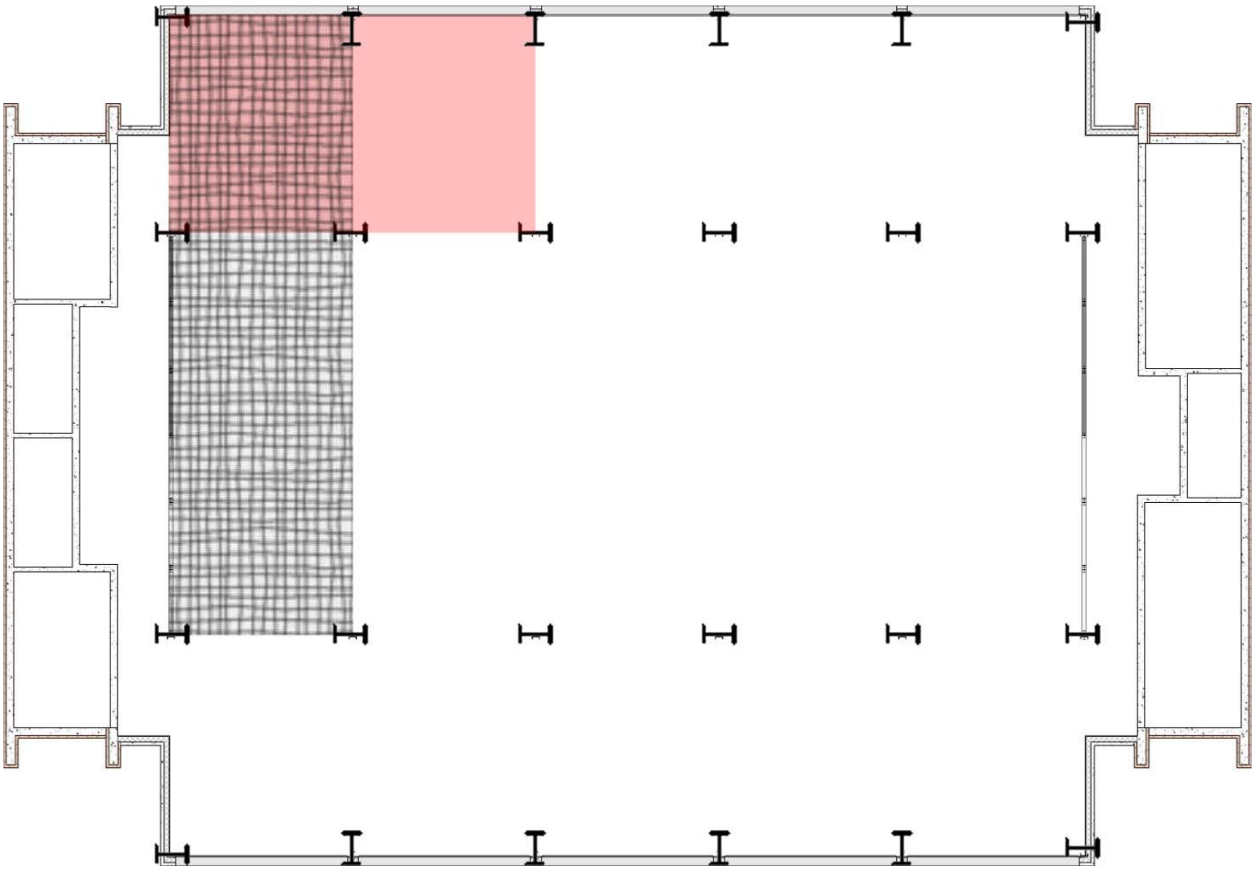


Figure 37: Areas analyzed for progressive collapse prevention design

The area tinted with a solid red color represents the tributary area supported by the PT cable system, provided that a non-corner column fails on the North façade. Similarly, the area indicated by the blue hatch represents the tributary area supported by the PT cable system if a non-corner column fails on the West façade of the building. Loads distributed over the area are assumed to act as a point load on the tendons at the location of the failed column.

The typical floor consisted of a composite 3” metal deck with 2.5” of lightweight concrete. Supporting the floors is a series of wide flange beams and custom-built trusses. In addition to these dead loads, this building is designed for an 80psf (pound per square foot) live load and 30psf snow load. As part of this analysis, an additional 15psf per floor was included to account for mechanical, electrical, and plumbing loads.

Tensile loads on the tendons are calculated based on the deflection of the floors during a structural failure incident. Initially, the deflection of each floor due to a failure of an exterior column and the resulting failure of the beams that transfer load to the column was calculated based on the moment capacity of the beams as listed in the AISC Steel Manual, but the deflections found were very small. Consequently, the loading placed on the tendons in order to keep the floor from deflecting further would greatly exceed the feasible limits of this type of structural retrofit. Therefore, it was assumed for the purposes of this analysis that floor deflection beyond 2 feet should be prevented by the prestressing tendons. This assumption allowed for a more reasonable configuration of steel tendons to be added to the existing structure.

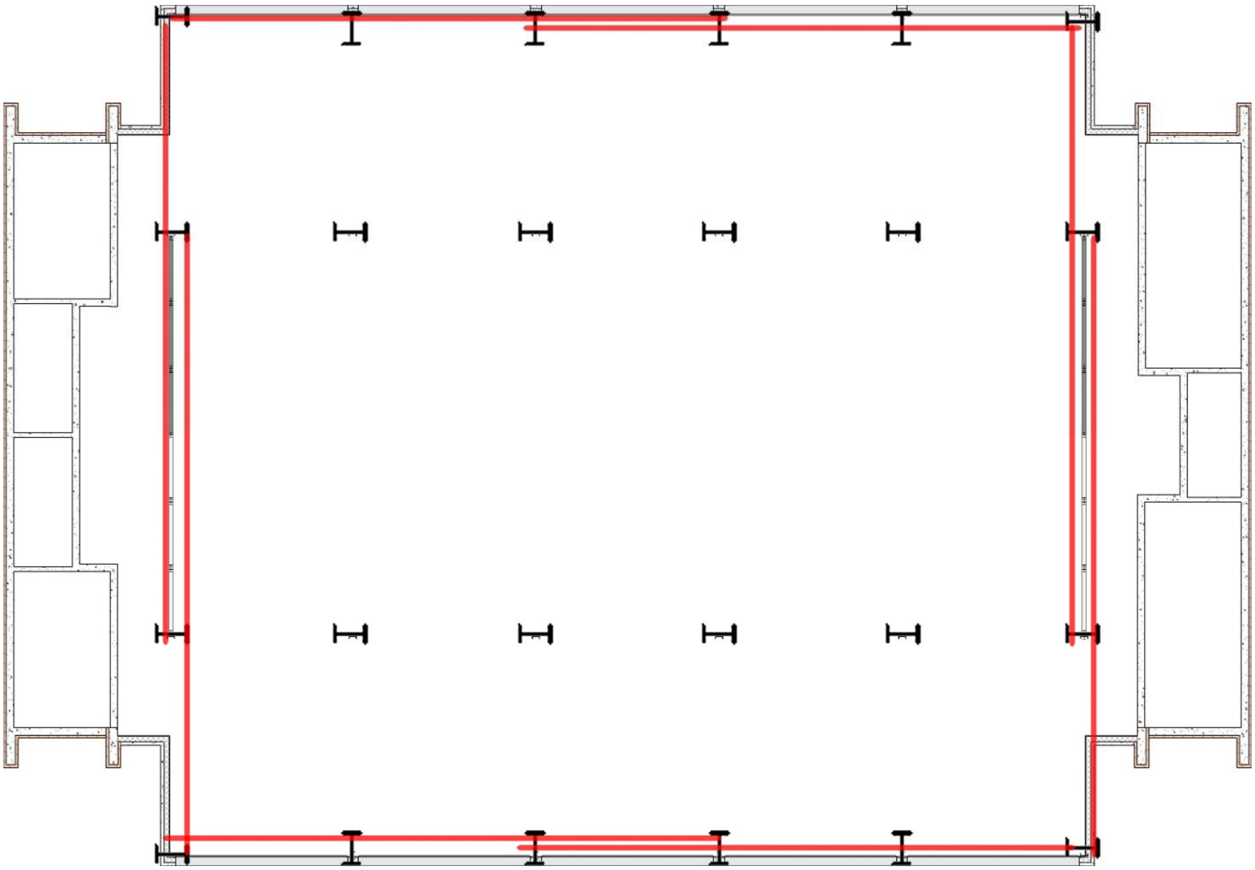


Figure 38: Diagram of tendon placement on typical floor

As shown in Figure 38 above, the proposed steel tendons would be arranged such that each tendon is less than 100 feet in length. In addition, a one-bay overlap of tendons would be used in order to truly protect the floor areas supported by a non-corner exterior column.

8.6 Calculation Process

While the bulk of calculations were performed in Microsoft Excel, the calculation process was developed through hand computation.

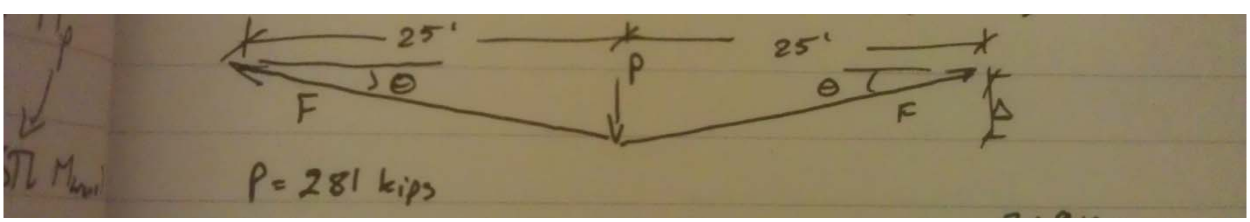


Figure 39: Image of hand-drawn diagram for sizing steel tendons

After loads were determined for each floor area, the loads were converted into point loads which act upon the tendons after the failure of a supporting column. In Figure 39 shown above, this load on the roof tendon if a column on the North façade fails equates to 281 kips. Using basic statics and trigonometry, the tension within the tendon can be easily determined. In the case of the North façade, bays are 25 feet wide, and allowable deflection (as previously discussed) is 2 feet. This allows for load demand to be determined, which in turn can be used to determine the number of strands will be needed based on material properties. In this example, the tendons on the North façade at the roof level require a minimum of 32 strands, including an assumed 5% additional loading due to debris falling from one floor to the next, which is important for floors below the roof level. This minimum of 32 strands is then rounded up to a typical tendon sizing, which in this case is a 37 strand tendon. Therefore, a 37 strand tendon will be used to protect the roof level on the North façade from progressive collapse.

8.7 Cost Implications

According to RS Means Building Construction Cost Data 2012, labor requirements (per pound) decrease as the size of a prestressing steel tendon increases. However, due to the challenges of installation associated with the Government Office Center renovation project, this economy of scale is ignored to account for these challenges. The resulting labor requirements equate to 4,527 work-hours to install this system. At an assumed ironworker labor rate of $40 per hour, the labor for this system will cost $181,080.

Based on pricing data from Mark Taylor of Nitterhouse Concrete Products, Inc., 270ksi low-relaxation 0.6" 7-wire strands have a material cost of $0.425 per foot. This unit price brings the total material cost to $256,062.50, with a total material and installation cost of $437,142.50.

8.8 Timing Implications

There are several factors to consider when deciding on an appropriate time to install this progressive collapse prevention system. This analysis aims to evaluate three construction scenarios based on these factors such that an appropriate recommendation can be made.

A major construction challenge for the current Government Office Center renovation project is the fact that it must remain operational for the building occupants within. Substantial coordination efforts took place in order to create a clear plan for tenant phasing and relocation. Because the building must remain occupied during this construction project, the Government Office Center would almost certainly remain occupied during future renovations as well. This issue effectively eliminates the installation of a progressive collapse prevention system during a separate and individual project as a feasible option, due to the cost of performing a tenant phasing analysis on top of general conditions costs and overall schedule duration. Therefore, this system should either be installed in the current renovation or the next major renovation of the Government Office Center.

The installation of this system during the current renovation project would have a variety of impacts. First, the added cost of the system may push the project beyond the available funds that were originally budgeted for the renovation. In addition, the installation of this progressive collapse prevention system would almost certainly extend the project schedule. However, because the Government Office Center was built long before government regulations required these systems, the inclusion of this work in the current project would allow the building to meet these regulations as quickly as possible.

If the decision is made to install the steel tendons as part of the next major renovation project, the Government Office Center will likely have to wait twenty to forty years before it can meet the current standards for progressive collapse resistance. From the perspective of the building occupants, this would not be ideal. In addition, costs can be almost guaranteed to rise in the next forty years. A conservative 2% yearly inflation rate would more than double the cost of installing this system in forty years, in addition to the likelihood of a better economy that allows installers to pursue larger profit margins.

8.9 Recommendation and Conclusion

By adding 270ksi low-relaxation prestressing steel tendons to the existing structural system, the building would be more equipped to resist progressive collapse in the event that an exterior column failed. These tendons would be less than 100 feet in length, requiring a one-bay overlap on each façade. Based on the previously discussed timing implications in section 8.8, the installation of this system would be most appropriate if added to the current scope of work of the Government Office Center renovation project, and would cost $437,142.50, as shown in section 8.7.

9.0 RECOMMENDATIONS AND CONCLUSIONS

The Government Office Center renovation project has been examined and evaluated extensively during the fall and spring semesters as part of a senior thesis project aimed at the importance of an engaged owner on complex construction projects, such as high performance retrofit projects. This focus is broken down into four key research and analysis topics which are included within this final thesis report. It is important to note that these analyses should be considered theoretical in nature, and that the conclusions drawn do not suggest perceived errors on the part of any member of the project team.

As shown in section 7.0, the benefits to having an engaged owner on any project are numerous and significant. For example, an actively engaged owner will provide a construction project with improved decision making processes, resulting in faster and more refined decision turnaround. The high involvement level of the owner allows him or her to be more educated on available options and their potential impacts on the final product. This in turn promotes optimization of the entire project over the optimization of specific parts or systems, which plagues and ultimately limits the potential of most projects. For the Government Office Center, this kind of optimization includes massive schedule acceleration as seen in the SIPS analysis in section 6.5, as well as the incorporation of a building integrated photovoltaic curtain wall system that pays back its marginal cost in less than two years as seen in section 6.6. If budget is limited, as it almost always is, the value of these changes can be reinvested into additional scopes of work that are desired but were initially cut from the program, such as the installation of a progressive collapse prevention system as described in section 8.0.

The analysis on the implementation of Building Information Modeling for facilities management purposes as described in section 5.0 demonstrates some of the ways in which information on equipment and other components within the building can be easily carried through the design and construction process and ultimately be delivered to the owner in a very useful manner. Because this type of BIM use is not typical or well-known, most owners would not be particularly comfortable in pursuing it. However, an engaged owner would understand how this implementation of BIM could directly help their facilities management personnel in their daily jobs and would therefore be supportive in its development process. The GSA is aware of the potential value of BIM for Facilities Management, and has even published a guide on the topic, but is inherently limited by bureaucratic protocol. As a result, this experimental BIM application will most likely need to be tested and proven within the private market before government agencies will pay for this service on their own projects.

As a whole, this thesis report points very strongly to the importance of an engaged owner on a project like the Government Office Center, and identifies major areas of improvement that could have been realized under more ideal circumstances, including schedule savings, additional photovoltaic electricity generation, and a progressive collapse prevention system – all while actually reducing the total project cost.

10.0 RESOURCES

Amt, Michelle. (16 January 2012). William McDonough + Partners. (A. Ward, Interviewer)

- This interview helped to establish an understanding of key considerations for a building integrated photovoltaic curtain wall.

BIM Guide for Facility Management. GSA. PDF.

- This document discusses the value of BIM for FM and current case studies.

Bolt, David. (10 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

- This interview provided necessary background information on the GOC schedule and need for BIM on site.

Building Integrated Photovoltaics. Onyx Solar. PDF.

- This document provides basic performance data for the proposed photovoltaic curtain wall system.

Carr, Tim. (23 January 2012). Heery International. (A. Ward, Interviewer)

- This interview helped to define key benefits to having an engaged owner on a project.

DeVito, Steve. (17 January 2012). GSA. (A. Ward, Interviewer)

- This interview helped to define the value of BIM for FM.

Dubler, Craig. (20 January 2012). Penn State OPP. (A. Ward, Interviewer)

- This interview helped to define the value of BIM for FM.

DYWIDAG Strand Anchor Systems. DYWIDAG-Systems International. PDF.

- This document provided data on the steel tendons used in the progressive collapse prevention system design.

Konchar, Mark. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

- This interview supported the engaged owner research effort.

Mounting Rack: Sunny Tower-US ST6US/ST36/ST42/ST48 Installation Guide. SMA. PDF.

- This document provides technical data pertinent to the photovoltaic curtain wall design.

Phelps, Andreas. (17 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

- This interview supported the engaged owner research effort.

Reece, Jason. (16 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

- This interview supported the BIM implementation analysis.

"Short Interval Production Schedule (SIPS)." *Pentagon Renovation Program*. Web. 19 Jan. 2012. <http://renovation.pentagon.mil/wedge2-5/sips.htm>.

- This website includes the non-traditional SIPS example image used.

Solnosky, Ryan. (24 January 2012). Penn State AE Graduate Student. (A. Ward, Interviewer)

- This interview provided the understanding needed to conduct the progressive collapse prevention design.

Top Ways Ideate BIMLink Saves Hours, Days – Even Weeks. Ideate. PDF.

- This document identifies some of the key benefits of Ideate BIMLink.

Unified Facilities Criteria - Design of Buildings to Resist Progressive Collapse. Department of Defense. PDF.

- This document contains substantial information and guidelines for progressive collapse prevention system design.

Whalen, Jesse. (19 January 2012). Balfour Beatty Construction. (A. Ward, Interviewer)

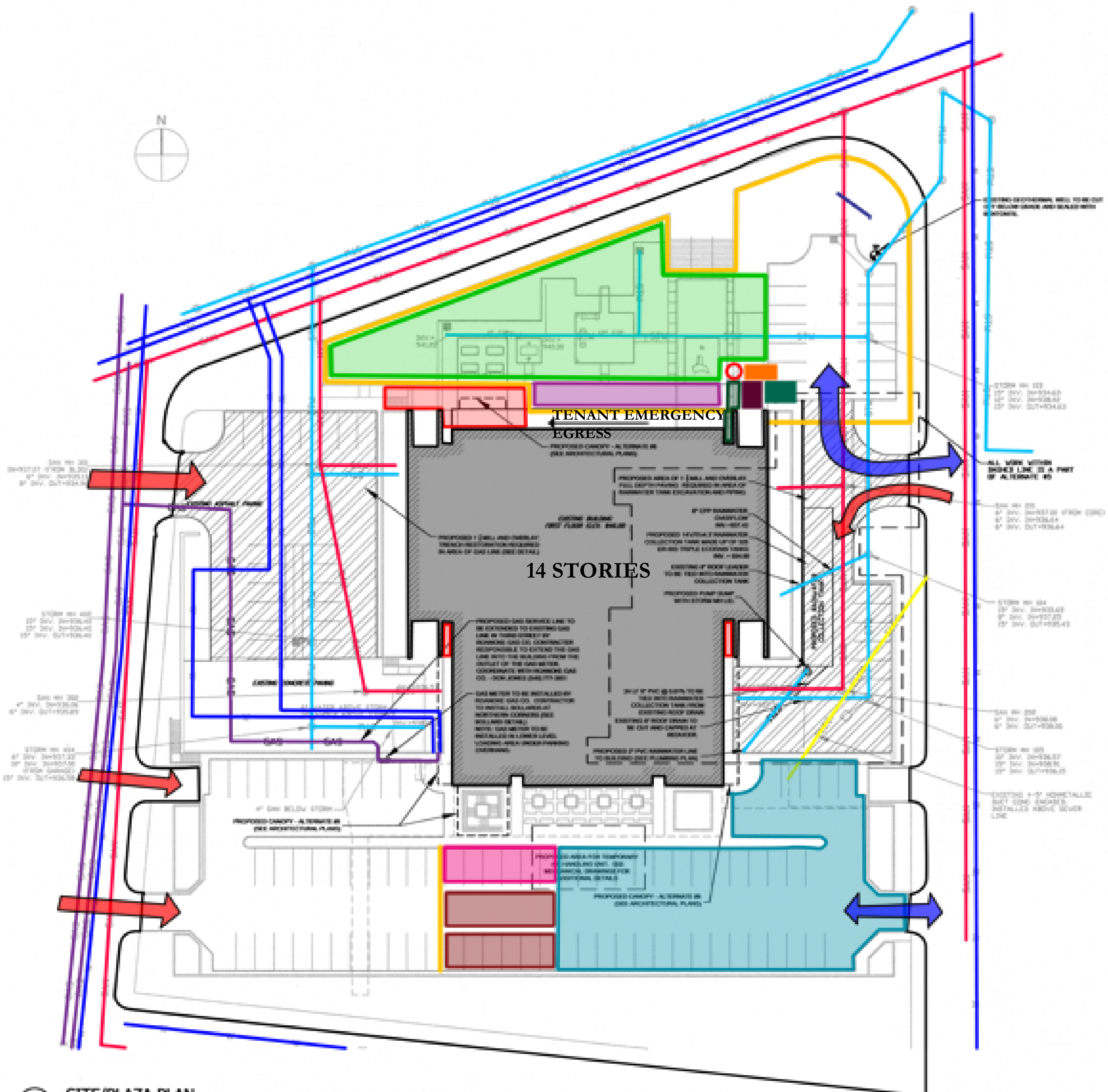
- This interview supported the BIM implementation analysis.

APPENDIX A –MAE REQUIREMENTS

MAE Requirements

The MAE requirements of this thesis project were accomplished through the BIM implementation analysis, SIPS study, photovoltaic curtain wall analysis, and the integrated processes analysis. Methods learned in AE 597F (Virtual Facilities Prototyping) were applied to the development of models for facilities management purposes. Concepts from AE 570 (Production Management in Construction) were applied to the implementation of SIPS for activities relating to the curtain wall demolition and replacement, while concepts from AE 897A (Solar Project Development) were applied in the development of the feasibility analysis for the building integrated photovoltaic curtain wall. Finally, information from AE 572 (Project Development and Delivery Planning) provided background knowledge and necessary support for research efforts that evaluated integrated teams and their needs.

APPENDIX B – SITE PLANS



SITE/PLAZA PLAN

LEGEND

- WATER LINE
- STORM SEWER
- SANITARY SEWER
- ELECTRICAL LINE
- GAS LINE
- PROPOSED GAS LINE
- EX. GEOTHERMAL WELL
- PROTECTED HARDSCAPE
- CONSTRUCTION STAGING
- CURTAIN WALL LAYDOWN
- TRAILERS
- TEMP. HVAC UNIT
- LOADING PLATFORM
- MATERIAL HOIST
- DUMPSTER
- TRASH CHUTE
- SCAFFOLD
- COVERED WALKWAY
- PROJECT SIGN
- SITE FENCE
- TENANT ACCESS
- CONSTRUCTION ENTRANCE/EXIT

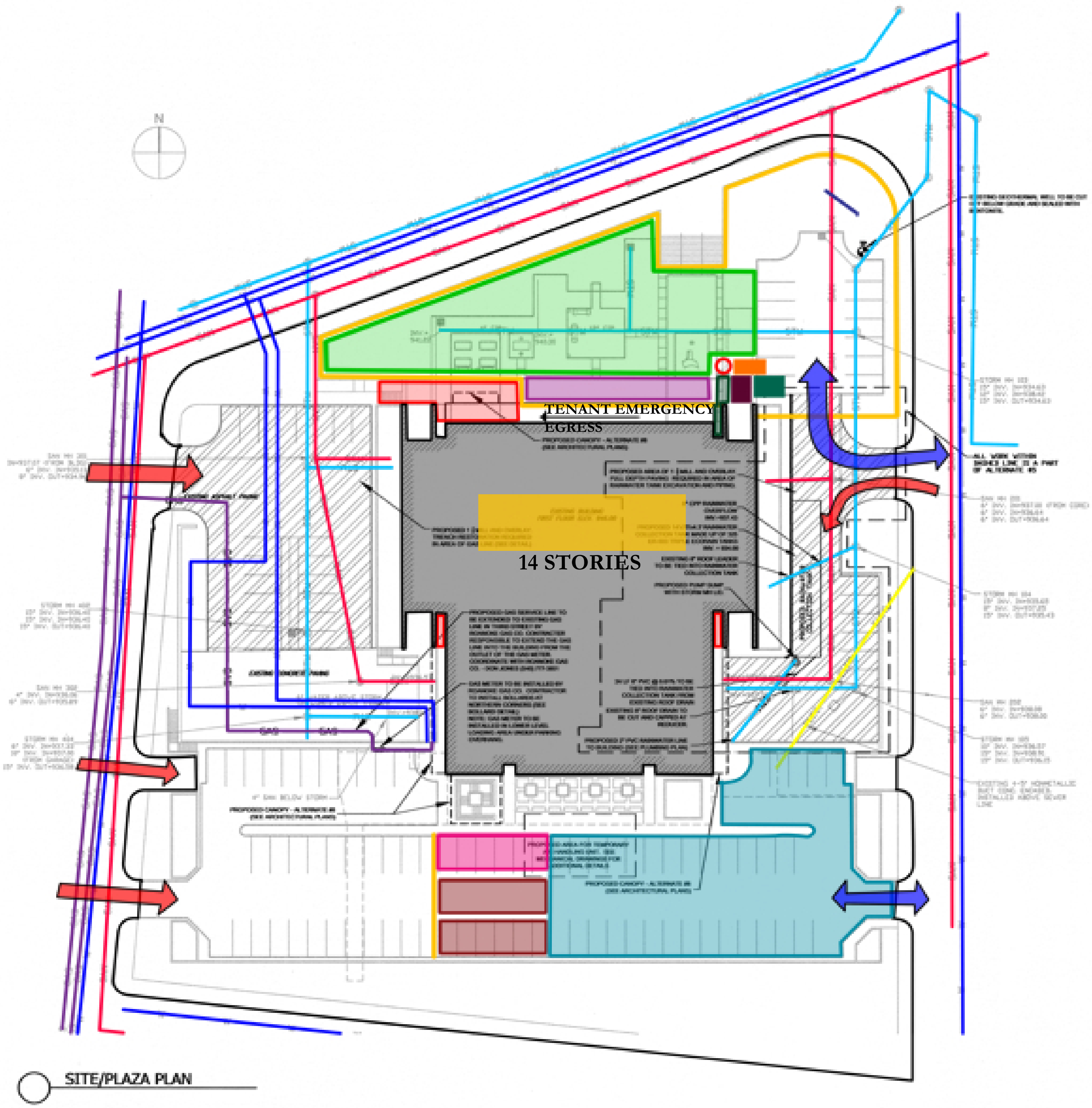
Government Office Center

Mid-Atlantic U.S.

Alexander Ward

23 September 2011

Existing Conditions



LEGEND

- WATER LINE
- STORM SEWER
- SANITARY SEWER
- ELECTRICAL LINE
- GAS LINE
- PROPOSED GAS LINE
- EX. GEOTHERMAL WELL
- PROTECTED HARDSCAPE
- CONSTRUCTION STAGING
- CURTAIN WALL LAYDOWN
- TRAILERS
- TEMP. HVAC UNIT
- LOADING PLATFORM
- MATERIAL HOIST
- DUMPSTER
- TRASH CHUTE
- SCAFFOLD
- COVERED WALKWAY
- PROJECT SIGN
- SITE FENCE
- TENANT ACCESS
- CONSTRUCTION ENTRANCE/EXIT
- MECHANICAL ROOMS LEVELS 1 & 14

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Phase 0 - Mechanical Rooms, Levels 1 and 14

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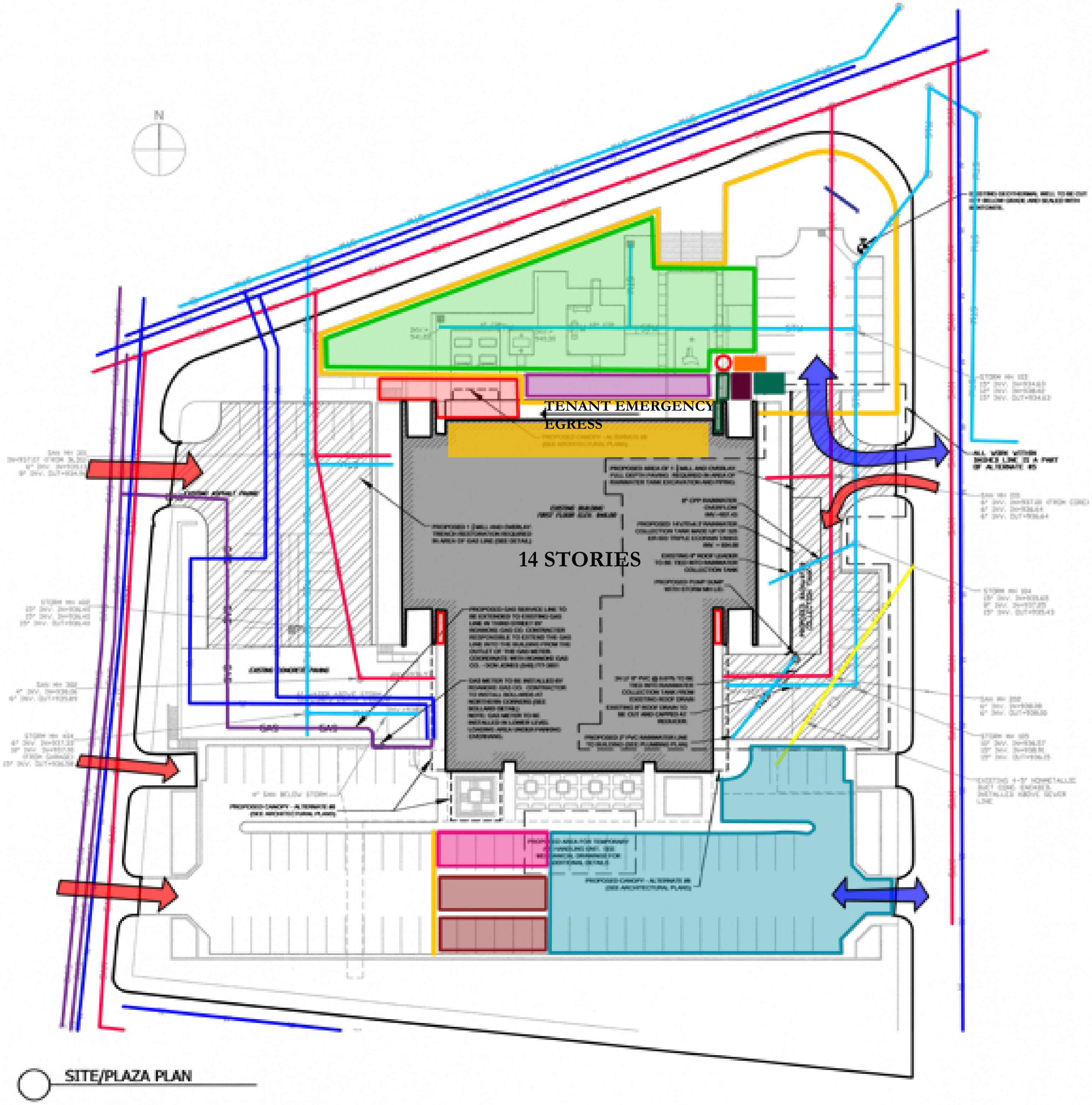
Phase 1A - North Curtain Wall



LEGEND

- WATER LINE
- STORM SEWER
- SANITARY SEWER
- ELECTRICAL LINE
- GAS LINE
- PROPOSED GAS LINE
- EX. GEOTHERMAL WELL
- PROTECTED HARDSCAPE
- CONSTRUCTION STAGING
- CURTAIN WALL LAYDOWN
- TRAILERS
- TEMP. HVAC UNIT
- LOADING PLATFORM
- MATERIAL HOIST
- DUMPSTER
- TRASH CHUTE
- SCAFFOLD
- COVERED WALKWAY
- PROJECT SIGN
- SITE FENCE
- TENANT ACCESS
- CONSTRUCTION ENTRANCE/EXIT
- CURTAIN WALL INST. W/ TEMP WALL

Government
Office Center

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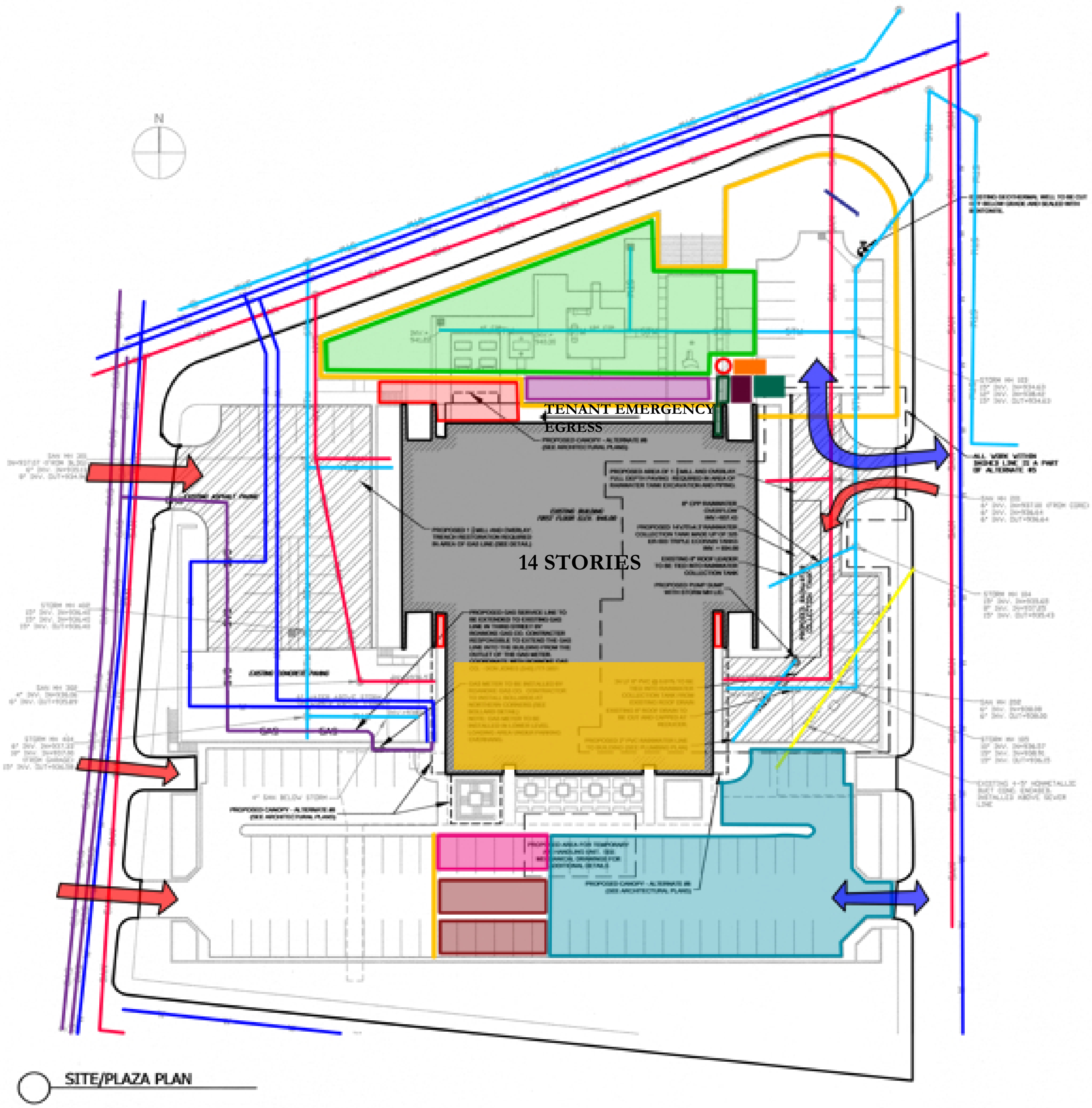
Phase 3 -
Lower Roof &
Solar Panels



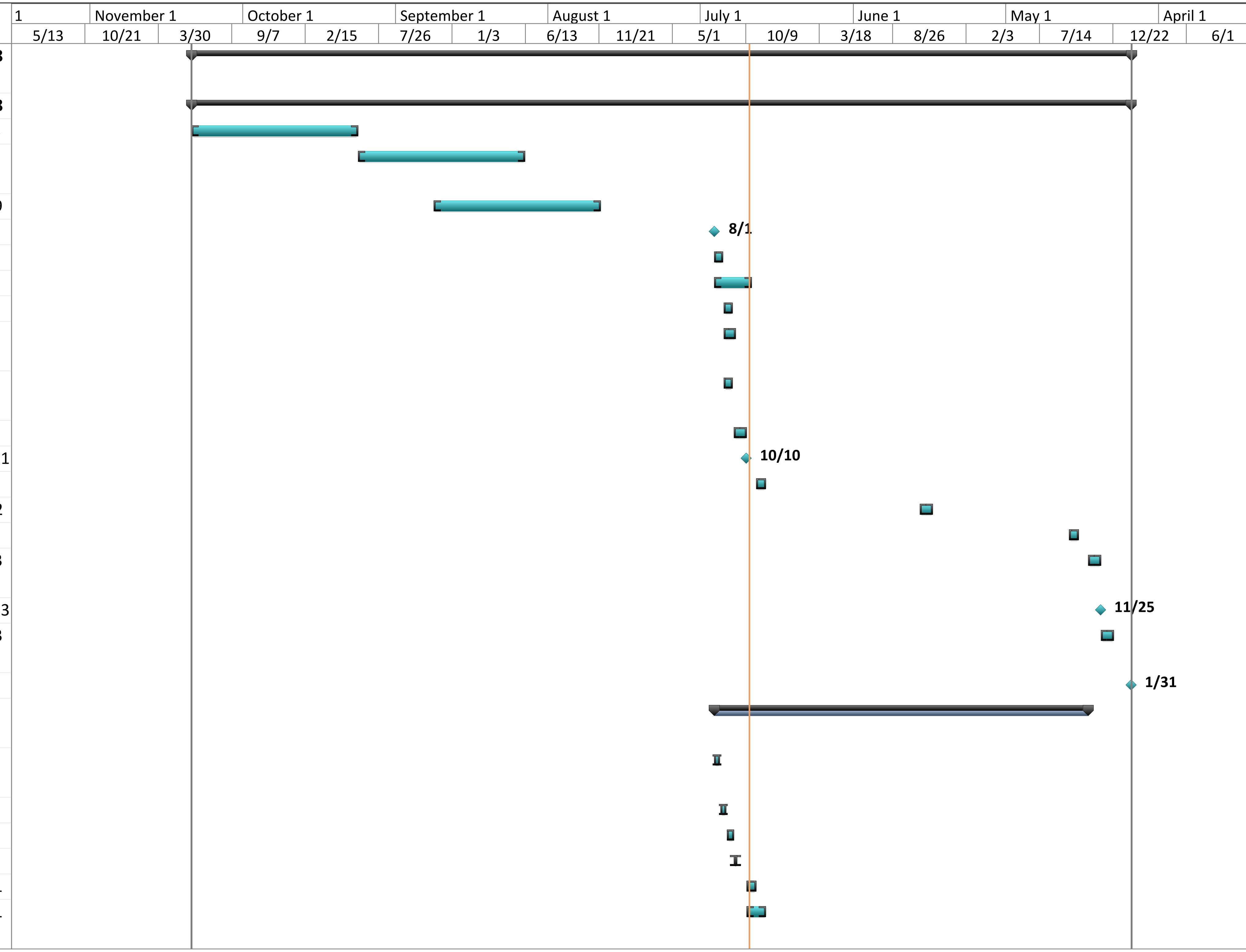
LEGEND

- WATER LINE
- STORM SEWER
- SANITARY SEWER
- ELECTRICAL LINE
- GAS LINE
- PROPOSED GAS LINE
- EX. GEOTHERMAL WELL
- PROTECTED HARDSCAPE
- CONSTRUCTION STAGING
- CURTAIN WALL LAYDOWN
- TRAILERS
- TEMP. HVAC UNIT
- LOADING PLATFORM
- MATERIAL HOIST
- DUMPSTER
- TRASH CHUTE
- SCAFFOLD
- COVERED WALKWAY
- PROJECT SIGN
- SITE FENCE
- TENANT ACCESS
- CONSTRUCTION ENTRANCE/EXIT
- LOWER ROOF AND SOLAR ARRAY

APPENDIX C – DETAILED SCHEDULE

Technical Assignment 1

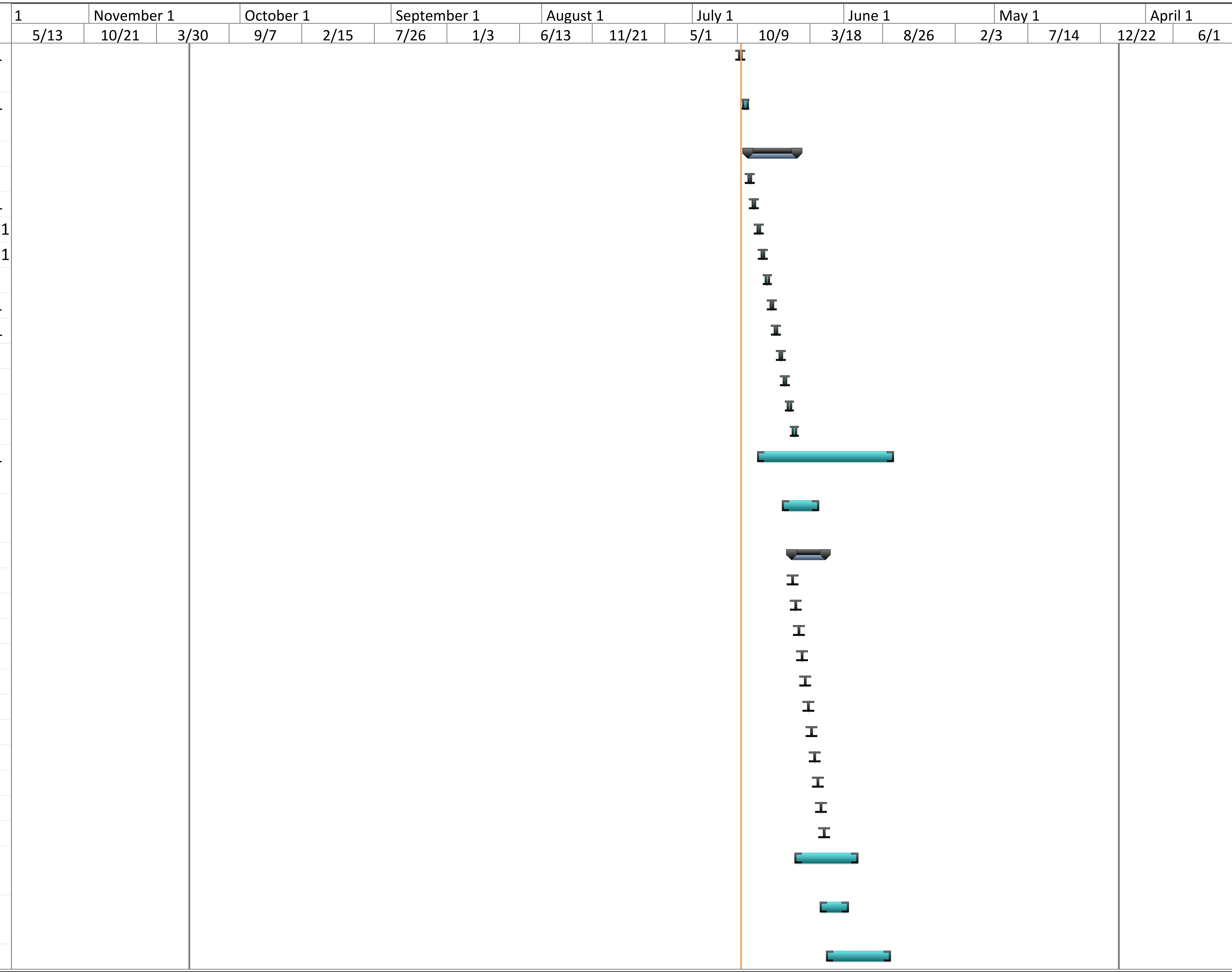
ID	Task Mode	Task Name	Duration	Start
1		**Government Office Center Project Lifecycle**	**1473 days**	**Wed 6/11/08**
2		**General Activities**	**1472 days**	**Wed 6/11/08**
3		Design Phase	261 days	Wed 6/11/08
4		Procurement of Construction Services	262 days	Thu 6/11/09
5		Preconstruction Services	262 days	Tue 11/24/09
6		NTP	0 days	Mon 8/1/11
7		Mobilize	15 days	Mon 8/1/11
8		Material Procurement	60 days	Mon 8/1/11
9		Site Demo & Protection	15 days	Mon 8/22/11
10		Furniture Relocation Level 6-13	20 days	Mon 8/22/11
11		Ceiling Demo at Truss Reinforcement Level 9-13	15 days	Mon 8/22/11
12		Hoist/Chute Erection	20 days	Tue 9/13/11
13		Hoist Available	0 days	Mon 10/10/11
14		Relocate Files	15 days	Tue 11/1/11
15		North Site Restoration	20 days	Thu 10/25/12
16		Remove Hoist	15 days	Tue 9/17/13
17		Curtainwall Punchlist / Final Clean	20 days	Tue 10/29/13
18		Curtainwall Complete	0 days	Mon 11/25/13
19		Northeast Site Restoration	20 days	Tue 11/26/13
20		Project Complete	0 days	Fri 1/31/14
21		**Phase 1A - North Curtain Wall**	**586 days**	**Mon 8/1/11**
22		Relocate Tenants from North Elev Level 3-5, 7, & 8	10 days	Mon 8/1/11
23		Weather Wall at Hoist	10 days	Mon 8/15/11
24		Demo Curtainwall at Hoist	11 days	Mon 8/29/11
25		Core Drill for HWS&R Riser	5 days	Tue 9/13/11
26		Truss Reinforce Level 9-13	15 days	Tue 10/11/11
27		Dust Partition / Weather Wall Level 3-13	30 days	Tue 10/11/11



Project: Tech 2 Detailed Project S
Date: Mon 10/17/11

Legend									
Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

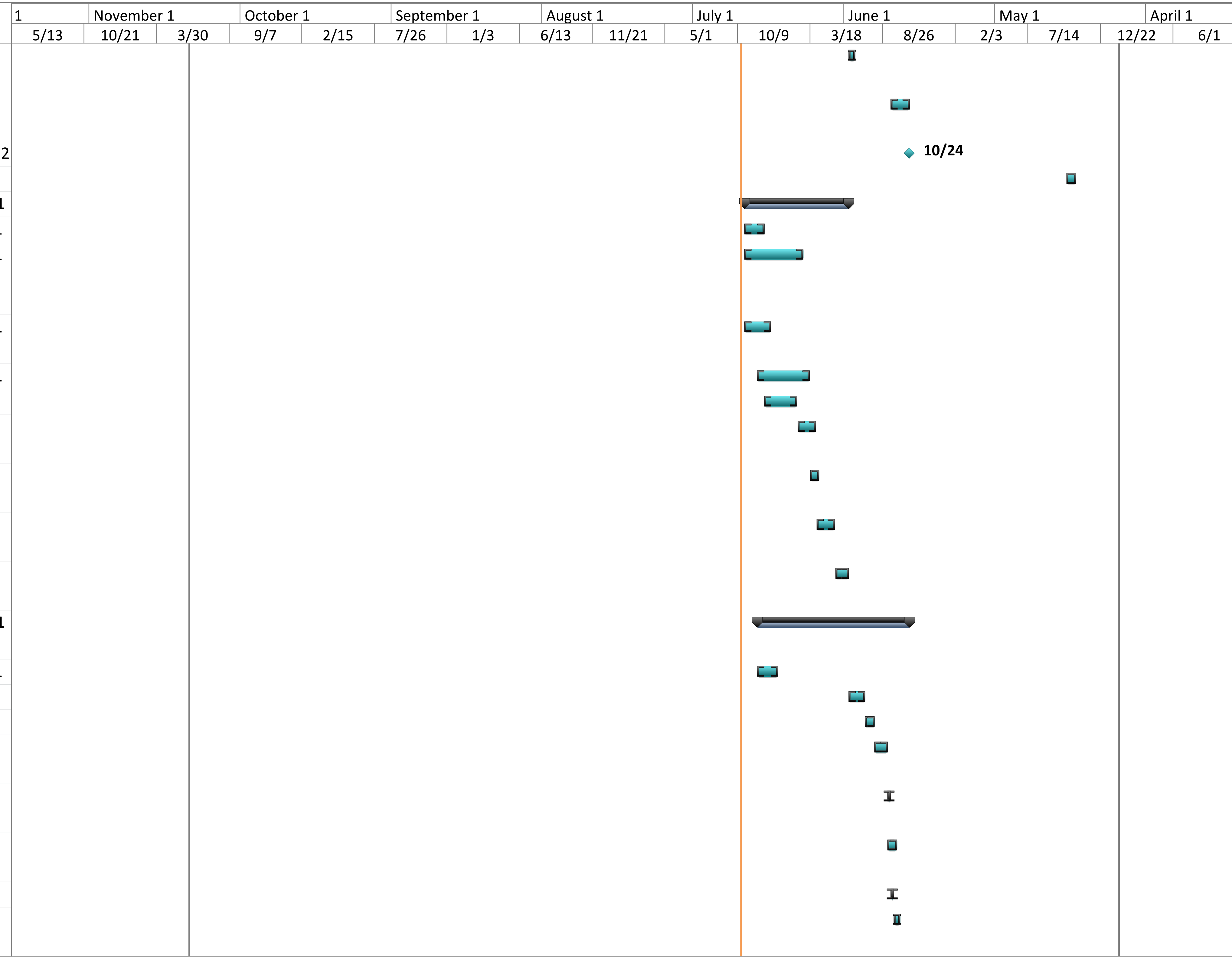
ID	Task Mode	Task Name	Duration	Start
28		Ceiling Removal East Corridor	7 days	Tue 10/11/11
29		HWS&R Riser & Mech. at East Corridor	10 days	Thu 10/20/11
30		**Demo North Curtainwall**	**79 days**	**Tue 11/1/11**
31		Level 13	7 days	Tue 11/1/11
32		Level 12	7 days	Thu 11/10/11
33		Level 11	7 days	Mon 11/21/11
34		Level 10	7 days	Wed 11/30/11
35		Level 9	7 days	Fri 12/9/11
36		Level 8	7 days	Tue 12/20/11
37		Level 7	7 days	Thu 12/29/11
38		Level 6	7 days	Mon 1/9/12
39		Level 5	7 days	Wed 1/18/12
40		Level 4	7 days	Fri 1/27/12
41		Level 3	9 days	Tue 2/7/12
42		Demo / Renovate West Toilet Stack	217 days	Tue 11/22/11
43		Renovate Level 3, 6, 8-10, 12, 13 Center	60 days	Mon 1/16/12
44		**Install North Curtainwall**	**55 days**	**Mon 2/6/12**
45		Level 13	5 days	Mon 2/6/12
46		Level 12	5 days	Mon 2/13/12
47		Level 11	5 days	Mon 2/20/12
48		Level 10	5 days	Mon 2/27/12
49		Level 9	5 days	Mon 3/5/12
50		Level 8	5 days	Mon 3/12/12
51		Level 7	5 days	Mon 3/19/12
52		Level 6	5 days	Mon 3/26/12
53		Level 5	5 days	Mon 4/2/12
54		Level 4	5 days	Mon 4/9/12
55		Level 3	5 days	Mon 4/16/12
56		Frame & Rough-In at Level 3-13 North	101 days	Mon 2/13/12
57		Panels & Louvers at North Elevation Level 14&15	46 days	Mon 4/9/12
58		Finishes Level 3-13 North	103 days	Mon 4/23/12



Project: Tech 2 Detailed Project S
Date: Mon 10/17/11

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

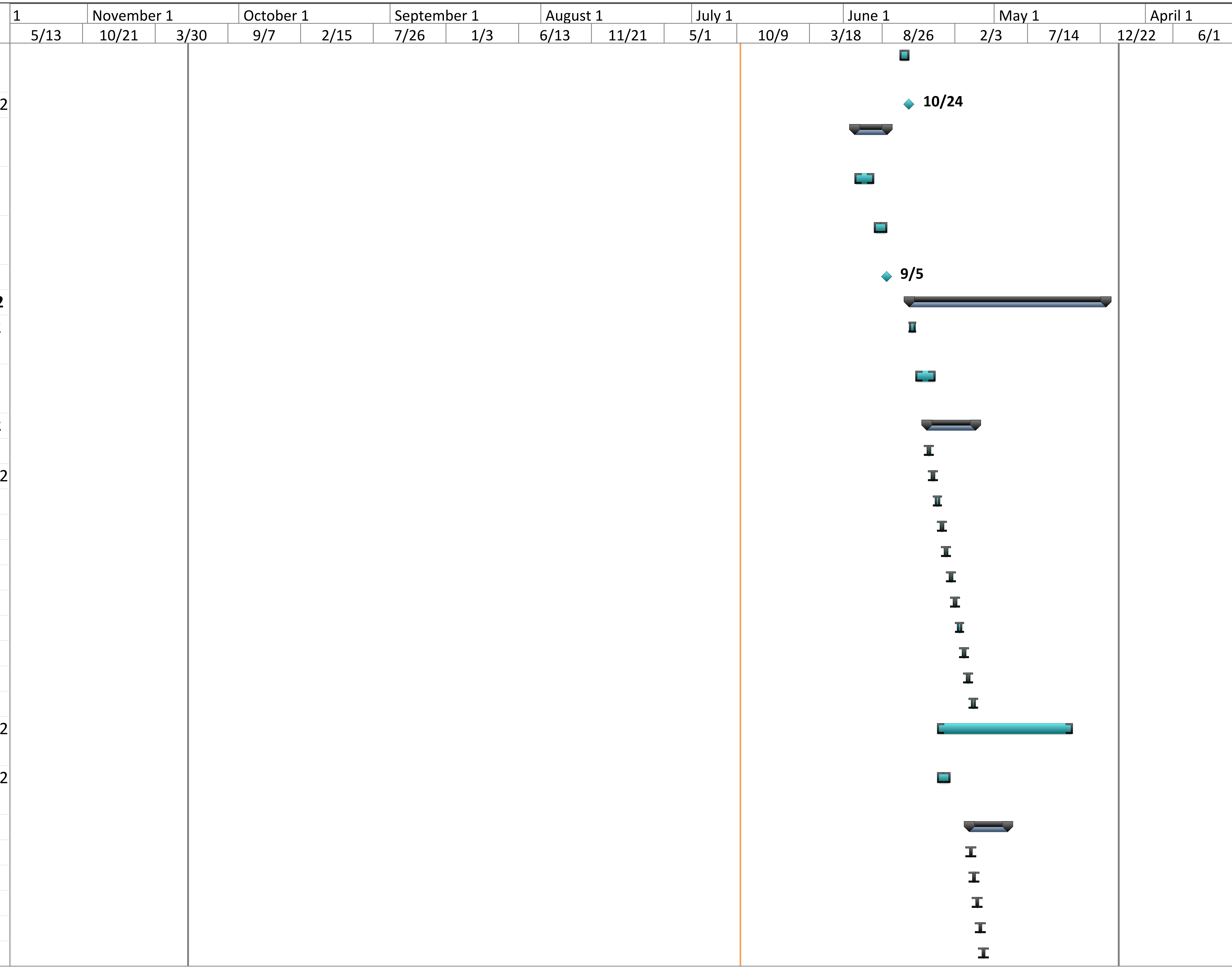
ID		Task Mode	Task Name	Duration	Start
59			Relocate Courts to North Side	10 days	Tue 6/12/12
60			Punchlist / Final Clean Phase 1A	30 days	Thu 9/13/12
61			Phase 1A Complete	0 days	Wed 10/24/12
62			Curtainwall at Hoist	15 days	Tue 10/8/13
63			**Phase 0 - Mechanical Rooms**	**165 days**	**Tue 10/25/11**
64			Temp AHU at Parking Deck	32 days	Tue 10/25/11
65			VAV/Light Fixture Replacement/Retrofit Level 1&2	94 days	Tue 10/25/11
66			Demo/Renovate Toilet Rooms Level 1	42 days	Tue 10/25/11
67			Level 14 MEP Renovation	84 days	Tue 11/22/11
68			Level 1 MEP Renovation	52 days	Thu 12/8/11
69			Level 1 HVAC & Plumbing Piping	30 days	Mon 2/20/12
70			Boiler and ATC Commissioned	15 days	Mon 3/19/12
71			Level 1 Finishes Restoration	30 days	Mon 4/2/12
72			Punchlist / Final Clean Level 1 & 2	21 days	Mon 5/14/12
73			**Phase 1C - Exterior Work Levels 1 and 2**	**242 days**	**Tue 11/22/11**
74			Roofing at Level 15	34 days	Tue 11/22/11
75			Entrance Canopy	26 days	Tue 6/12/12
76			Stone Veneer	15 days	Wed 7/18/12
77			Panels at North Soffit & 2nd Floor	21 days	Wed 8/8/12
78			Reglaze Level 1 North Windows	5 days	Thu 9/6/12
79			North Entry Doors & Revolver	15 days	Thu 9/6/12
80			Windows Level 2 North	5 days	Thu 9/13/12
81			Restore Finishes Level 2 North	10 days	Thu 9/20/12



Project: Tech 2 Detailed Project S
Date: Mon 10/17/11

Task
Split
Milestone
Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
Deadline
Progress

ID	Task Mode	Task Name	Duration	Start
82		Punchlist / Final Clean Phase 1C	15 days	Thu 10/4/12
83		Phase 1C Complete	0 days	Wed 10/24/12
84		**Phase 1B - MEP Work Levels 4 and 5**	**52 days**	**Tue 6/26/12**
85		Demo / Renovate Level 4 & 5	31 days	Tue 6/26/12
86		Punchlist / Final Clean Phase 1B	21 days	Wed 8/8/12
87		Phase 1B Complete	0 days	Wed 9/5/12
88		**Phase 2 - South Curtain Wall**	**312 days**	**Thu 10/25/12**
89		Relocate Tenants Level 3-5, 7, 8 South	10 days	Thu 10/25/12
90		Dust Partition / Weather Wall Phase 2 Level 3-13	32 days	Thu 11/8/12
91		**Demo South Curtainwall**	**78 days**	**Mon 12/3/12**
92		Level 13	7 days	Mon 12/3/12
93		Level 12	7 days	Wed 12/12/12
94		Level 11	7 days	Fri 12/21/12
95		Level 10	7 days	Tue 1/1/13
96		Level 9	7 days	Thu 1/10/13
97		Level 8	7 days	Mon 1/21/13
98		Level 7	7 days	Wed 1/30/13
99		Level 6	7 days	Fri 2/8/13
100		Level 5	7 days	Tue 2/19/13
101		Level 4	7 days	Thu 2/28/13
102		Level 3	8 days	Mon 3/11/13
103		Demo / Renovate East Toilet Stack	214 days	Wed 12/26/12
104		Demo / Renovate Level 11 Phase 2 Center	21 days	Wed 12/26/12
105		**Install South Curtainwall**	**61 days**	**Thu 3/7/13**
106		Level 13	5 days	Thu 3/7/13
107		Level 12	5 days	Thu 3/14/13
108		Level 11	5 days	Thu 3/21/13
109		Level 10	5 days	Thu 3/28/13
110		Level 9	5 days	Thu 4/4/13



Project: Tech 2 Detailed Project S
Date: Mon 10/17/11

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

Technical Assignment 1

ID	Task Mode	Task Name	Duration	Start
111		Level 8	6 days	Thu 4/11/13
112		Level 7	6 days	Fri 4/19/13
113		Level 6	6 days	Sat 4/27/13
114		Level 5	6 days	Mon 5/6/13
115		Level 4	6 days	Tue 5/14/13
116		Level 3	7 days	Wed 5/22/13
117		Frame & Rough-In South Level 3-13	61 days	Thu 3/14/13
118		Finishes Level 3-13 South	77 days	Fri 5/31/13
119		Sun Shades	46 days	Fri 5/31/13
120		Punchlist / Final Clean Phase 2	32 days	Tue 10/22/13
121		Phase 2 Complete	0 days	Wed 12/4/13
122		Furniture Move-In	22 days	Thu 12/5/13
123		**Phase 3 - Lower Roof**	**176 days**	**Fri 5/31/13**
124		Panels & Louvers South Elevation Level 14/15	51 days	Fri 5/31/13
125		Panels at Level 2 South Building Extension	41 days	Mon 8/12/13
126		Roofing at Level 3 South	21 days	Mon 8/12/13
127		Install Photovoltaics	40 days	Tue 9/10/13
128		Windows at Level 2 South	10 days	Tue 10/8/13
129		CMU Wall Reinforcing Level 2 South	20 days	Tue 10/8/13
130		South Canopies	54 days	Tue 10/22/13
131		Restore Finishes Level 2 South	15 days	Tue 11/5/13
132		Punchlist / Final Clean Phase 3	20 days	Mon 1/6/14
133		Phase 3 Complete	0 days	Fri 1/31/14

Project: Tech 2 Detailed Project S
Date: Mon 10/17/11

Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress

APPENDIX D – GENERAL CONDITIONS ESTIMATE

Project Supervision and Staffing						
Line Item	**Unit Rate**		**Unit**	**Quantity**	**Cost**	Source
Vice President	$	5,000.00	Week	26	$ 130,000.00	Assumption
Senior Project Manager	$	3,650.00	Week	130	$ 474,500.00	01 31 13.20 0220
Superintendent	$	2,950.00	Week	130	$ 383,500.00	01 31 13.20 0260
Superintendent	$	2,950.00	Week	130	$ 383,500.00	01 31 13.20 0260
Project Engineer	$	1,950.00	Week	130	$ 253,500.00	01 31 13.20 0120
Project Accountant	$	630.00	Week	130	$ 81,900.00	01 31 13.20 0020
Site Labor	$	2,075.00	Week	130	$ 269,750.00	01 31 13.20 0160
Subtotal					**$ 1,976,650.00**	

Temporary Facilities & Safety						
Line Item	**Unit Rate**		**Unit**	**Quantity**	**Cost**	Source
Field Office Trailer	$	315.00	Month	30	$ 9,450.00	01 52 13.20 0450
Storage Trailer	$	103.00	Month	30	$ 3,090.00	01 52 13.20 1350
Construction Site Fence	$	3,100.00	EA	1	$ 3,100.00	Altered Actual Data
Personal Protective Equipment	$	-				Assumption
Dumpster	$	695.00	Week	130	$ 90,350.00	02 41 19.23 0725
Signage	$	29.50	SF	40	$ 1,180.00	01 58 13.50 0020
Builder's Risk	$	132,600.00	EA	1	$ 132,600.00	01 31 13.30 0020
Subtotal					**$ 239,770.00**	

Temporary Utilities						
Line Item	**Unit Rate**		**Unit**	**Quantity**	**Cost**	Source
Temporary Network Connection	$	-				Assumption
Temporary Telephone Service	$	-				Assumption
Temporary Power	$	-				Assumption
Temporary Water	$	-				Assumption
Temporary Toilets	$	177.00	Month	30	$ 5,310.00	01 54 33.40 6410
Potable Water	$	-				Assumption
Subtotal					**$ 5,310.00**	

Contingency						
Line Item	**Unit Rate**		**Unit**	**Quantity**	**Cost**	Source
Contingency for Cost of Work	$	1,100,000.00	EA	1	$ 1,100,000.00	Altered Actual Data
Subtotal					**$ 1,100,000.00**	

Total	**$**	**3,321,730.00**

APPENDIX E – LEED SCORECARD

LEED 2009 for Existing Buildings: Operations & Maintenance

Project Checklist

Government Office Center

19 October 2011

Sustainable Sites — Possible Points: 26

Y	?	N			
10	9	7		**Sustainable Sites**	Possible Points: 26
		4	Credit 1	LEED Certified Design and Construction	4
1			Credit 2	Building Exterior and Hardscape Management Plan	1
1			Credit 3	Integrated Pest Mgmt, Erosion Control, and Landscape Mgmt Plan	1
7	8		Credit 4	Alternative Commuting Transportation	3 to 15
		1	Credit 5	Site Development—Protect or Restore Open Habitat	1
		1	Credit 6	Stormwater Quantity Control	1
		1	Credit 7.1	Heat Island Reduction—Non-Roof	1
1			Credit 7.2	Heat Island Reduction—Roof	1
	1		Credit 8	Light Pollution Reduction	1

Water Efficiency — Possible Points: 14

Y	?	N			
9	4	1		**Water Efficiency**	Possible Points: 14
Y			Prereq 1	Minimum Indoor Plumbing Fixture and Fitting Efficiency	
2			Credit 1	Water Performance Measurement	1 to 2
5			Credit 2	Additional Indoor Plumbing Fixture and Fitting Efficiency	1 to 5
1	4		Credit 3	Water Efficient Landscaping	1 to 5
1		1	Credit 4	Cooling Tower Water Management	1 to 2

Energy and Atmosphere — Possible Points: 35

Y	?	N			
20	11	4		**Energy and Atmosphere**	Possible Points: 35
Y			Prereq 1	Energy Efficiency Best Management Practices	
Y			Prereq 2	Minimum Energy Efficiency Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
10	8		Credit 1	Optimize Energy Efficiency Performance	1 to 18
2			Credit 2.1	Existing Building Commissioning—Investigation and Analysis	2
2			Credit 2.2	Existing Building Commissioning—Implementation	2
2			Credit 2.3	Existing Building Commissioning—Ongoing Commissioning	2
1			Credit 3.1	Performance Measurement—Building Automation System	1
1	1		Credit 3.2	Performance Measurement—System-Level Metering	1 to 2
1	2	3	Credit 4	On-site and Off-site Renewable Energy	1 to 6
1			Credit 5	Enhanced Refrigerant Management	1
		1	Credit 6	Emissions Reduction Reporting	1

Materials and Resources — Possible Points: 10

Y	?	N			
7	2	1		**Materials and Resources**	Possible Points: 10
Y			Prereq 1	Sustainable Purchasing Policy	
Y			Prereq 2	Solid Waste Management Policy	
1			Credit 1	Sustainable Purchasing—Ongoing Consumables	1
	1		Credit 2.1	Sustainable Purchasing—Electric-Powered Equipment	1
	1		Credit 2.2	Sustainable Purchasing—Furniture	1
1			Credit 3	Sustainable Purchasing—Facility Alterations and Additions	1
1			Credit 4	Sustainable Purchasing—Reduced Mercury in Lamps	1
		1	Credit 5	Sustainable Purchasing—Food	1

Materials and Resources, Continued

Y	?	N			
1			Credit 6	Solid Waste Management—Waste Stream Audit	1
1			Credit 7	Solid Waste Management—Ongoing Consumables	1
1			Credit 8	Solid Waste Management—Durable Goods	1
1			Credit 9	Solid Waste Management—Facility Alterations and Additions	1

Indoor Environmental Quality — Possible Points: 15

Y	?	N			
12	3			**Indoor Environmental Quality**	Possible Points: 15
Y			Prereq 1	Minimum IAQ Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
Y			Prereq 3	Green Cleaning Policy	
1			Credit 1.1	IAQ Best Mgmt Practices—IAQ Management Program	1
1			Credit 1.2	IAQ Best Mgmt Practices—Outdoor Air	1
	1		Credit 1.3	IAQ Best Mgmt Practices—Increased Ventilation	1
	1		Credit 1.4	IAQ Best Mgmt Practices—Reduce Particulates in Air Distribution	1
1			Credit 1.5	IAQ Mgmt Plan—IAQ Mgmt for Facility Alterations and Additions	1
1			Credit 2.1	Occupant Comfort—Occupant Survey	1
1			Credit 2.2	Controllability of Systems—Lighting	1
	1		Credit 2.3	Occupant Comfort—Thermal Comfort Monitoring	1
1			Credit 2.4	Daylight and Views	1
1			Credit 3.1	Green Cleaning—High Performance Cleaning Program	1
1			Credit 3.2	Green Cleaning—Custodial Effectiveness Assessment	1
1			Credit 3.3	Green Cleaning—Sustainable Cleaning Products, Materials Purchases	1
1			Credit 3.4	Green Cleaning—Sustainable Cleaning Equipment	1
1			Credit 3.5	Green Cleaning—Indoor Chemical and Pollutant Source Control	1
1			Credit 3.6	Green Cleaning—Indoor Integrated Pest Management	1

Innovation in Operations — Possible Points: 6

Y	?	N			
3	3			**Innovation in Operations**	Possible Points: 6
1			Credit 1.1	Innovation in Operations: Specific Title	1
	1		Credit 1.2	Innovation in Operations: Specific Title	1
	1		Credit 1.3	Innovation in Operations: Specific Title	1
	1		Credit 1.4	Innovation in Operations: Specific Title	1
1			Credit 2	LEED Accredited Professional	1
1			Credit 3	Documenting Sustainable Building Cost Impacts	1

Regional Priority Credits — Possible Points: 4

Y	?	N			
1	3			**Regional Priority Credits**	Possible Points: 4
1			Credit 1.1	Regional Priority: Specific Credit	1
	1		Credit 1.2	Regional Priority: Specific Credit	1
	1		Credit 1.3	Regional Priority: Specific Credit	1
	1		Credit 1.4	Regional Priority: Specific Credit	1

Total — Possible Points: 110

Y	?	N		
62	35	13	**Total**	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

APPENDIX F – BUILDING INFORMATION MODELING USE EVALUATION GRAPHICS

BIM GOALS WORKSHEET

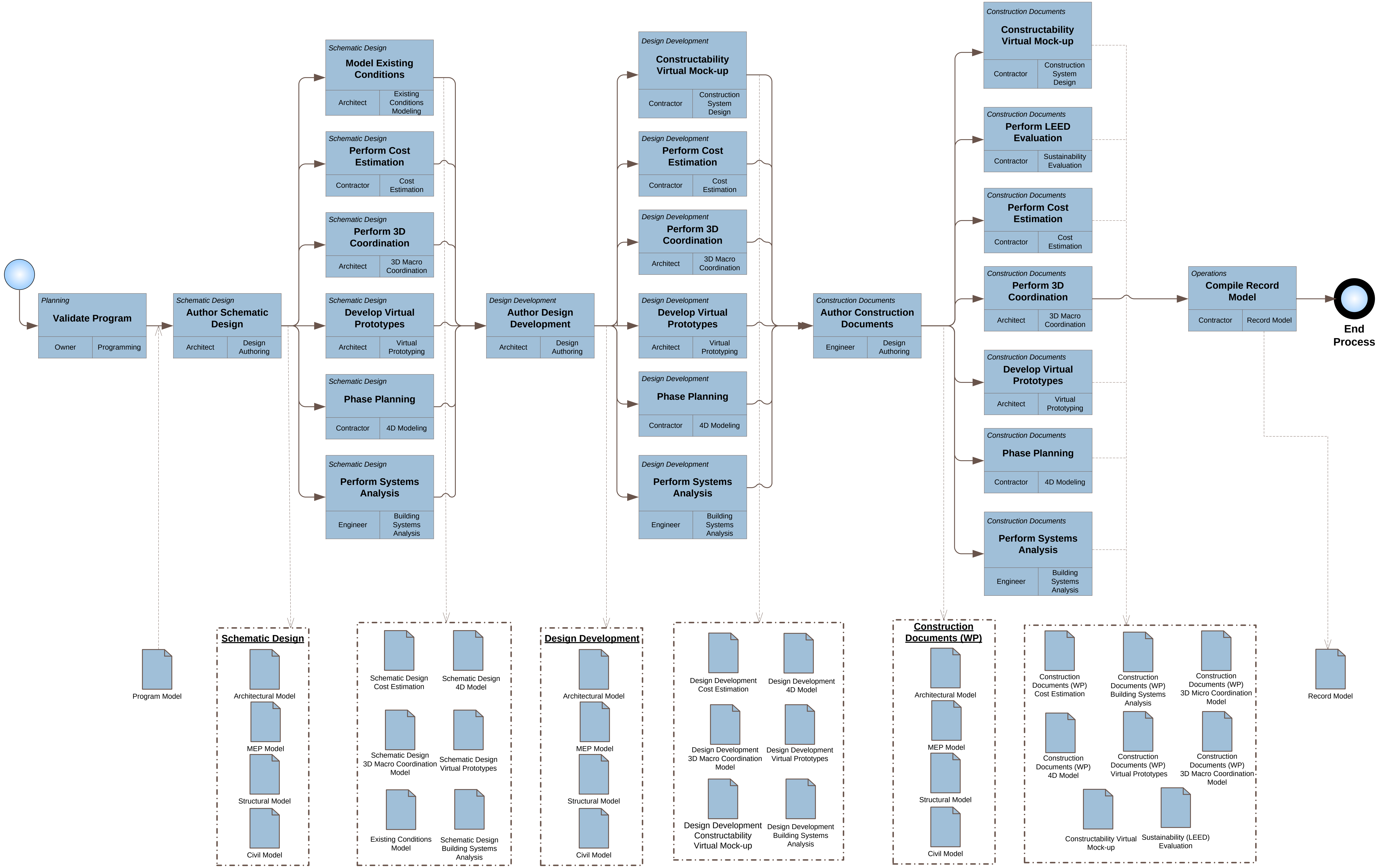
Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	**Value added objectives**	
1	Ensure building's mechanical, electrical, and curtain wall systems are performing to specified design and sustainable standards	Building Systems Analysis
2	Improve constructability and safety of curtain wall demolition and installation	Construction System Design (Virtual Mock-up)
2	Reduce and eliminate field conflicts and improve on-site productivity	3D Coordination
3	Design visualization and improved collaboration between project stakeholders and BIM users	Design Authoring
3	Align scheduling and material quantities tracking	Sustainability (LEED) Evaluation
2	Optimize building performance by tracking energy use and indoor air quality for adherence to LEED standards	Sustainability (LEED) Evaluation
1	Plan phased occupancy requirements and improve owner and project participants' understanding of the phasing schedule	Phase Planning (4D Modeling)
3	Generate an accurate quantity take-off and cost estimate to provide cost effects of additions and modifications	Cost Estimation
1	Document existing building and site conditions to aid in renovation efforts	Existing Conditions Modeling

BIM USE ANALYSIS
Version 2.0

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resources / Competencies Required to Implement	Notes	Proceed with Use
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)					YES / NO / MAYBE
				Resources	Competency	Experience			
Building Systems Analysis	HIGH	MEP Engineer	HIGH	3	3	3		Systems should perform as intended	**YES**
Construction System Design (Virtual Mock-up)	MED	Contractor	HIGH	3	3	3		High value for Contractor and Sub	**YES**
		Subcontractors	HIGH	1	2	2	None if Contractor creates model	building temp. weather wall	
3D Coordination (Construction)	MED	Contractor	HIGH	3	3	3		Contractor to facilitate Coord.	**YES**
		Subcontractors	HIGH	2	2	2	Coordination software required	Potential modeling learning curve	
Design Authoring	LOW	Architect	HIGH	3	3	3			**YES**
		MEP Engineer	HIGH	3	3	3			
		Structural Engineer	MED	3	3	3			
Sustainability (LEED) Evaluation	MED	Sustainability Cons.	HIGH	3	3	3	Accurate systems performance data		**YES**
		Architect	HIGH	2	3	3			
		MEP Engineer	HIGH	2	3	2	Accurate building loads		
Phase Planning (4D Modeling)	HIGH	Contractor	HIGH	3	3	3		High value to owner due to	**YES**
								phasing complications	
								Use for Phasing & Construction	
Cost Estimation	LOW	Owner's Advisor	MED	2	3	3			**YES**
Existing Conditions Modeling	HIGH	Architect	HIGH	3	3	3			**YES**
		Owner's Advisor	MED	3	2	2			

* Additional BIM Uses as well as information on each Use can be found at http://www.engr.psu.edu/ae/cic/bimex/

Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr/psu.edu/ae/cic/bimex



APPENDIX G – UNITY SCRIPT EXAMPLES

PARENTOBJECTCLICK.JS – ATTACHED TO AN EMPTY PARENT OBJECT

```
var showing: boolean;
var currLink: String;
var currTitle: String;


function OnGUI () {
    if (!showing) return;

    if (GUI.Button(Rect(10, 10, 150, 30), currTitle)) {
        Application.OpenURL(currLink);
    }

    if (GUI.Button(Rect(10, 50, 50, 30), "Exit")) {
        showing = false;
    }
}


function ChangeLink(newLink: String) {
    showing = true;
    currLink = newLink;
}

function ChangeTitle(newTitle: String) {
    showing = true;
    currTitle = newTitle;
}
```

ChildObjectClick.js – Attached to a Child Object Within the Empty Parent

```
var myLink: String;
var myTitle: String;


function OnMouseDown() {
        SendMessageUpwards("ChangeLink", myLink);
        SendMessageUpwards("ChangeTitle", myTitle);
}
```

Visibility Toggle C.js – Attached to Any Object to Toggle Visibility with 'C' Key

```
function Update() {

   if (Input.GetKeyDown(KeyCode.C)) {
      // toggle visibility:
      renderer.enabled = !renderer.enabled;
   }
}
```

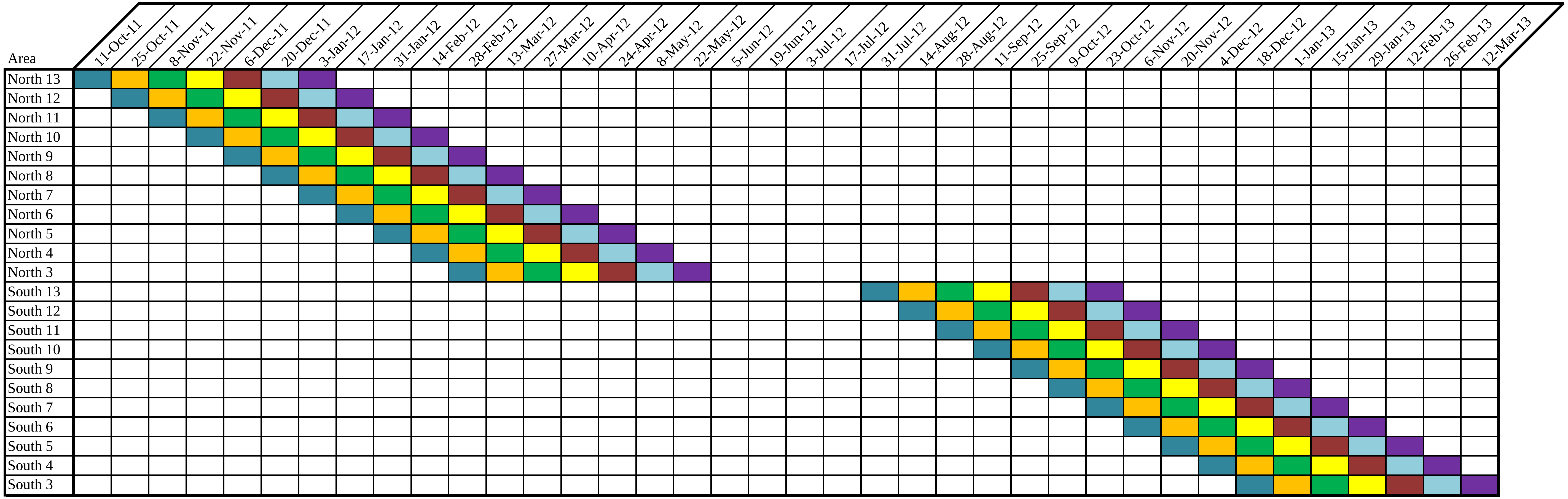
Visibility Toggle Z.js – Attached to Any Object to Toggle Visibility with 'Z' Key

```
function Update() {

   if (Input.GetKeyDown(KeyCode.Z)) {
      // toggle visibility:
      renderer.enabled = !renderer.enabled;
   }
}
```

APPENDIX H – SHORT INTERVAL PRODUCTION SCHEDULE

Schedule Acceleration Through Non-Traditional SIPS Method



Activity Key	
Weather wall installation and curtain wall bracing	
Demolition of existing curtain wall	
Installation of new structural steel supports	
Installation of new curtain wall system	
Demolition of weather wall	
Frame and rough-in	
Restoration of finishes	

APPENDIX I – SUNNY TOWER ST42 TECHNICAL DATA

11.2 Sunny Tower ST42 equipped with Sunny Boy SB 7000US

PV generator connection

Recommended Maximum PV Power (Module STC)	52.5 kW
DC Maximum Voltage	600 V
Peak Power Tracking Voltage	250 V ... 480 V
DC Maximum Input Current	180 A
Number of Fused String Inputs (AC-DC disconnect)	24
PV Start Voltage (Adjustable)	300 V
Power Factor (Nominal)	0.99

Grid connection

AC Nominal Power	42.0 kW
AC Maximum Power	42.0 kW
AC Maximum Output Current at 208 V (3-Phase Only)	117 A
AC Maximum Output Current at 240 V (3-Phase Only)	101 A
AC Maximum Output Current at 277 V (3-Phase Only)	51 A
AC Nominal Voltage Range at 208 V Delta or WYE (3-Phase Only)	187 V ... 229 V
AC Nominal Voltage Range at 240 V Delta (3-Phase Only)	211 V ... 264 V
AC Nominal Voltage Range at 277 V WYE (3-Phase Only)	244 V ... 305 V
AC Frequency Nominal	60 Hz
AC Frequency Range	59.3 Hz ... 60.5 Hz
Power consumption at night	0.6 W

Efficiency

Peak Inverter Efficiency	97.1 %
CEC Weighted Efficiency at 208 V	95.5 %
CEC Weighted Efficiency at 240 V/277 V	96.0 %

Ambient conditions

Ambient Temperature Range	− 13 °F ... +113 °F (− 25 °C ... +45 °C)

Mechanical data

Width x Height x Depth	43.3 in x 70.5 in x 39 in (1.100 mm x 1.791 mm x 991 mm)
Tower Weight	330 lbs (150 kg)
6 Inverters Weight	846 lbs (384 kg)
Total Shipping Weight	1.388 lbs (630 kg)

Features

Topology	LF transformer
Sunny Boy cooling concept	OptiCool ™ , forced active cooling
RS485 communication	yes
Wireless communication	optional
LCD display	yes

APPENDIX J – PROGRESSIVE COLLAPSE NOTES AND CALCULATIONS

Reference Tables

Concrete **R0341 Precast Structural Concrete**

R034136-90 Prestressed Concrete, Post-Tensioned

In post-tensioned concrete the steel tendons are tensioned after the concrete has reached about 3/4 of its ultimate strength. The cableways are grouted after tensioning to provide bond between the steel and concrete. If bond is to be prevented, the tendons are coated with a corrosion-preventative grease and wrapped with waterproofed paper or plastic. Bonded tendons are usually used when ultimate strength (beams & girders) are controlling factors.

High strength concrete is used to fully utilize the steel, thereby reducing the size and weight of the member. A plasticizing agent may be added to reduce water content. Maximum size aggregate ranges from 1/2″ to 1-1/2″ depending on the spacing of the tendons.

The types of steel commonly used are bars and strands. Job conditions determine which is best suited. Bars are best for vertical prestresses since they are easy to support. The trend is for steel manufacturers to supply a finished package, cut to length, which reduces field preparation to a minimum.

Bars vary from 3/4″ to 1-3/8″ diameter. Table below gives time in labor-hours per tendon for placing, tensioning and grouting (if required) a 75′ beam. Tendons used in buildings are not usually grouted; tendons for bridges usually are grouted. For strands the table indicates the labor-hours per pound for typical prestressed units 100′ long. Simple span beams usually require one-end stressing regardless of lengths. Continuous beams are usually stressed from two ends. Long slabs are poured from the center outward and stressed in 75′ increments after the initial 150′ center pour.

Labor Hours per Tendon and per Pound of Prestressed Steel

Length	100′ Beam		75′ Beam		100′ Slab	
Type Steel	Strand		Bars		Strand	
Diameter	0.5″		3/4″	1-3/8″	0.5″	0.6″
Number	4	12	1	1	1	1
Force in Kips	100	300	42	143	25	35
Preparation & Placing Cables	3.6	7.4	0.9	2.9	0.9	1.1
Stressing Cables	2.0	2.4	0.8	1.6	0.5	0.5
Grouting, if required	2.5	3.0	0.6	1.3		
Total Labor Hours	8.1	12.8	2.3	5.8	1.4	1.6
Prestressing Steel Weights (Lbs.)	215	640	115	380	53	74
Labor-hours per Lb. Bonded	0.038	0.020	0.020	0.015		
Non-bonded					0.026	0.022

Flat Slab construction — 4000 psi concrete with span-to-depth ratio between 36 and 44. Two way post-tensioned steel averages 1.0 lb. per S.F. for 24′ to 28′ bays (usually strand) and additional reinforcing steel averages .5 lb. per S.F.

Pan and Joist construction — 4000 psi concrete with span-to-depth ratio 28 to 30. Post-tensioned steel averages .8 lb. per S.F. and reinforcing steel about 1.0 lb. per S.F. Placing and stressing averages 40 hours per ton of total material.

Beam construction — 4000 to 5000 psi concrete. Steel weights vary greatly.

Labor cost per pound goes down as the size and length of the tendon increase. The primary economic consideration is the cost per kip for the member.

Post-tensioning becomes feasible for beams and girders over 30′ long; for continuous two-way slabs over 20′ clear; also in transferring upper building loads over longer spans at lower levels. Post-tension suppliers will provide engineering services at no cost to the user. Substantial economies are possible by using post-tensioned Lift Slabs.

788

RS Means Tendon installation labor data

	Distributed Loads in psf			
Weight of:	Dead	Live	Snow	*Assume 15psf for MEP allowance
Roof	82	20	30	2.5 psf for new roofing membrane + 7" LW conc
14th Floor	75	80		3" Metal Deck with 5" LW conc
13th Floor	54	80		3" Metal Deck with 2.5" LW conc
12th Floor	54	80		3" Metal Deck with 2.5" LW conc
11th Floor	54	80		3" Metal Deck with 2.5" LW conc
10th Floor	54	80		3" Metal Deck with 2.5" LW conc
9th Floor	54	80		3" Metal Deck with 2.5" LW conc
8th Floor	54	80		3" Metal Deck with 2.5" LW conc
7th Floor	54	80		3" Metal Deck with 2.5" LW conc
6th Floor	54	80		3" Metal Deck with 2.5" LW conc
5th Floor	54	80		3" Metal Deck with 2.5" LW conc
4th Floor	54	80		3" Metal Deck with 2.5" LW conc
3rd Floor	49	80		1.5" Metal Deck with 2.5" LW conc
2nd Floor	49	80		1.5" Metal Deck with 2.5" LW conc

Distributed loads

Truss Weights	***From S4.02 and AISC Steel Construction Manual; lb**	
Group 2	T2	4288
	T9	4984
	T11	9307
	T15	5835
Group 3	T3	1073
	T12	1846
Group 4	T4	2291
Group 5	T5	3026
	T14	5022
Group 6	T6	4963
	T7	4515
	T16	5599
	T17	8951
Group 7	T8	8703

Truss weights

North: Tributary Area = 50'*30'= 1500SF				
Beams/Trusses		**(psf)**	Columns (Point Load)	
Roof	2(25'(48+31+22+22+22+26) + 10'(22)) + 30'(68)	7.4	0	0
14th Floor	4(T12) + 2(25'(94+32.51))	9.1	W12x40	533.3
13th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x53	706.6
12th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x53	706.6
11th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x72	960.0
10th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x72	960.0
9th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x92	1226.6
8th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x92	1226.6
7th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x120	1600.0
6th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x120	1600.0
5th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x133	1773.3
4th Floor	4(T3) + 2(25'(61+37.61))	6.1	W12x133	1773.3
3rd Floor	4*30'*35+30'*50+25'*55+25'*68+2(25'(35.11))	7.0	W12x161	2146.6
2nd Floor	25'(2*35+6*26+2*31)+2000	6.1	W12x161	2146.6

North side load calculations

West: Tributary Area = 25'*85' = 2125SF				
Beams/Trusses		**(psf)**	Columns (Point Load)	
Roof	30'*(68) + 1(T17) + 25'(10*31)	8.8	0	0
14th Fl	30'*76 + 1(T17) + 1(T16) + 1(T11) + 2(T12) + 1(T14)	16.4	W14x68	906.6
13th Fl	30'*49 + T7 + T16 + T15 + T14 + 2(T3)	11.6	W14x68	906.6
12th Fl	30'*49 + T7 + T6 + T15 + T5 + 2(T3)	10.3	W14x87	1160.0
11th Fl	30'*49 + T7 + T6 + T15 + T5 + 2(T3)	10.3	W14x87	1160.0
10th Fl	30'*49 + T7 + T6 + T15 + T5 + 2(T3)	10.3	W14x119	1586.6
9th Fl	30'*49 + T7 + T6 + T15 + T5 + 2(T3)	10.3	W14x119	1586.6
8th Fl	30'*49 + T7 + T6 + T15 + T5 + 2(T3)	10.3	W14x158	2106.6
7th Fl	30'*49 + T7 + T6 + T15 + T14 + 2(T3)	11.3	W14x158	2106.6
6th Fl	30'*49 + T7 + T8 + T2 + T5 + 2(T3)	11.4	W14x193	2573.3
5th Fl	30'*49 + T7 + T8 + T2 + T5 + 2(T3)	11.4	W14x193	2573.3
4th Fl	30'*49 + T7 + T8 + T2 + T5 + 2(T3)	11.4	W14x219	2919.9
3rd Fl	30'(55+35+35) + 25'*116 + T15 + 55'*84 + 2(20'*31)	8.6	W14x219	2919.9
2nd Fl	2000 + 25'(84+31+26+26+26) + T15 + 2(T9)	10.6	W14x246	3279.9

West side load calculations

North				
	P (kip)	Δ (feet)	Strands (#)	Use
Roof	281	2	32	37
14th Floor	344	2	39	(2) 27
13th Floor	301	2	34	37
12th Floor	301	2	34	37
11th Floor	301	2	34	37
10th Floor	301	2	34	37
9th Floor	302	2	34	37
8th Floor	302	2	34	37
7th Floor	302	2	34	37
6th Floor	302	2	34	37
5th Floor	302	2	34	37
4th Floor	302	2	34	37
3rd Floor	295	2	34	37
2nd Floor	294	2	33	37

North side tendon sizing

West				
	P (kip)	Δ (feet)	Strands (#)	Use
Roof	402	2	70	(2) 37
14th Floor	506	2	89	(2) 48
13th Floor	440	2	77	(2) 48
12th Floor	437	2	77	(2) 48
11th Floor	437	2	77	(2) 48
10th Floor	438	2	77	(2) 48
9th Floor	438	2	77	(2) 48
8th Floor	439	2	77	(2) 48
7th Floor	441	2	77	(2) 48
6th Floor	442	2	77	(2) 48
5th Floor	442	2	77	(2) 48
4th Floor	442	2	77	(2) 48
3rd Floor	422	2	74	(2) 37
2nd Floor	428	2	75	(2) 48

West side tendon sizing

Material:	$0.425	per foot			
		per 0.6" 7-wire 270ksi low-relaxation strand			
	$ 256,062.50	material			
Labor:	12 Strand	27 Strand	37 Strand	48 Strand	
(Hours)	7.4	16.7	22.8	29.6	Preparation & Placing Cables
	2.4	N/A	N/A	N/A	Stressing Cables
	3.0	N/A	N/A	N/A	Grouting
	Total:	4527	hours @	$ 40.00	**$ 181,080.00**
Total:	**$ 437,142.50**				

Cost calculations

Anchor Properties

DYWIDAG Strand Anchors utilize 0.6" dia. 7-wire, Low Relaxation 270 KSI Strand conforming to ASTM A416 (bare strand) or ASTM A882 (epoxy coated strand).

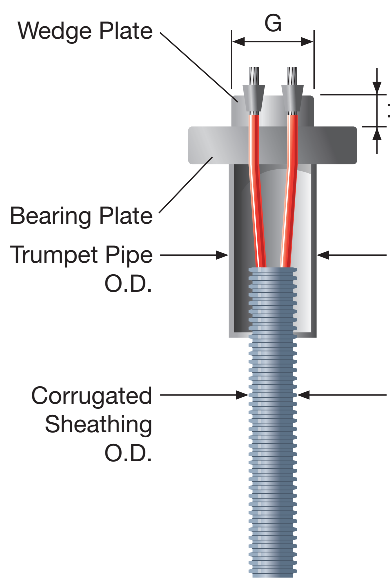
Number of Strands	Nominal Cross Section Area (Aps)	Ultimate Strength (Fpu x Aps)	Prestressing Force			Nominal Weight (bare steel only)
			0.80 Fpu x Aps	0.70 Fpu x Aps	0.60 Fpu x Aps	
[ea]	[in²] / [mm²]	[kips] / [kN]	[kips] / [kN]	[kips] / [kN]	[kips] / [kN]	[lbs/ft] / [kg/m]
1	0.217 / 140	58.6 / 261	46.9 / 208	41.0 / 182	35.2 / 156	0.74 / 1.09
2	0.434 / 280	117.2 / 521	93.7 / 417	82.0 / 365	70.3 / 313	1.48 / 1.64
3	0.651 / 420	175.8 / 782	140.6 / 625	123.0 / 547	105.5 / 469	2.22 / 3.27
4	0.868 / 560	234.4 / 1,043	187.5 / 834	164.1 / 730	140.6 / 626	2.96 / 4.46
5	1.085 / 700	293.0 / 1,303	234.4 / 1,043	205.1 / 912	175.8 / 782	3.70 / 5.51
6	1.302 / 840	351.6 / 1,564	281.3 / 1,251	246.1 / 1,095	221.0 / 938	4.44 / 6.55
7	1.519 / 980	410.2 / 1,825	328.2 / 1,460	287.2 / 1,277	246.2 / 1,095	5.18 / 7.74
8	1.736 / 1,120	468.8 / 2,085	375.0 / 1,668	328.1 / 1,460	281.3 / 1,251	5.92 / 8.78
9	1.953 / 1,260	527.4 / 2,346	421.9 / 1,877	369.2 / 1,642	316.4 / 1,408	6.66 / 9.97
12	2.604 / 1,680	703.2 / 3,128	562.6 / 2,503	492.3 / 2,190	422.0 / 1,877	8.88 / 13.24
15	3.255 / 2,100	879.0 / 3,910	703.2 / 3,128	615.3 / 2,737	527.4 / 2,346	11.10 / 16.52
19	4.123 / 2,660	1,113.4 / 4,953	890.7 / 3,962	779.4 / 3,467	668.0 / 2,972	14.06 / 20.98
27	5.859 / 3,780	1,582.2 / 7,038	1,265.8 / 5,631	1,107.6 / 4,927	949.4 / 4,223	19.98 / 29.76
37	8.029 / 5,180	2,168.2 / 9,645	1,734.6 / 7,716	1,517.8 / 6,751	1,301.0 / 5,787	27.38 / 40.78
48	10.416 / 6,720	2,812.8 / 12,512	2,250.2 / 10,009	1,968.9 / 8,758	1,687.7 / 7,507	35.52 / 52.83
54	11.718 / 7,560	3,164.4 / 14,076	2,531.5 / 11,261	2,215.1 / 9,853	1,898.6 / 8,446	39.96 / 59.38
61	13.237 / 8,540	3,574.6 / 15,901	2,859.7 / 12,721	2,502.2 / 11,131	2,144.8 / 9,540	45.14 / 67.12

Aps = Area Prestressing Steel
Fpu = Minimum Ultimate Strength

Anchor Properties – DCP Components & Wedge Plates

Max. No. of 0.6" Strands*	Corrugated Sheathing O.D.	Pipe O.D.	Wedge Plate	
[ea]	[in] / [mm]	[in] / [mm]	Ø G [in] / Ø G [mm]	H [in] / H [mm]
3	2.4 / 61	4.5 / 115	4.7 / 120	2.0 / 51
4	3.6 / 92	4.5 / 115	4.7 / 120	2.0 / 51
7	3.6 / 92	4.5 / 115	5.6 / 143	2.4 / 61
9	3.6 / 92	5.6 / 142	5.5 / 141	2.2 / 55
12	4.7 / 120	6.6 / 169	6.3 / 161	2.6 / 66
15	4.7 / 120	6.6 / 169	7.1 / 181	2.8 / 70
17	4.7 / 120	8.6 / 220	7.9 / 200	3.4 / 87
24	5.8 / 148	8.6 / 220	9.4 / 241	4.1 / 105
27	6.9 / 176	8.6 / 220	9.4 / 241	4.1 / 105

* based on the use of a single max. 1/2" I.D. grout tube



Please consult with your local sales office for systems exceeding 27 strands.
Bearing plate sizes are dependent on project specific conditions. DSI staff can assist with sizing of bearing plates.