Ian Bower

Final Report

The Concordia Hotel

4/3/2013

General Information

- Location: Washington DC
- Building Type: Hotel R-2
- Building Size: 96,200 SF
- Height: 10 Stories, 90 Ft
- Construction Dates: November 2011-December 2012
- Cost: $23 Million
- Delivery: CM @ Risk/CM Agency

Architecture

- Extended stay facility with two main structures connected at the ground floor.
- Composed of 178 rooms the bond building has 78 while the Concordia houses the other 100
- Designed in by Berla & Able
- New façade will consist of aluminum composite panels as well as aluminum trellis'

Structural

- Reinforced concrete columns
- 42" thick mat foundation on Micro piles

Project Team

CM/GC: Turner Construction
Architects: Bonstra Haresign Architects LLP
Engineers:
(MEP) WSP Flack + Kurtz
(Structural) SK&A
(Landscape Architect) Landscape Architecture Bureau
(Civil) Wiles Mensch Corporation

Mechanical

- Two main Air Handling Units will condition and circulate the air for the entire building (1 located on the roof, 1 located in mechanical room-cellar level).
- One Make-up Air Unit providing supply air for the building (located in mechanical room-cellar level).
- 9 fan units (5 supplies, 1 return, 2 exhaust/returns)
- Variable Refrigerant Volume (VRV) systems installed into the structure
- 11 VRV air cooled condenser outdoor units located on every floor.
- 3 air cooled split systems located in the fire control room, IT/telecom room and the elevator control room.
- 2 electric unit heaters and one 1 relief hood

Fire Suppression

- Combination of a wet-pipe system and a dry-pipe system in areas such as the loading dock and parking garage.

CPEP Website: http://www.engr.psu.edu/ae/thesis/portfolios/2013/isb5006/index.html

Executive Summary

The main purpose of the Senior Thesis Proposal is to provide readers with a project background which is followed by an identification and overview of the four research analyses areas to be performed, over the duration of the spring semester, on the Concordia Hotel project. For each analysis topic, the problem and the goal are clearly defined. For each analyses the research that will be performed, the potential solutions and the outcomes and resources that will be used to gain these outcomes is discussed. A weight matrix at the end of the report, following the technical analyses descriptions, illustrates how efforts will be distributed among the four analyses and how they meet the core requirements as the following: research; value engineering analysis; constructability review; and schedule reduction. A time table will also be developed to help show the dates of which certain analyses steps will be taken. The timetable will be followed by a description of the breadth topics along with a description of the MAE topic that will be considered. At the end of the course the proposed analyses are presented to the Architectural Engineering Faculty and attending jury members. Below are brief descriptions of the problems, the solution, and the potential benefits of the solutions application. A further description and explanation of these analyses will be presented later in the body of the document.

Analysis 1: Building Information Modeling (BIM) Application to Renovations/Rehabs

There were several key activities that caused increased costs and schedule delays. These problems could have been overcome with greater utilization of BIM to facilitate prefabrication. BIM could be used to help apply prefabrication to the extensive Mechanical/Electrical/Plumbing (MEP) systems and the drywall/framing of the interior partitions. These issues will be discussed further in the following paragraphs. This BIM consideration will allow for advantages in construction and efficiency in materials. The benefits of applying BIM to conduct prefabrication would be the potential to reduce the schedule and project costs. The analysis will consider the role which BIM can play in initiating prefabrication on the Concordia project. The goal is to improve the project’s construction efficiency to improve the project schedule and costs.

Analysis 2: Re-sequencing of the Demolition Efforts

The demolition of the Concordia project consisted of the removal of MEP systems, drywall partitions, interior finishes and several interior slabs. The demolition initiatives which took place throughout the structure were extensive and repetitious on several floors. Even though demolition of the interior slabs and several structural columns was somewhat repetitious this activity still delayed concurrent and succeeding activities from being completed. These delays resulted in the project being completed behind schedule approximately two months. The goal of this analysis is to consider alternate sequences to demolish the structural slabs and columns in order to accelerate the activities schedule and to result in overall savings to the project.

Analysis 3: Implementation of Mechanical, Electrical & Plumbing (MEP) Prefabrication

The extensive construction and installation of the MEP systems caused extensive delays on the project. The delays resulted in employing crews for overtime work during the week and weekends. These delays and costs could have been avoided if the MEP systems were fabricated at an off-site warehouse and then transported to the construction site using prefabrication techniques. This will result in several benefits which include cost savings from reduced labor, and prevention of overtime. It will result in greater productivity, safety, quality and efficiency of materials which will potentially result in greater Leadership in Energy and Environmental Design (LEED) achievements. The analysis will discuss how to achieve the goal of putting the schedule back on track and to reduce construction costs. Since the project is about one month behind schedule, the generated 3D model used for 3D coordination and clash detection can be used to produce clash free shop drawings for MEP prefabrication.

Analysis 4: Alternate Roof Systems

The Concordia Hotel employs two different roofing systems, a green roof and a Thermoplastic Polyolefin (TPO) in different areas. Alternation of these roofing systems caused constructability issues and inefficiencies in the ordering of materials. The roofing system could have been optimized by utilizing one system over the other in order to capitalize on bulk order savings and labor efficiencies with repetitive tasks. Utilizing one system for the entire roofing area could have also optimized the potential to earn a greater amount of LEED credits. The goal of the analyses is to consider the advantages and disadvantages of applying either a cool roof, green roof, or a conventional TPO roof system to the entire roofing area. This analysis will also include a consideration of the effects on construction related to costs, schedule impacts, and constructability issues. Additionally, out of option breadths will arise during this analysis to determine how implementing a cool roof to the tenth floor roof will affect structural and mechanical systems that support the building’s function.

Credit & Acknowledgements

Thank you to my family, friends, and fellow Architectural Engineering (AE) Students in helping me on my journey through the Penn state AE Program the past five years.

Others I would like to thank for the help in my thesis this year include:

The Turner Construction Company

Gary L. Ball-Project Executive

Michael J. Whearty-Preconstruction Services Manager

John T. Armstrong-Project Manager/Engineer

Charles McClellan-Assistant Superintendent

Grace Harriet-VDC/BIM Preconstruction Engineer

Bailey Wilson-Assistant Project Engineer

ACEco

Nathan Lytle-Project Manager

Southland Industries

Andrew Rhodes-Design Engineer

Pierce Associates, Inc.

Matt Corrigan-Vice President, Project Management & Engineering

Baskervill-Architecture + Engineering + Interior Design

Jennifer L. Farris-Interior Designer

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Building Introduction

The Concordia is an extended stay facility located in the heart of Washington D.C. near Dupont Circle. The building is 10-stories plus a cellar level and underground parking garage with two main structures connected at the ground floor. The owner of the Concordia hotel has sold off one of the two structures focusing renovation efforts on only one of the structures. More details concerning the building, construction, and team information are contained in tables 1, 2, & 3.

The structure to be renovated is a total of 10 stories plus a cellar level and underground parking garage which consists of a total square footage of 96,200 square foot. While the entire building is composed of 178 rooms the bond building has 78 while the Concordia houses the other 100. It was designed in by Berla & Able.

Building Information	
Building Name	The Concordia
Location & Site	Confidential
Occupant Name	IMF
Building Area	96,200 Square Feet
Stories Above Grade	10 Stories

Table 1 Building Information

Construction Information	
Construction Cost	$23,000,000
Construction Duration	November 2011-December 2012
Contract Type	Lump Sum
Delivery Method	XXXX

Table 2 Construction Information

Project Team	
Owner	IMF
Architect	Bonstra Haresign Architects LLP
General Contractor	Turner Construction Company

Table 3 Project Team

Project Information

Local Conditions

1. Subsurface conditions-unable to locate this information based on inefficient maps and programs that do not show the soil conditions in the areas. Faculty provided website that was, unfortunately, not operating or capable of providing such information. Will provide details and more information as it becomes available.
2. Water issues-Since there is hardly any excavation and that this project is predominantly a renovation there is no real threat to the project cost or schedule due to water related issues.
3. Tipping fees and recycling-the plan is to employ a system of having the mixed garbage hauled off site where it is then sorted and recycled for an extra fee. This process will be beneficial to the site in order to ease congestion.
4. Parking-parking spaces will be provided on site for the project team and major foremen. Contractor parking will be off-site and employees will carpool or bus into the construction site.
5. Preferred methods of construction-since there are height restrictions in D.C. most structures are erected utilizing concrete.
6. Hauling permits exceptions-The "District of Columbia law prohibits a carrier from exceeding 21,000 gross weight for a single axle and 34,000 for a tandem axle. Any vehicle wider than 8 feet-6 inches including the load or over 40 feet long will have to apply for a permit. Also a vehicle with a combined overall length of 55 feet or higher than 13' 6" including the load will have to apply for a permit.
7. Zoning-the building lot is located in DC/R-5-E Overlay

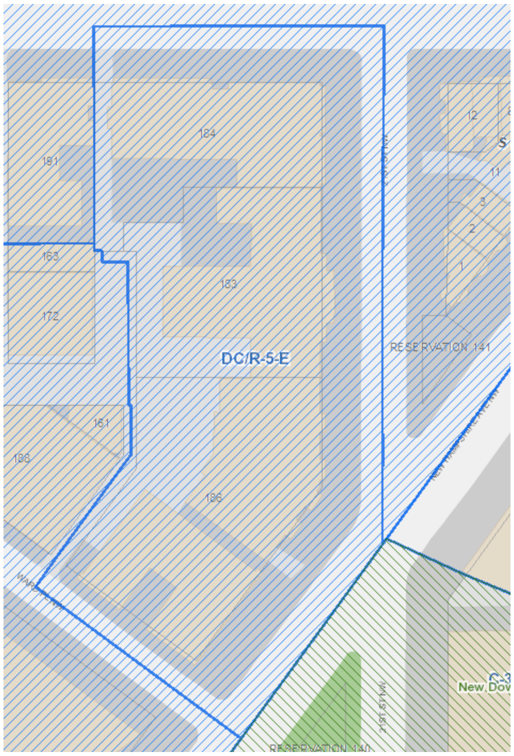


Figure 1 zoning map of the site

Site Plans

The traffic flow will not be disrupted except for material/equipment deliveries and trash/recyclable removal in which case flaggers will be present to ensure safe transport into and out of the site perimeter. We will require that all deliveries and pickups be made prior to 6:00 am unless otherwise restricted or special permission is provided. Adjacent building heights have been listed and the specific address has not been disclosed in accordance with the owner's requests. Materials will be hoisted into location by a crane or through the freight elevator located in the center of the building. The freight elevator will be faced with the main task of transporting personnel to and from each floor. Due to the congestion of the site perimeter fences have been placed and pedestrian traffic has been rerouted this eliminating the requirement of overhead protection. The existing conditions and utilities are shown on the site plan drawing labeled existing conditions. These utilities are very congested and may cause logistical issues with assessments of the current status and their locations. Workforce considerations and key safety features will include a site fence in order to prevent pedestrians from entering the site. One way traffic will pass through the site in order to ease flow of traffic and reduce congestion or required turnaround areas. Flaggers utilizing the proper Personal Protective Equipment will be required anytime there are deliveries or pickups of trash or recyclables.

1. Existing Conditions
2. Site layout
    a. Staging of equipment and materials

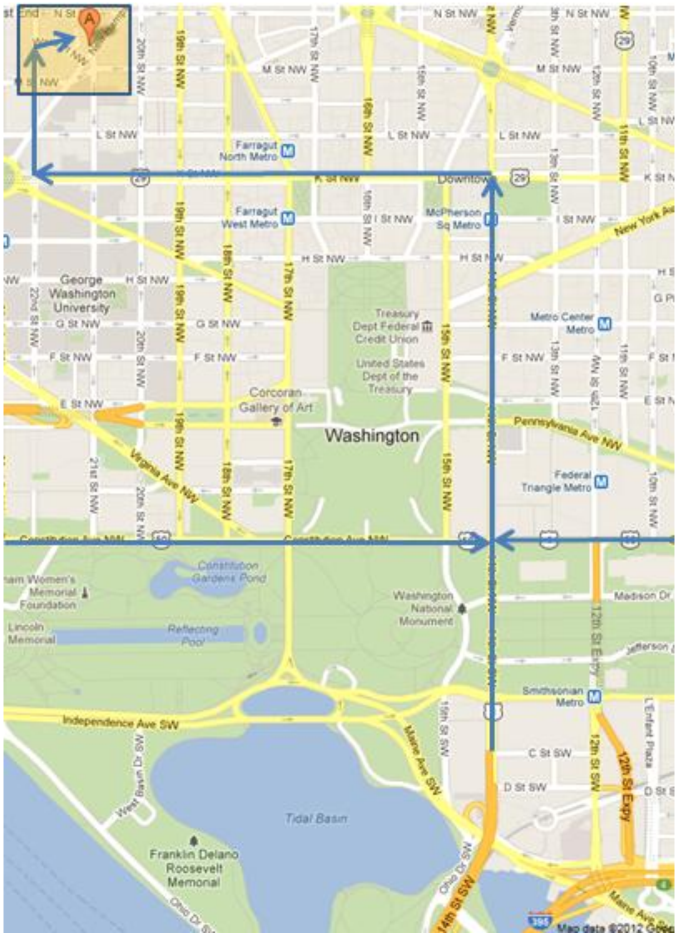


Figure 2 shows the main route suggested for material and equipment deliveries

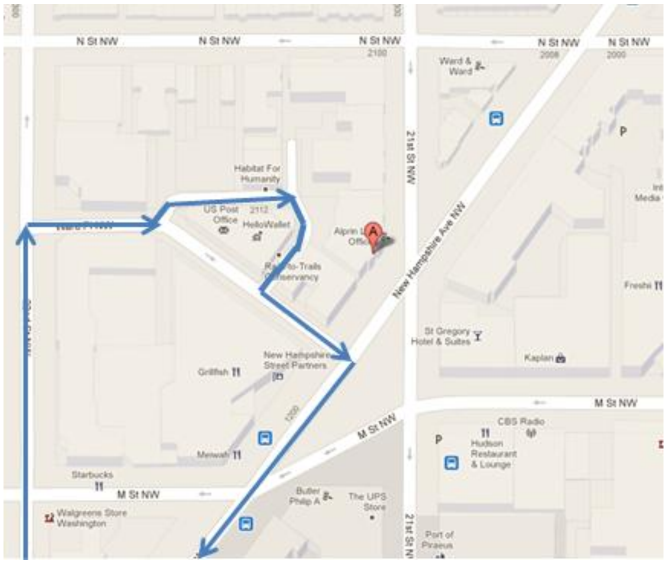


Figure 3 shows the suggested route for delivery of materials and equipment

b. Demolition

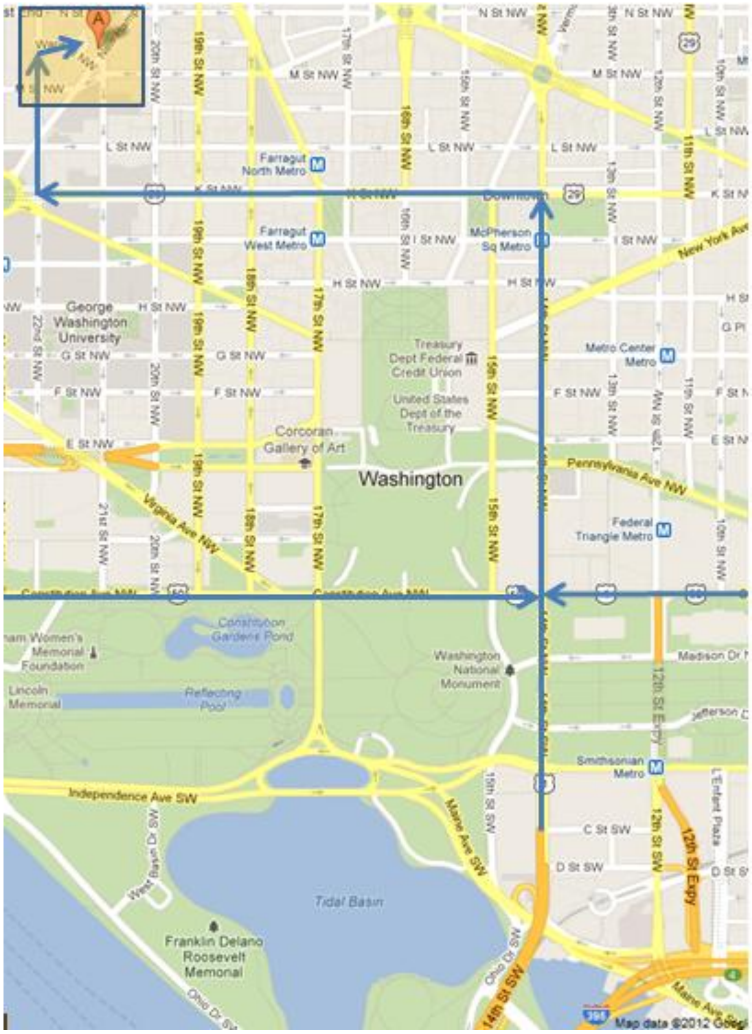


Figure 4 shows the suggested route for trash and recycled material removal

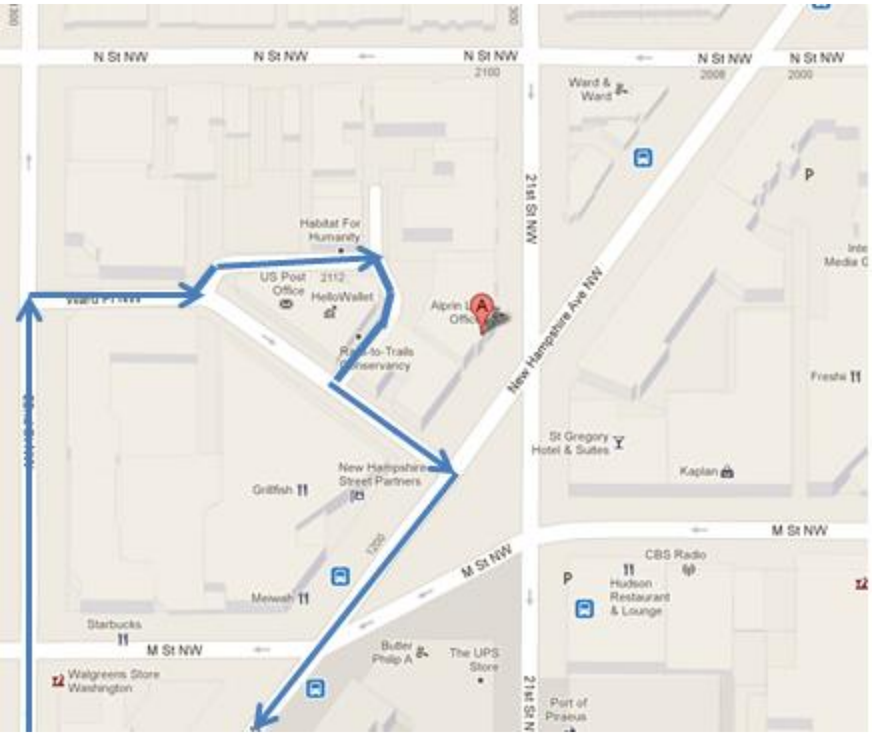


Figure 5 shows the suggested route for trash and recycled material removal

c. Renovations

Client Information

The owner has requested that they not be mentioned or any other information be divulged concerning them, their company or their intentions concerning this renovation. They have requested early on that they do not wish to be exposed or mentioned in any reports for the thesis project. Based on the acceptance of this project for review I have agreed to a strict requirement of not providing any information in this matter. Information can be provided upon faculties' request. The owner is expecting a high-quality and efficient building with an extended life cycle and the capabilities of achieving LEED gold certification. They are expecting that the project be turned over on-time with little or no defects in order to optimize profits for the month of December and the New Year. The owner has expressed strong desires to eliminate any delays in turnover or phasing of completion that might result in construction contractors or other employees completing substantial projects during the month of December when guests are expected to be housed. In order to meet owner's expectations contractors will need to follow the strict schedule in place and be willing to work 5-10 hour days and weekends if necessary in order to assure consistent progress and schedule of the project.

Existing Conditions

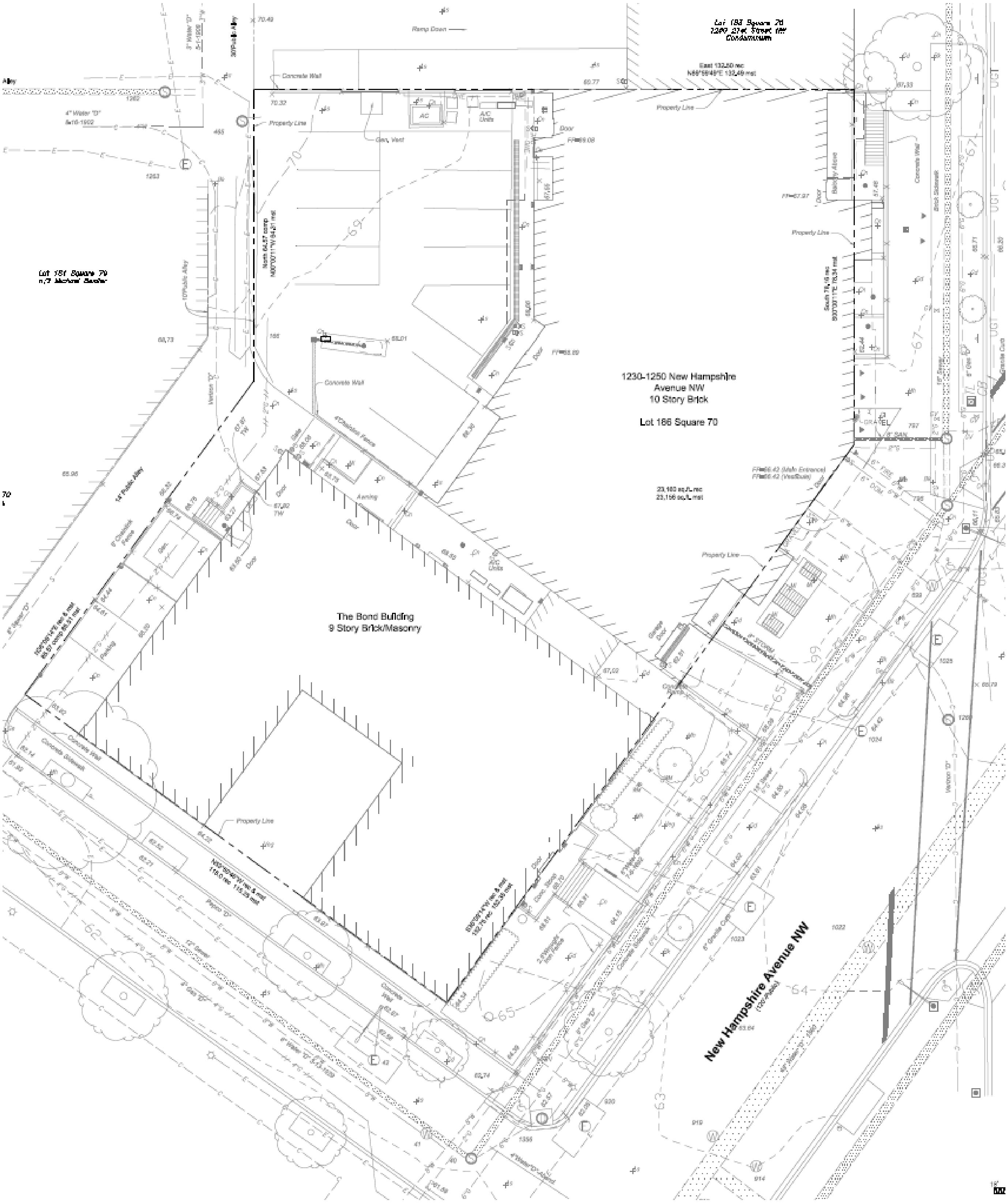


Figure 6 Existing Site Conditions

Project Delivery System

The project delivery system is a hybrid system of CM @ risk and CM agency with Turner holding many of the contracts associated with the construction of the building. They have a desire to eliminate any concern that owners might have by absorbing a great deal of risk in the construction process. The contractor selection method was done so using the lowest bid that met the full scope of work requirements with proper financial capabilities. And contractors that did not meet these requirements were immediately turned away. Contractor companies contracted for this project will be include 50 percent women, or minority owned companies and union labor contractors will also be responsible for the construction of this project.

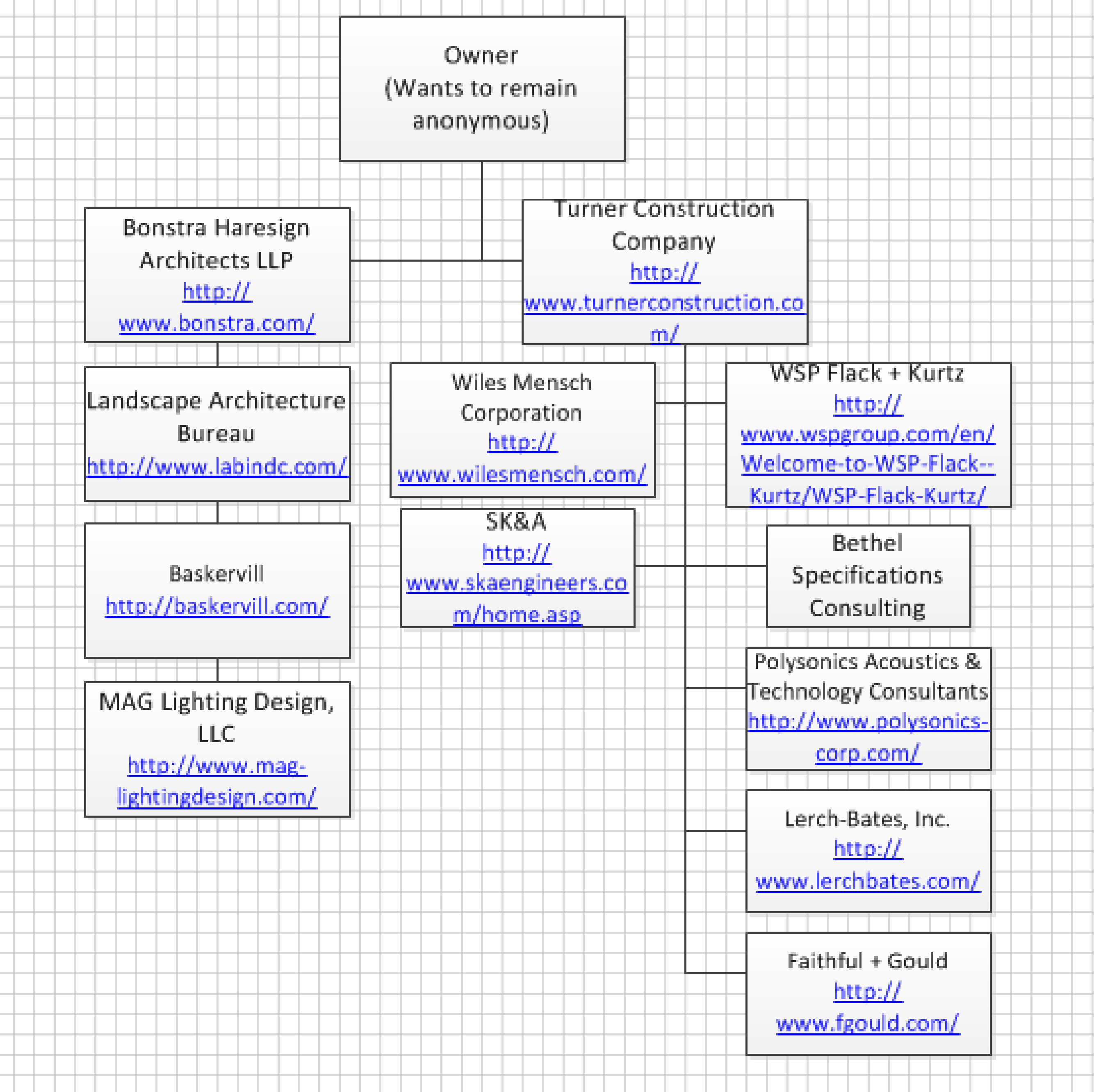


Figure 7 Project Delivery Organization

Staffing Plan

The project executive Gary Ball will oversee the Assistant Superintendent Charles “Chuck” McClellan and the Preconstruction Services Manager Michael J. Whearty. This is only a partial staffing plan which is missing the Project Manager, and the Superintendent. Requests for the full information have been made previously and have not yet to be provided. Further details and information will be provided upon receipt of this information from the Turner Construction Company.

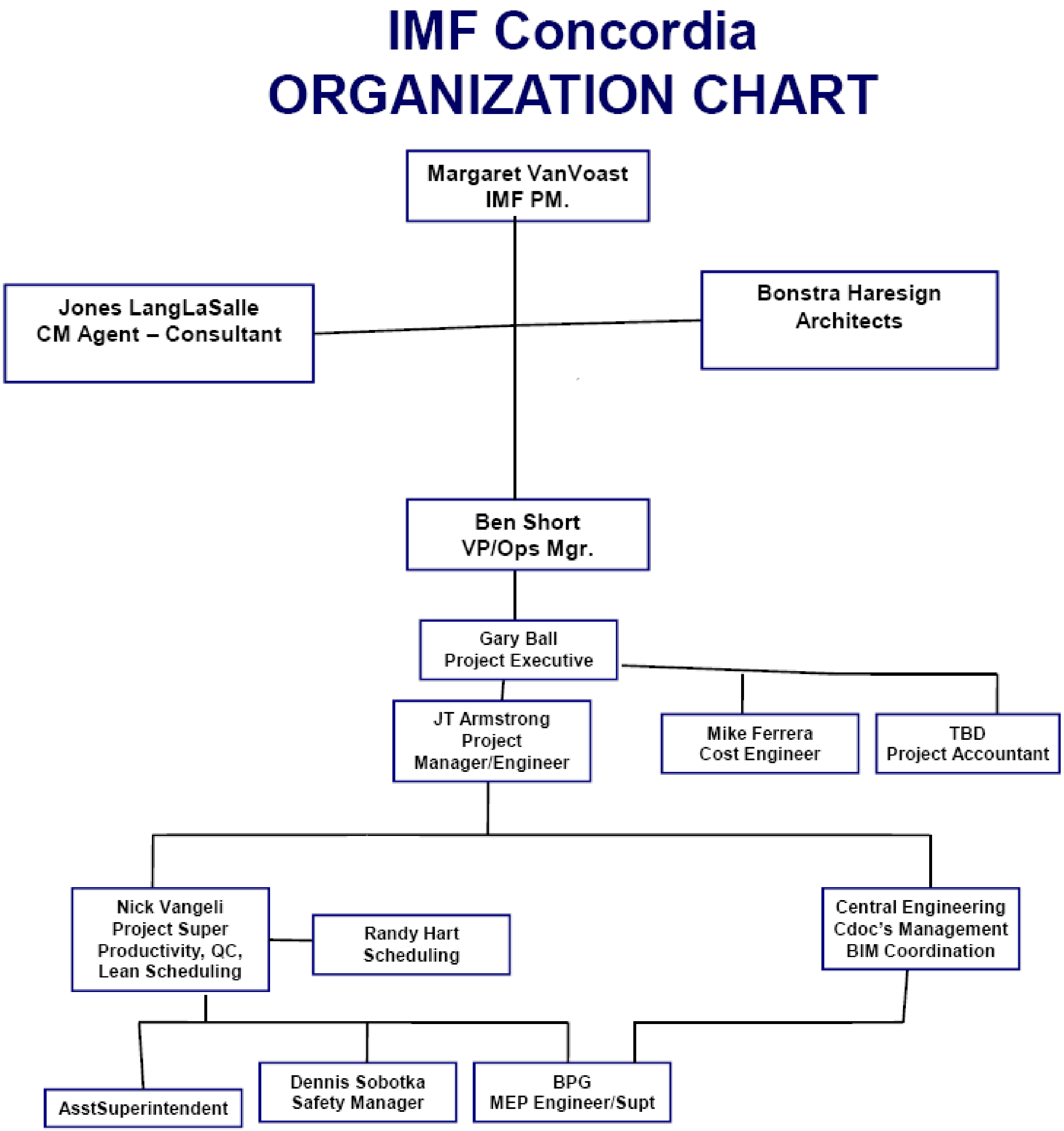


Figure 8 Staffing Plan Organization

Building Systems

The Concordia Hotel's renovation will involve an extensive replacement of the MEP systems throughout the structure. The renovation has set the goal of achieving a LEED gold certification. This certification will be dependent on the successful interaction between the many plumbing, electrical and mechanical systems. There will also be unique green building project features which will be covered in this extensive report.

Demolition

The demolition will involve the demolition of many slabs and walls located throughout the building. This demolition is primarily the removal of outdated MEP systems as well as the removal of multiple slabs and walls located throughout the structure. Extensive abatement and removal of asbestos will conducted as part of the renovation. The demolition will essentially include the removal of the façade except for the southern side, the MEP systems and extensive interior finishes. This description will predominantly focus on the exorbitant amount of concrete slabs that need to be assessed and demolished based on their required finish heights for new façade designs and new layouts. We will start with the description of the cellar level demolition and work our way up and through the building's floors. The demolition will involve two teams, one progressing from the penthouse down to the 5th floor while another team will start soon after and work from the 4th floor down to the cellar-level.

- **Cellar Level-**The black areas shown in figure 1 show the locations of extensive demolition of the existing slabs located on the cellar level. Located throughout the floor and other areas of the structure are Existing Floor Drains (EFD) all of which have removal and capping requirements. There are also several wall locations that will be demolished to make way for the new curtain wall and space on the cellar level. These locations are highlighted in green in figure 9. Figure 9 also shows the demolition of interior walls with in the core of the structure.

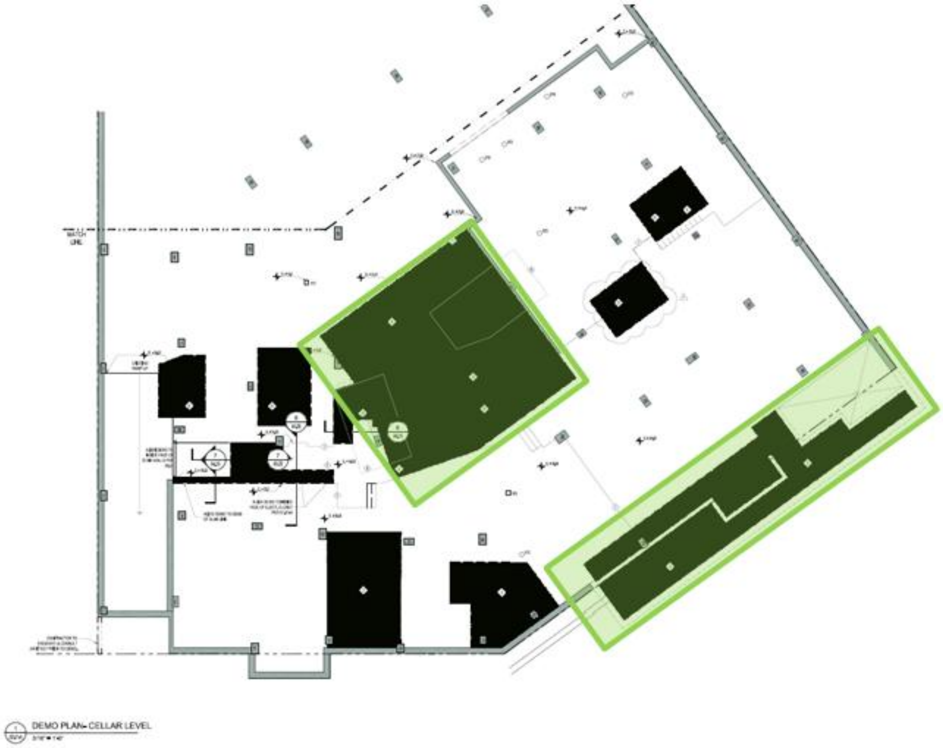


Figure 9 Slabs and walls that require extensive demolition located on the cellar level. Highlights show locations of which existing walls need to be demolished

- **Ground Level-**As I stated previously the black areas show the locations of extensive demolition of the existing slabs located on the cellar level. Located throughout the floor are Existing Floor Drains (EFD) all of which have removal and capping requirements. There are also several wall locations that will be demolished; these locations are highlighted in green in figure 10. Figure 10 also shows the demolition requirements for the ground level that call for demolition of slabs in order to meet specified finish heights.

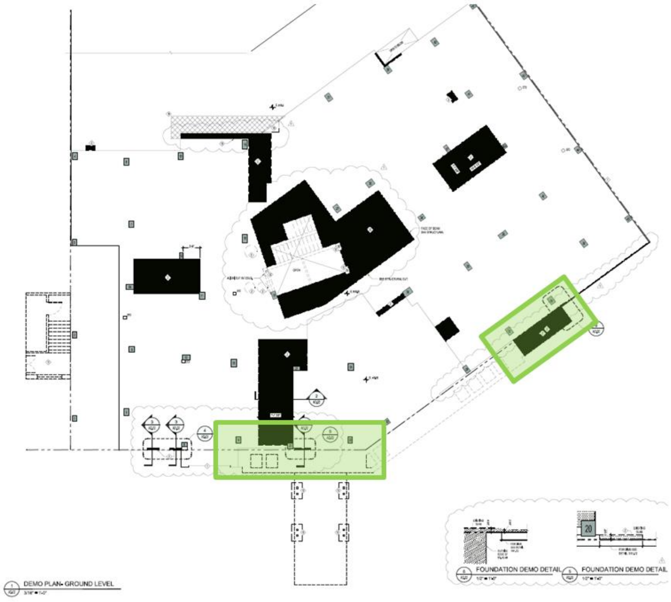


Figure 10 shows the demolition plan for the ground level

- **Second, fourth, sixth and eighth level-**on the even floors there is significantly less required demolition of slabs that need to be demolished however they are shown in black and once again the walls in the interior of the building where the stairs are located require demolition (highlighted in green) in figure 11. The most significant demolition on the second floor will be of the existing canopy located on the east side of the structure on the second level.

Figure 11 shows the demo plan for the even levels with the typical slab and interior wall demolition

- **Third, fifth, seventh and ninth level-**the hatched areas, shown in figure 9, are the locations of required demolition of the slabs. One can also note that the wall demolition is located in the core of the building near the stairwell similar to all the previous mentioned floors. Highlighted in green shows the location of demolition sensitive areas which are shown below in the details for demolition in figure 12.

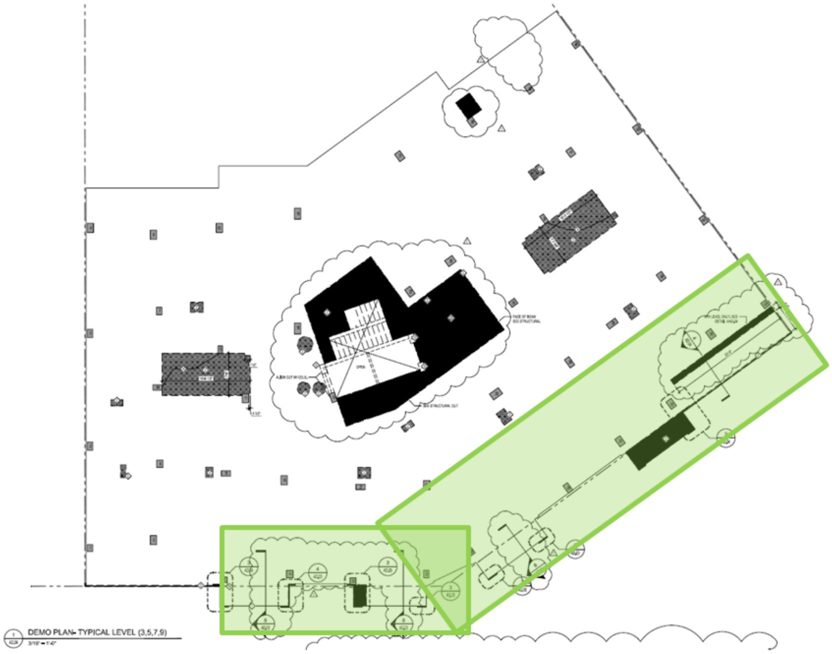


Figure 12 shows the areas of the slab that require demolition along with the walls once again in the core of the building near the stairwell

- **Tenth level-**in figure 13 the demolitions of the slabs are once again shown in black. Similar to the floors below the extent of the demolition required for the walls is isolated to the main stairwell.

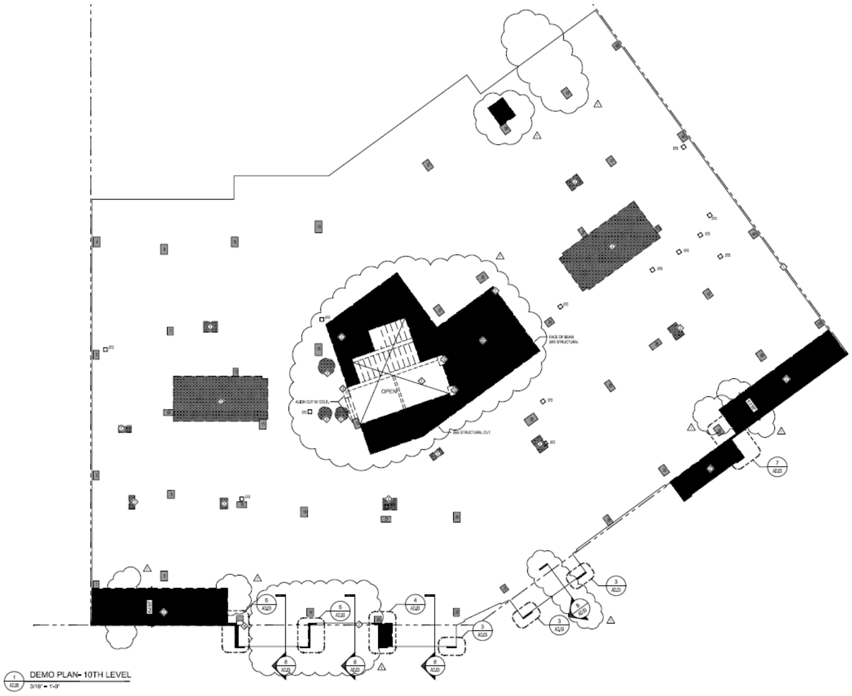


Figure 13 shows the demolition of the slabs and the walls located in the core of the structure

- **Roof level-**The demolition plan below shows the slabs and walls located on the roof level which require demolition. Reference figure 14 for greater detail of the extent of demolition to be conducted on the roof level.

Figure 14 shows the demolition of the slabs and the walls located in the core of the structure

Curtain wall

The curtain wall system is composed of decorative aluminum paneling and trellises. I have also included the many other wall types for review and understanding of the building's entire faced system. The curtain wall will be installed utilizing a scaffolding lift system which will advance from the top floor penthouse down to the lower levels. The design and construction responsibility of the contractor installing the curtain wall is to construct a water tight building envelope. The construction team will need to create a building mock-up in order to show the quality and appearance of the building envelope for owner approval. The building envelope will require testing and quality assurance in order to meet the stringent quality standards required for this type of construction project. This project is planning to achieve LEED Gold certification and in order to achieve this certification the building envelope construction will be inspected and expected to meet the requirements of top quality construction.

- **Exterior wall type # 12** consists of 6" Batt insulation, 5/8" thick exterior sheathing, liquid applied air barrier, 2" rigid insulation, aluminum clip, sealant with backer rod and shims where required. The last layer to make up the wall is the aluminum composite material panel as shown in figure 15.

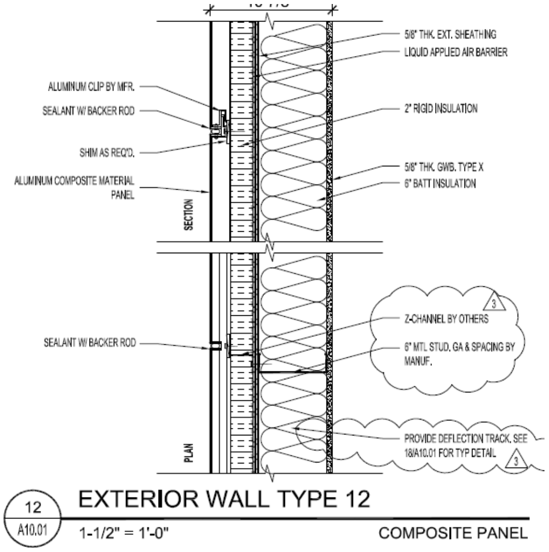


Figure 15 Exterior wall type # 12

- **Exterior wall type # 14** will be composed of 7-5/8” thick Concrete Masonry Units (CMU) with a liquid applied air barrier, Z-channel fasteners @ 16” O.C., 2” moisture resistant rigid insulation, required shim to separate aluminum channel from Z-channel, max shims ¾” thick, weeped calcium silicate channel, and finally a calcium silicate masonry unit as shown in figure 16.

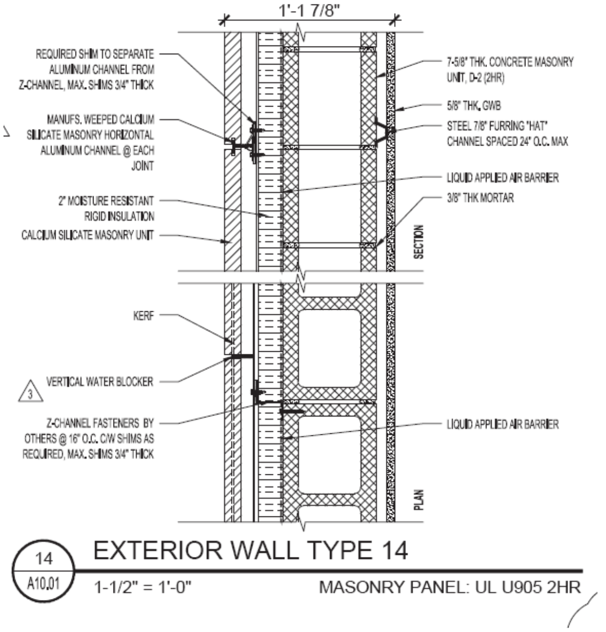


Figure 16 Exterior wall type # 14

- **Exterior wall type # 15** has 7-5/8” thick CMUs while wall type 15a has 11-5/8” thick CMUs. They have essentially matching components which include liquid applied air barriers, 2” rigid insulation, aluminum clip, sealant with backer rod and shims where required. The last layer to make up the wall is the aluminum composite material panel as shown in figure 17.

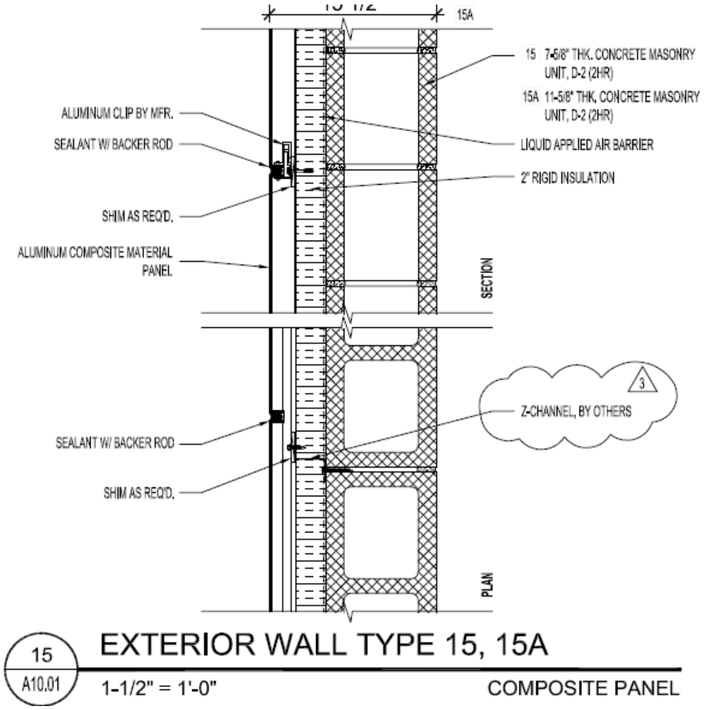


Figure 17 Exterior wall type # 15

- **Exterior wall type # 16** has 5-5/8” CMUs, liquid applied air barrier, 2” rigid insulation, 3-5/8” CMU, and lastly metal anchors as shown in figure 18.

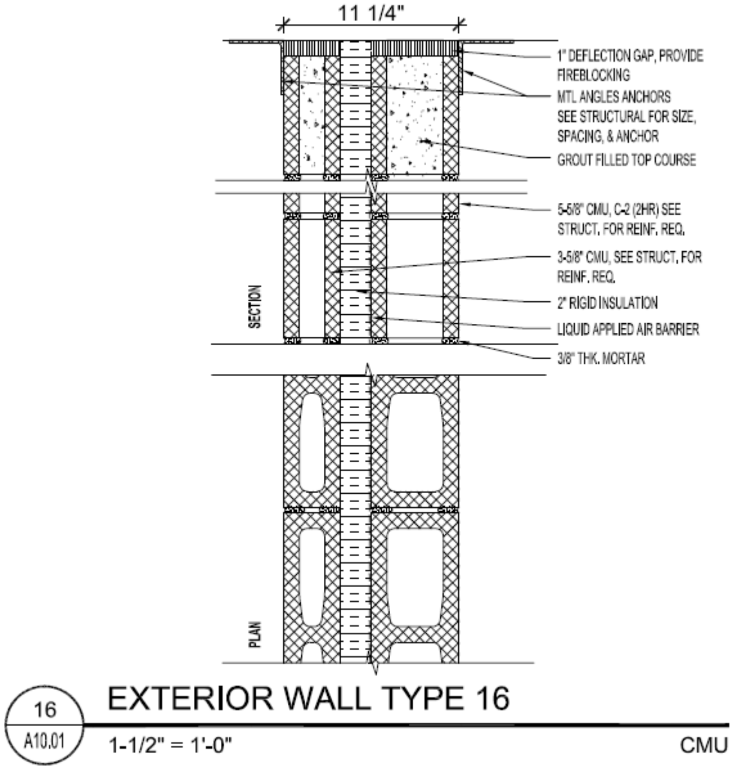


Figure 18 Exterior wall type # 16

- **Screen/Coping** the building façade has an Aluminum Trellis and aluminum panels with aluminum coping as shown in figure 19.

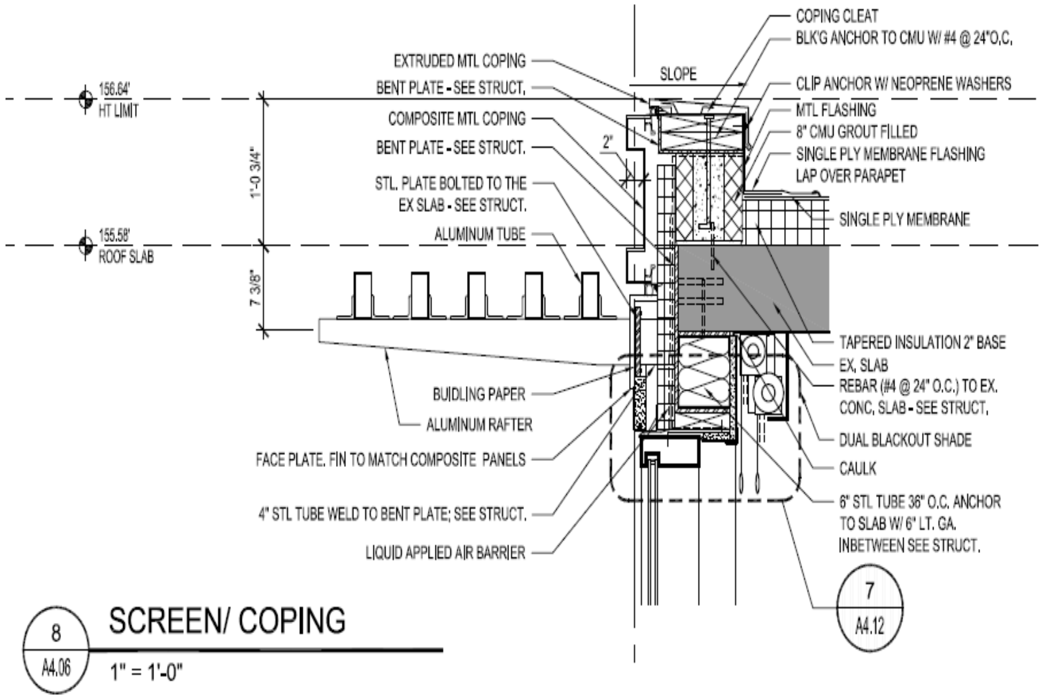


Figure 19 Screen/Coping Detail

Mechanical

The mechanical system will consist of two (2) Air Handling Units (AHU) to condition and circulate air for the entire building and one Makeup Air Unit (MAU) for providing supply air for the building. AHU-01 will be a 100 % outside air packaged energy recovery AHU which will be electric heat. In figure 20 the AHU-01 is highlighted in blue, it will be located in the mechanical room cellar and it will service the ground level. The detail and location of AHU-01 is shown in figure 21. AHU-02 will also be a 100 % outside air packaged energy recovery AHU; however, it will be gas heat. AHU-02 will be located on the rooftop and will be responsible for servicing the guestrooms its location is shown highlighted in yellow in figure 22 and the mechanical section is shown highlighted in yellow in figure 23 as well. MAU-1 will be a 100% outside air MAU which will be indirect gas-fired and it will be located in the cellar level in the same location as AHU-01 shown highlighted in red in figure 20. The MAU mechanical section is shown in figure 21 with the MAU highlighted in red. The building will have nine (9) fans for the many areas requiring ventilation which will be five (5) supplies, one (1) exhaust, one (1) return and two (2) exhaust/returns. As I stated in my Building Statistics there will be new Variable Refrigerant Volume (VRV) systems installed into the structure as well as eleven (11) VRV air cooled condenser outdoor units located on every floor, and three (3) air cooled split system located in the fire control room the IT/telecom room and the elevator control room. Lastly, there will be two (2) electric unit heaters and one (1) relief hood.

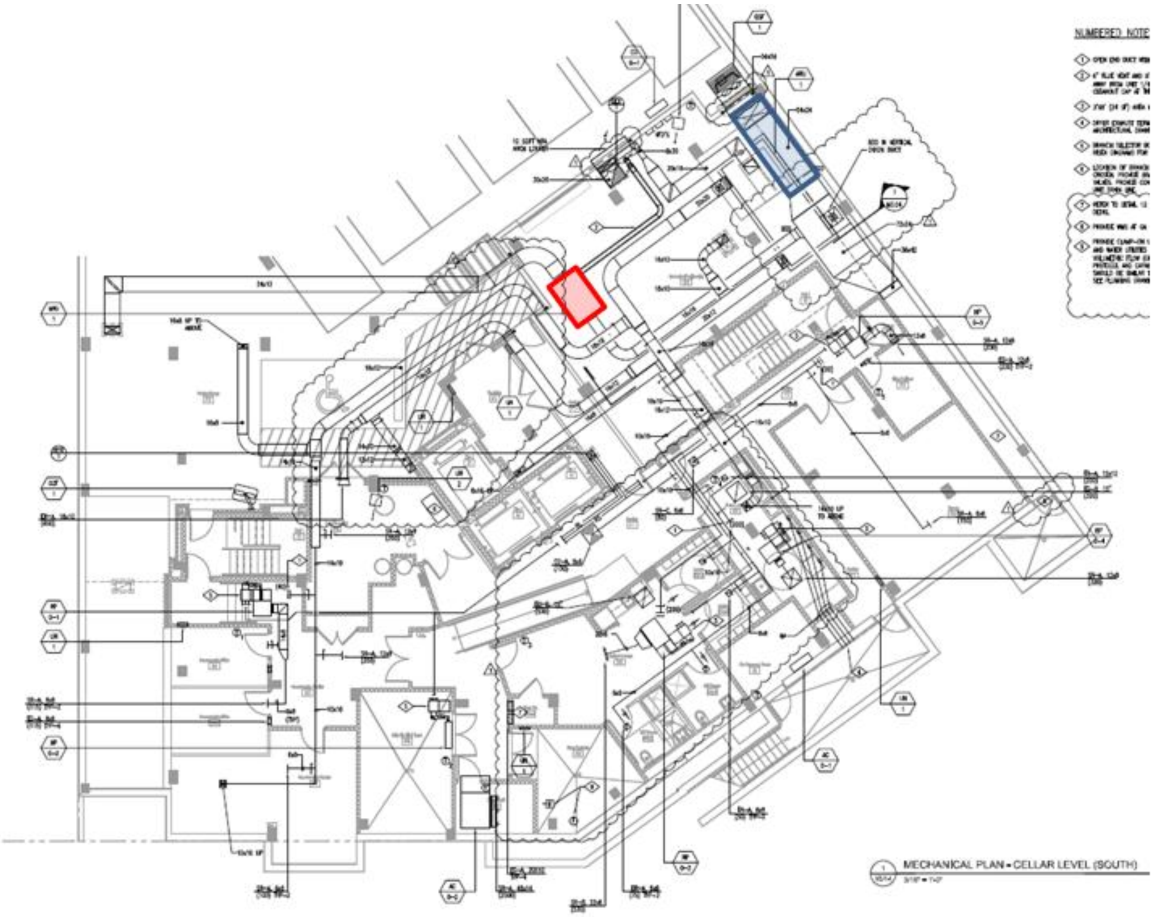


Figure 20 shows the location of the air handling unit AHU-1 outlined in blue as well as the make-up air unit MAU-1 outlined in red

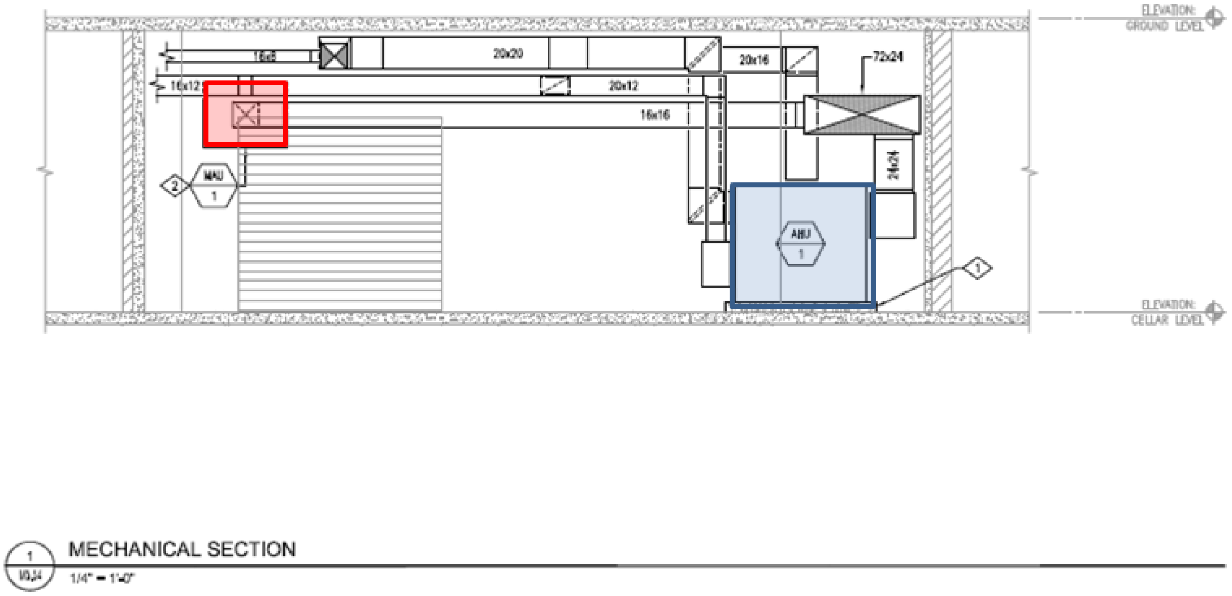


Figure 21 shows a section view of the mechanical room where the AHU-01 and MAU-1 are located

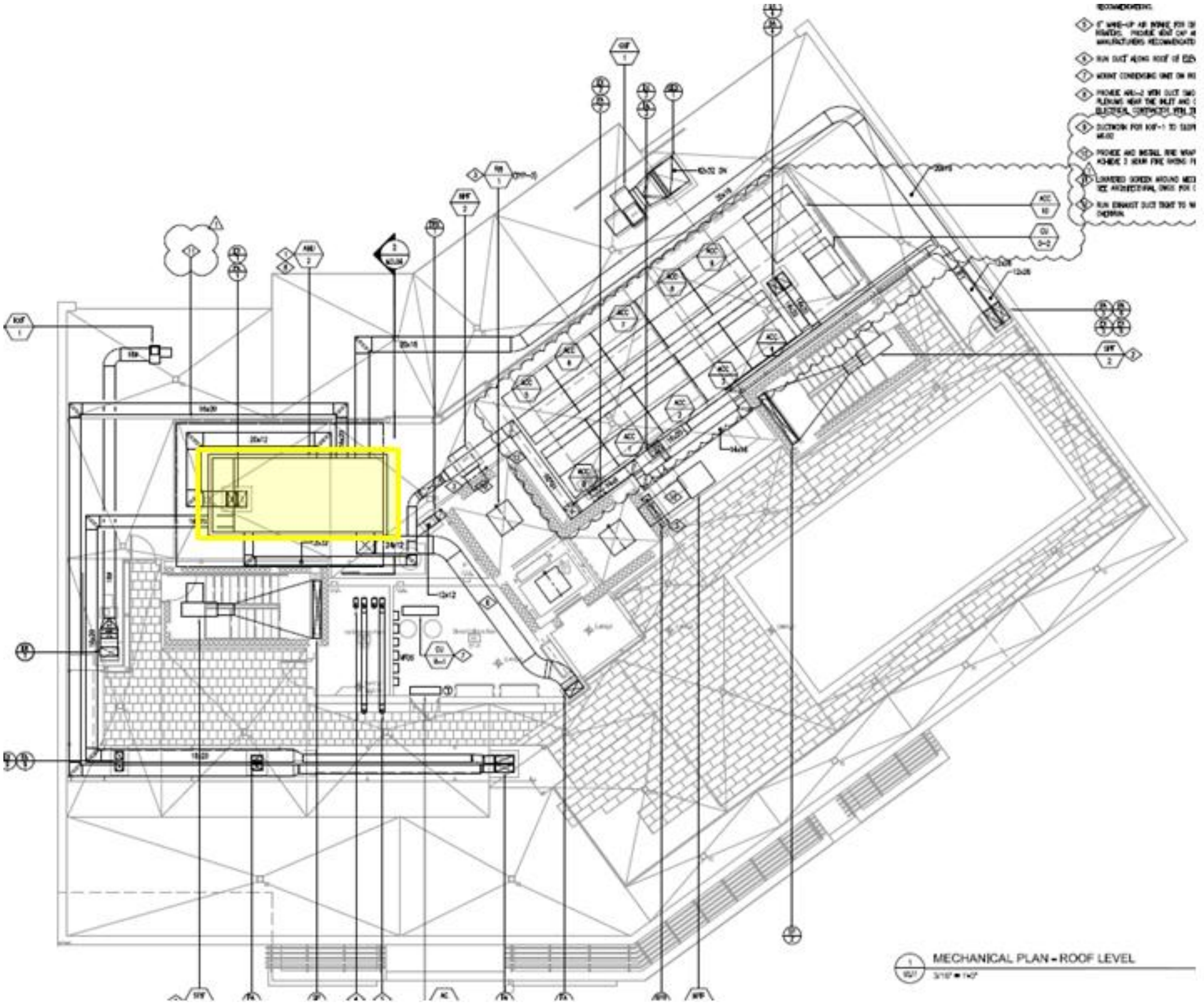


Figure 22 shows the location of the AHU-2 on a floor plan of the roof level of the structure

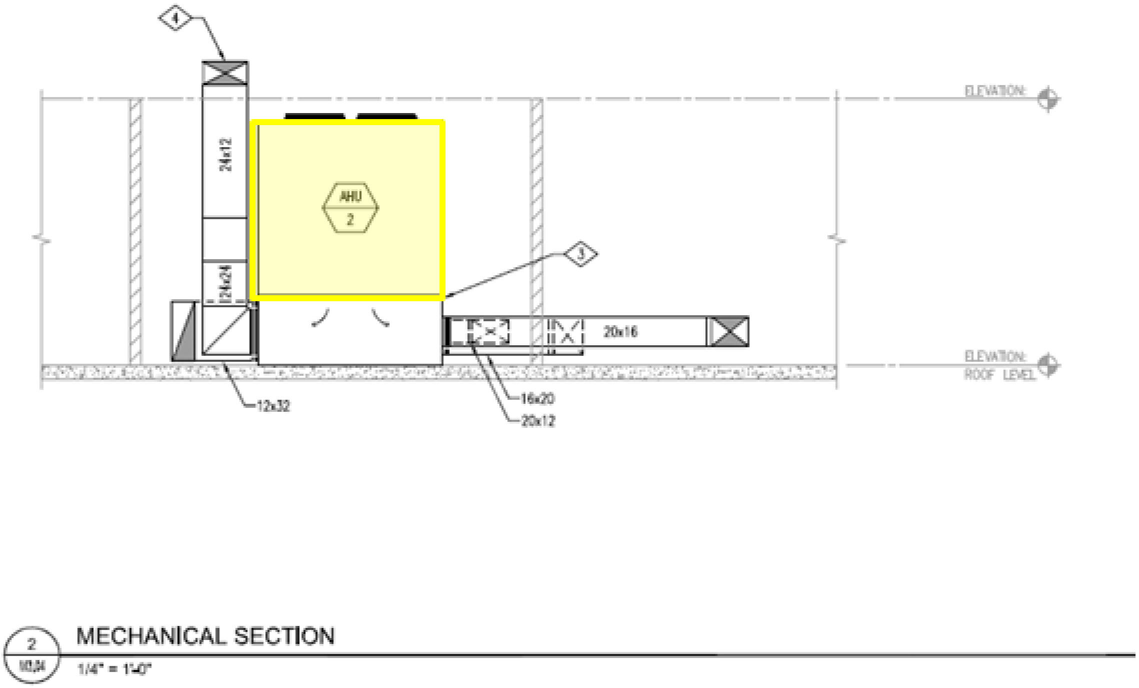


Figure 23 shows AHU-2 located on the roof of the structure and responsible for servicing

Fire Suppression

The fire suppression system that will be used is a combination of a wet-pipe system and a dry-pipe system in areas where the freeze thaw cycle is likely to occur. A Peerless model T41 jockey pump combined with a Peerless Model 6AEF10 Horizontal Split Case Fire Pump. The pump and jockey pump will distribute water to the sprinkler system and maintain water pressure throughout the building. The loading dock will have a dry pendant fire sprinkler system (based on winter freezing conditions) connected to the wet-pipe system located in the heated ceiling space. Details are provided below of concealed and upright sprinkler systems.

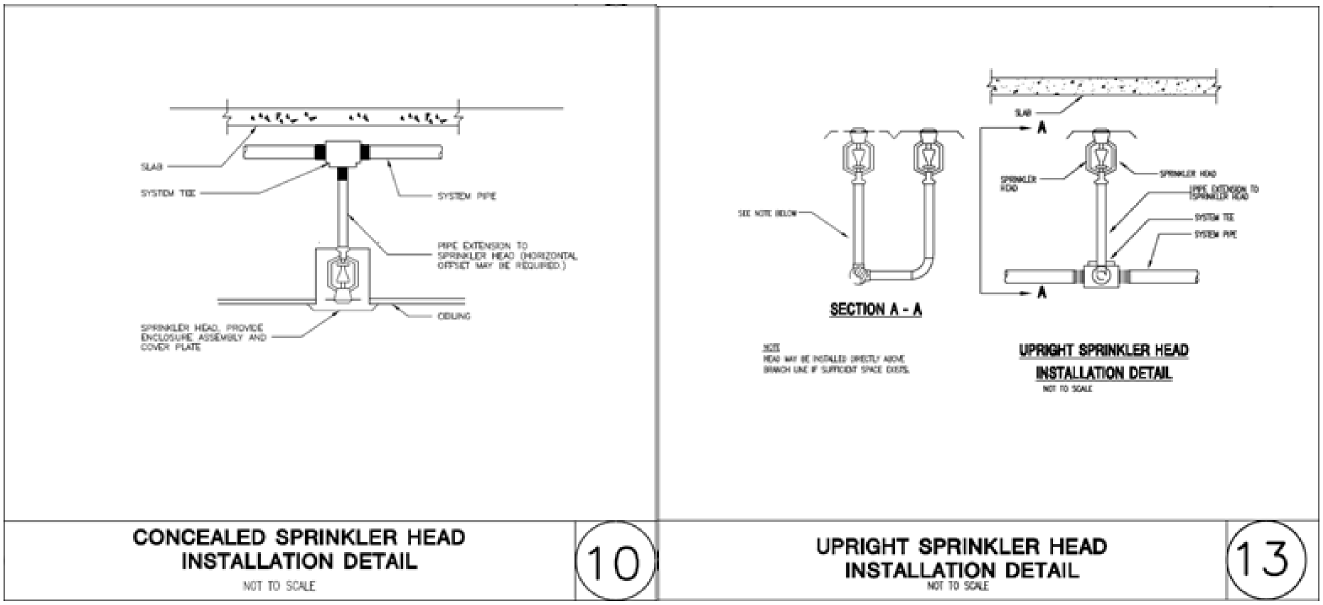


Figure 24 Details 10 & 13 show the required sprinkler head concealment and installation

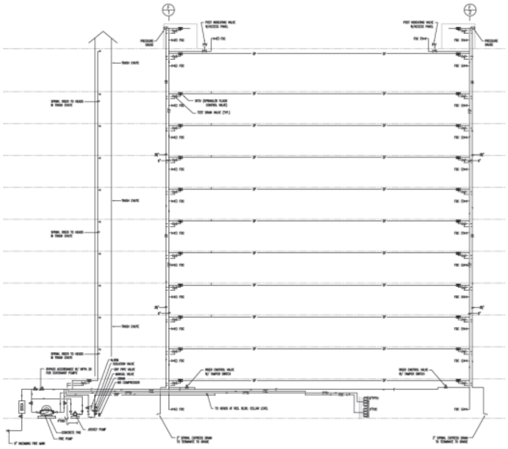


Figure 25 shows the riser diagram for the fire suppression system of the structure

Green Building Project Features

Due to the outdated inefficient systems which were installed when the building was completed this renovation will gut and renovate all the major MEP systems. The renovation of the IMF Concordia is planning to achieve a LEED Gold certification. The goal of achieving this certification will be dependent on the many systems of the structure coming together to produce an efficient building.

- Plumbing
  - IMF Concordia's renovation will include the installation of Domestic Booster Pumps in order to help produce a more efficient, energy saving plumbing systems
- Electrical
  - Turner's renovation of the Concordia will include the installation of LED down lights in many of the corridors as well as many other LED fixtures throughout the building.
- Mechanical
  - This renovation will make the building's mechanical system more efficient by installing 100% outside air packaged energy recovery air handling units and 100% outside air makeup air units
  - The mechanical system will be improved drastically by installing Variable Refrigerant Volume (VRV) systems. (http://www.mechanicalservicesfiji.com/vrv_aircon.html)
- Roofing
  - The live planter roofing will consist of a liquid applied air barrier installed on top of the existing slab which will be followed by much thicker tapered insulation, a single ply membrane and lastly live roof planter beds.

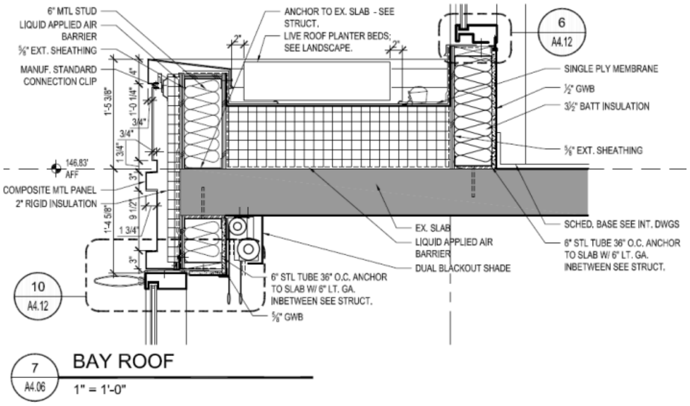


Figure 26 live planter for bay area of roofing detail

Electrical

The electrical system will consist of 13 transformers. The sizes of these transformers are a 3, 6, 9, 15, 30, 45, 75, 112.5, 150, 225, 300, 500 and 750 KVA transformers. There will be 28 panel boards located throughout the building faced with the task of providing power to equipment and systems located on each floor in different regions of the structure. The main utility electric will come in from the eastern side of the structure and travel into the main electrical room located in the cellar of the structure. In the main electrical room (located in the cellar) the electric will be fed into the Main switchboard (MS-1), a 4000A 208/120V-3phase 4W 100KAIC system which will distribute electric to the remainder of the building. MS-1 will then provide power to DPR-1 which will provide service to the LPR-1 and the LP-POOL for the major pool equipment. MS-1 will also service DPC-1, DPL-3, SLPC-1ELPC-1 and AHU-2 located on the roof of the structure. The electrical system will have a 15 KVA Uninterruptable Power Supply (UPS) system utilizing an Automatic Transfer Switch (ATS) and a generator located in the garage level of the structure.

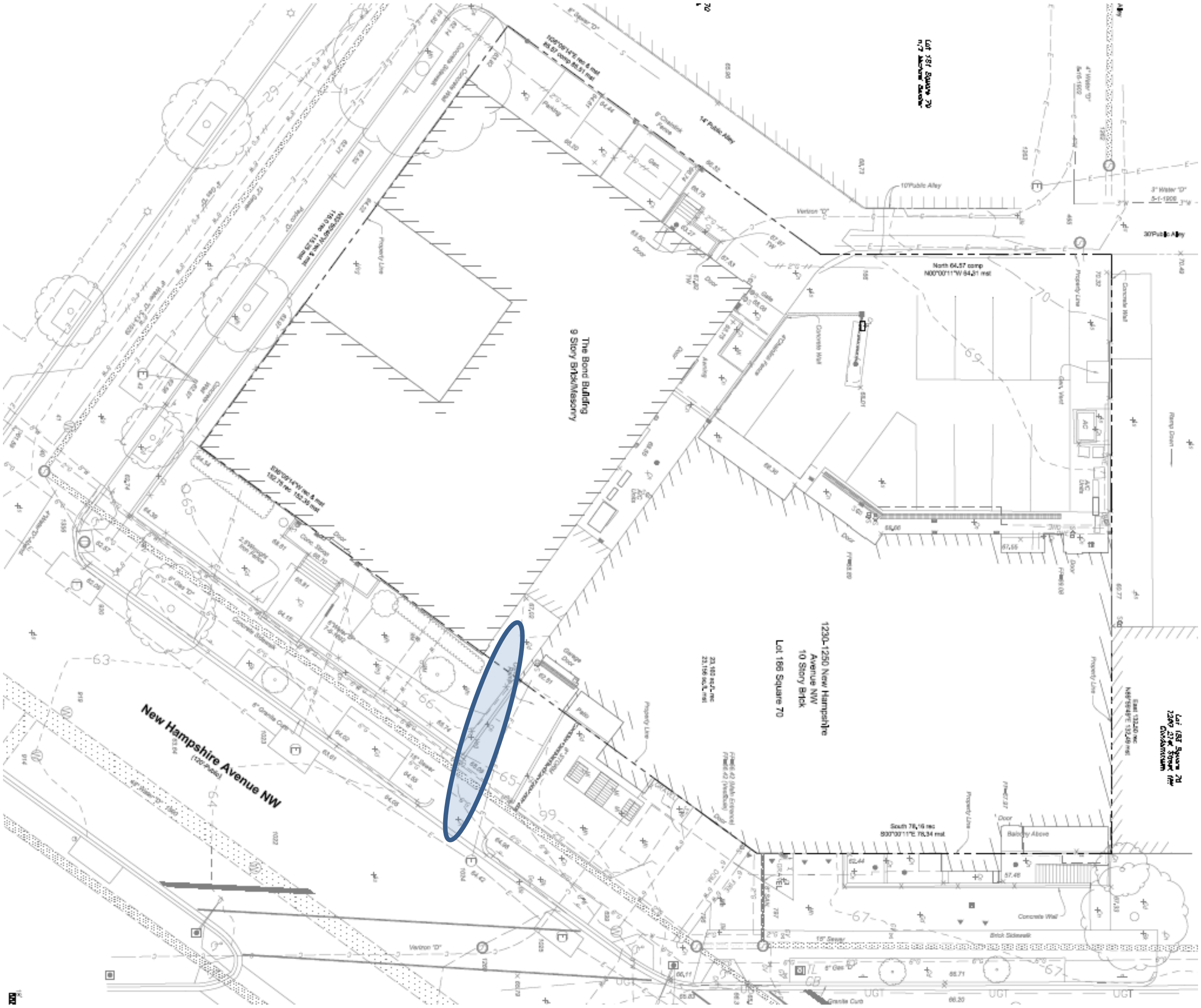


Figure 27 shows the electric utility, outlined in blue, entering the structure from the eastern side

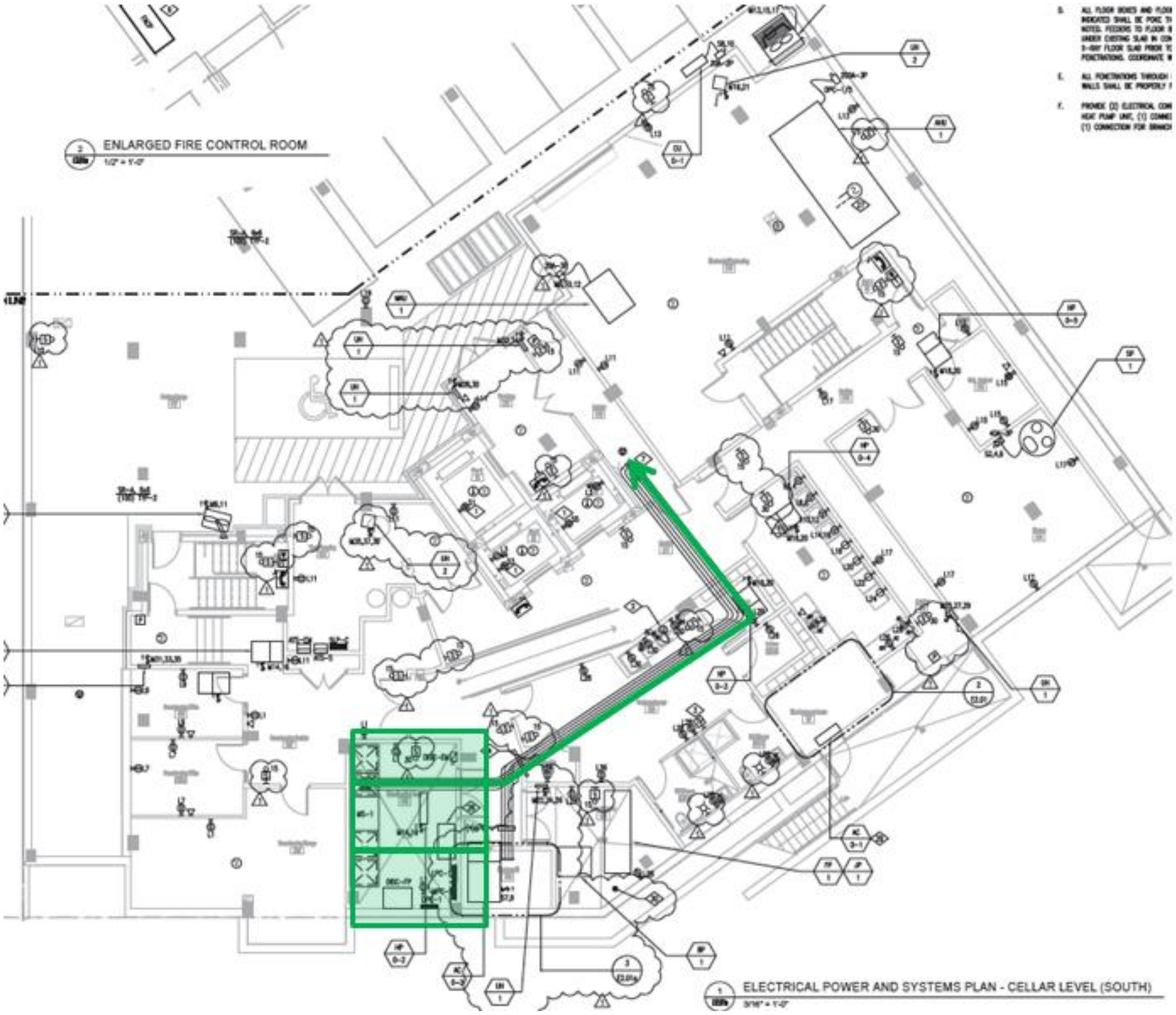


Figure 28 shows the electric utility coming into the main switchgear MS-1 located in the main electrical room, highlighted in green, in the cellar level. Green arrows show the direction of power traveling to floor penetrations where it continues up to the second

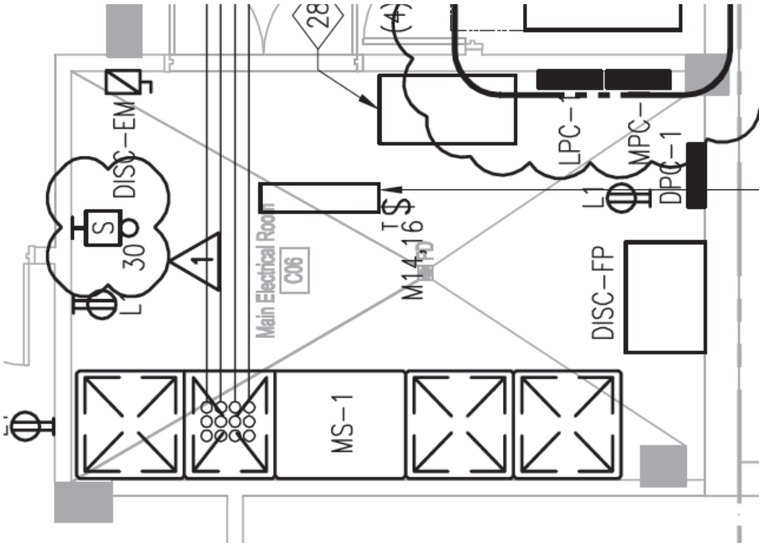


Figure 29 shows a zoom in on the main electrical room showing the main switchboard MS-1

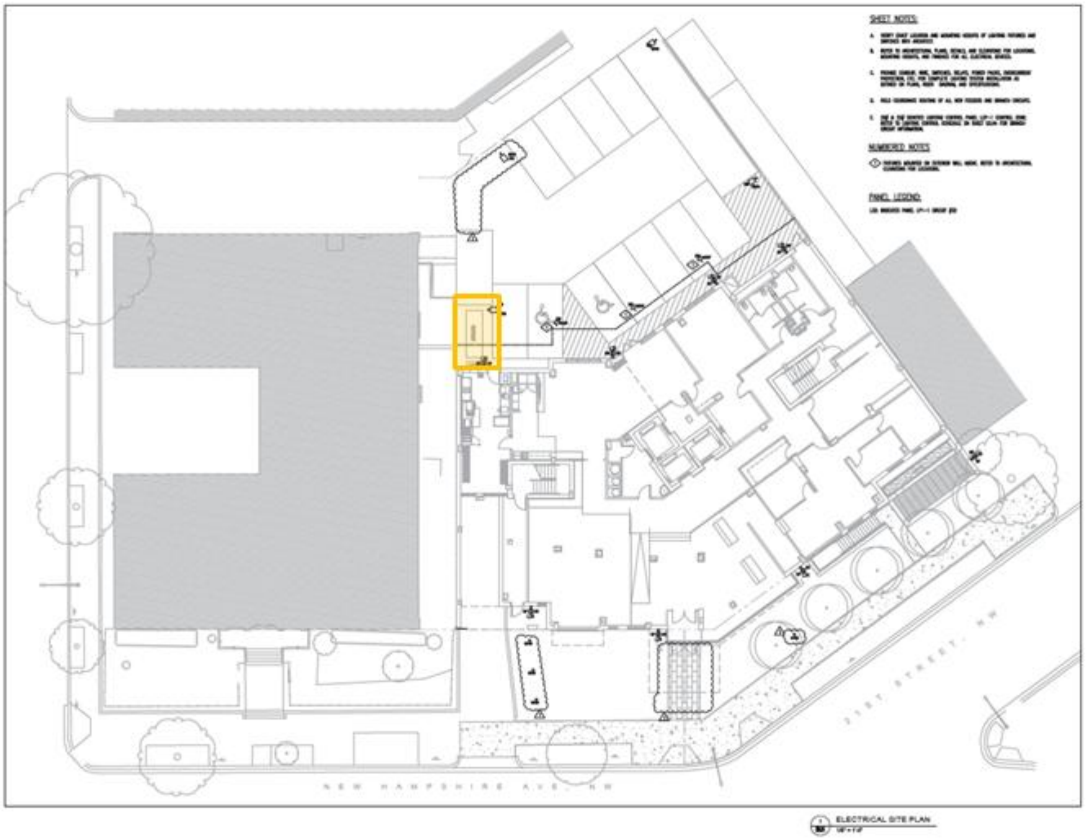


Figure 30 shows the generator's location in the parking garage, which is outlined in orange

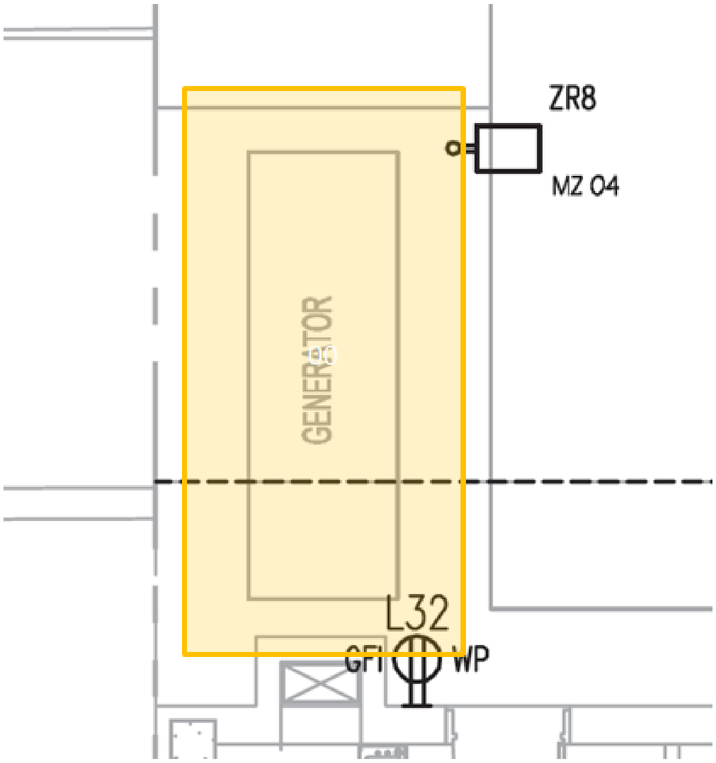


Figure 31 shows a zoom in on the generator used for the 15 KVA UPS system

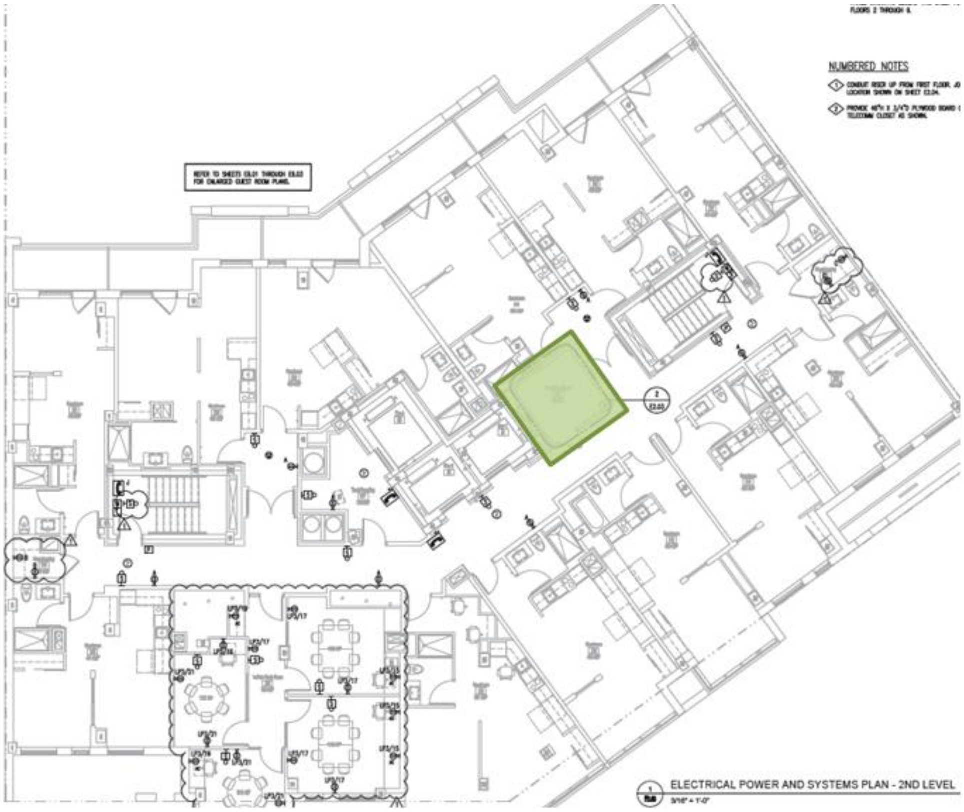


Figure 32 shows the location of the electric room on the second floor, which is repeated on each consecutive floor above

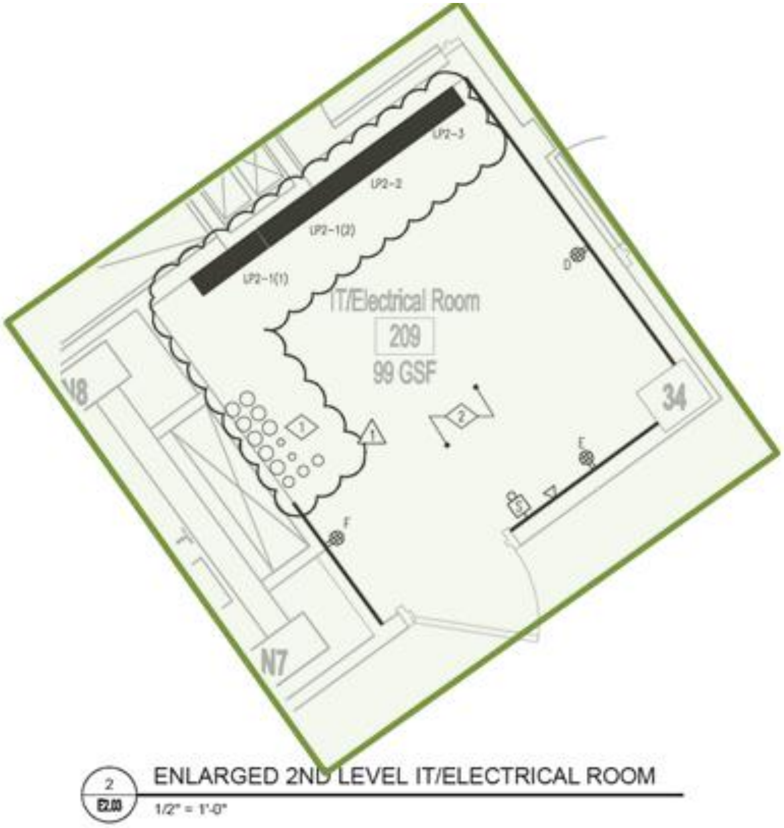


Figure 33 shows a zoom in of the electrical room located on the second floor

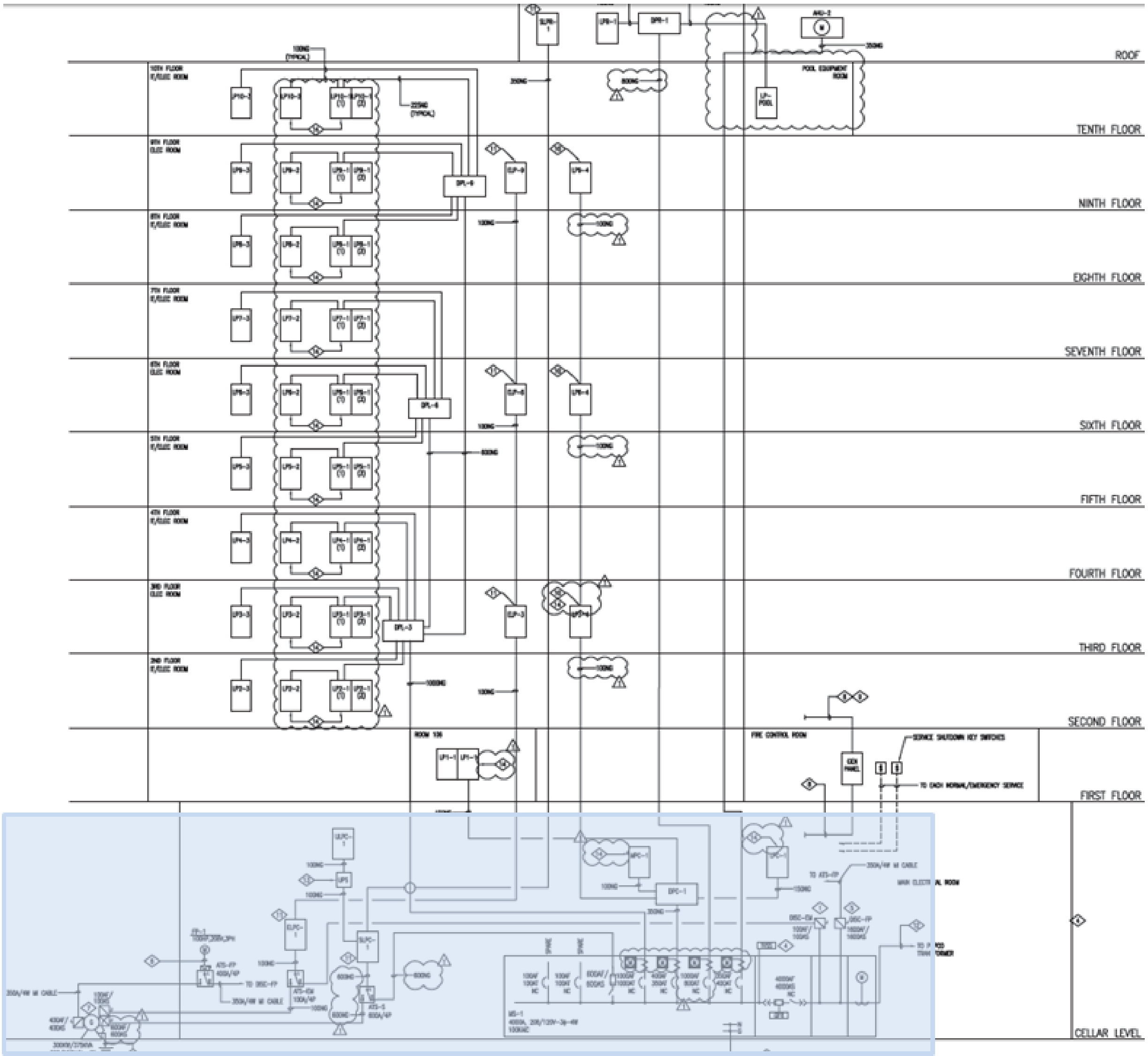


Figure 34 shows the riser diagram for the electrical system of the structure, outlined in blue is the redundant system as well as the Main Switchboard (MS-1)

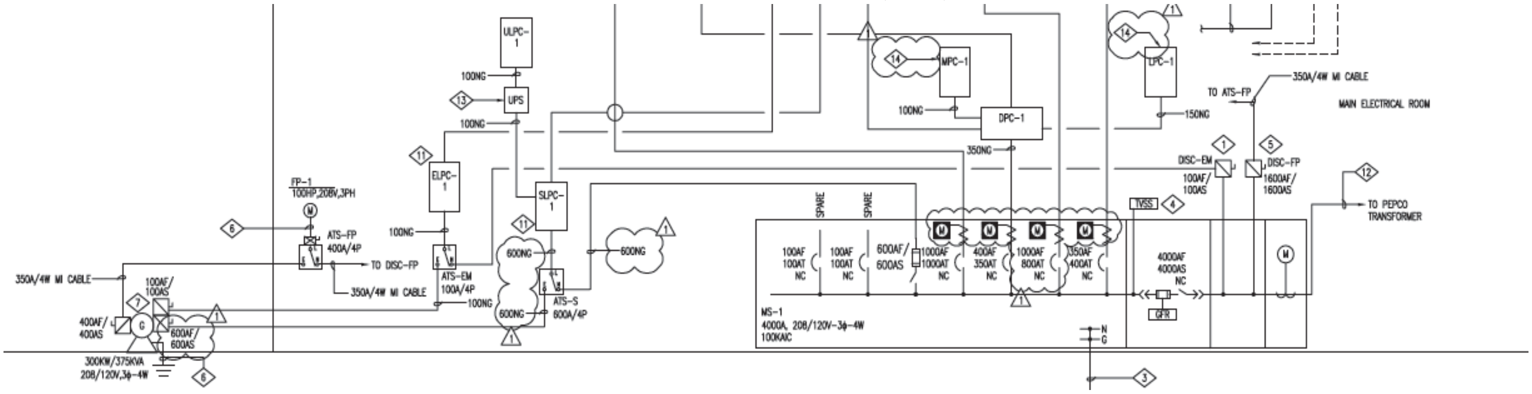


Figure 35 shows the riser diagram of the electrical system focusing on the redundant system and MS-1

Project Cost Evaluation

Project Team

Total Project Cost	$ 23,000,000.00
Detailed Structural Estimate	$ 5,132,564.81
General Conditions Costs	$ 1,330,610.00
Square Foot Estimate	$ 22,336,000.00
Construction Cost (CC)	$ 22,000,000.00
Major Building Systems Costs	$ 10,200,000.00

Table 4 Project Cost Summary

Detailed Structural Systems Estimate

The existing structure consists of concrete columns, and beams. This structure received many upgrades to the structure and foundation due to the additional dead load of the new elevator/stair core. And the dead load of the swimming pool on the upper floors. Some of the upgrades included a renovation of the foundation through the installation of 78 Micro piles and carbon fiber reinforcement to slabs and beams.

The detailed Structural estimate is broken up into four parts starting with a beam takeoff and cost estimate, a column estimate, a foundation estimate and finally a slab cost analysis for the demolished floors. Unfortunately this report was not able to include the Carbon Fiber Reinforcement Panels (CFRP) Due to R.S. Means not having this as one of their takeoff items. In order to assemble a more accurate structural estimate this should also be included. A summary of the costs are shown in Table 5.

Table 5: Detailed Structural Estimate

Item	Description	Extended Total	Extended Total O&P
1	Cast-in-Place Beam	$ 147,792.20	$ 197,877.33
2	Cast-in-Place Columns	$ 2,314,994.51	$ 3,010,473.14
3	Micro Piles	$ 159,939.00	$ 200,421.00
4	Concrete Slabs	$ 1,349,318.19	$ 1,723,793.34
5	Total	$ 3,972,043.90	$ 5,132,564.81

Table 5 Detailed Schedule Estimate Summary of Major Systems

1. Cast-In-Place Concrete Beams

New Beams were installed to strengthen and support slabs and replace beams that were removed from the structure. Some beams were removed to make room for the new stairs and elevator cores. Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate. For the cast-in-place concrete beams the item that most closely matched the beams within the building was the item with a line item # 033053400300 and with a description of “Structural concrete, in place, beam (3500 psi), 5 kip per L.F., 10’ span, includes forms(4 uses), reinforcing steel, concrete, placing and finishing”. This item came with an extended total of $953.41/C.Y. as well as an extended total with O&P of $1,276.51/C.Y. The analysis began with the first floor and moved up and through the building to the high roof. The High roof beams were accurately assessed under similar beam types with similar measurements. This was completed so as to save space and eliminate confusion in the detailed takeoff below. Details concerning the descriptions, measurements, quantities as well as the costs of these beams are listed below in table 6.

Table 6: Cast-In-Place Beam Schedule

Item	Description	Length (ft.)	Width (ft.)	Depth (ft.)	C.Y.	Extended Total	Extended Total O&P
1	1B01	73.32	1.5	1.5	6.1	$ 5,825.34	$ 7,799.48
2	1B02	71.47	1.5	1.5	6.0	$ 5,678.35	$ 7,602.68
3	1B03	26.21	0.9	2.1	1.9	$ 1,802.82	$ 2,413.78
4	1B04	10.13	0.7	2.1	0.5	$ 506.75	$ 678.48
5	1B05	23.06	0.7	2.1	1.2	$ 1,153.57	$ 1,544.50
6	TB01	54.18	1.0	1.5	3.0	$ 2,869.76	$ 3,842.30
7	TB01C	33.05	1.0	1.5	1.8	$ 1,750.57	$ 2,343.81
8	TB02	170.32	1.0	1.5	9.5	$ 9,021.38	$ 12,078.62
9	TB03	150.71	1.0	1.5	8.4	$ 7,982.69	$ 10,687.93
10	TB04	60.53	1.0	1.5	3.4	$ 3,206.11	$ 4,292.62
11	TB04C	19.88	1.0	1.5	1.1	$ 1,052.99	$ 1,409.83
12	TB06	210.41	1.0	1.5	11.7	$ 11,144.83	$ 14,921.69
13	TB06C	18.35	1.0	1.5	1.0	$ 971.95	$ 1,301.33
14	TB08	123.24	1.0	1.5	6.8	$ 6,527.68	$ 8,739.84
15	TB09	119.13	1.0	1.5	6.6	$ 6,309.99	$ 8,448.37
16	TB11	133.75	1.0	1.5	7.4	$ 7,084.37	$ 9,485.18
17	TB12	114.18	1.0	1.5	6.3	$ 6,047.80	$ 8,097.33
18	TB13	126.77	1.0	1.5	7.0	$ 6,714.65	$ 8,990.18
19	TB14	246.38	1.0	1.5	13.7	$ 13,050.06	$ 17,472.59
20	TB15	227.27	1.0	1.5	12.6	$ 12,037.86	$ 16,117.36
21	TB16	126.16	1.0	1.5	7.0	$ 6,682.34	$ 8,946.92
22	TB17	155.29	1.0	1.5	8.6	$ 8,225.28	$ 11,012.74
23	TB17C	92.05	1.0	1.5	5.1	$ 4,875.63	$ 6,527.93
24	TB18	192.26	1.0	1.5	10.7	$ 10,183.48	$ 13,634.55
25	TB18C	28.03	1.0	1.5	1.6	$ 1,484.67	$ 1,987.81
26	TB19	78.04	1.0	1.5	4.3	$ 4,133.56	$ 5,534.38
27	TB19C	27.71	1.0	1.5	1.5	$ 1,467.72	$ 1,965.12
28				Total		$ 147,792.20	$ 197,877.33

Table 6 Cast-In-Place Beam Estimate

2. Cast-In-Place Concrete Column Estimate

Certain columns were removed and relocated to provide additional support for key areas near the elevator/stair core and to support the swimming pool on the top floor. Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate. For the cast-in-place concrete columns the item that most closely matched the columns within the building was the item with a line item # 033053400920 and with a description of "Structural concrete, in place, beam (4000 psi), square, avg. reinforcing, 24"x24",includes forms(4 uses), reinforcing steel, concrete, placing and finishing". This item came with an extended total of $1,032.01/C.Y. as well as an extended total with O&P of $1,342.05/C.Y. The following estimate is not entirely accurate based on the fact that most of the columns are 12"x30" while the estimate is taking off for square columns that are 24"x24". This discrepancy will cause an inaccuracy in the estimate; while it is a slight difference it will cause a substantial difference. This estimate can still be used as a reference for the cost of installing the cast-in-place columns. The analysis began with the first floor and moved up and through the building. The estimate includes all the newly constructed cast-in-place columns all the way to the Roof since there are no newly constructed columns located on in the High Roof area. Details concerning the descriptions, measurements, quantities as well as the costs of these beams are listed below in Table 7.

Table 7: Cast-In-Place Column Schedule							
Item	Description	Length (ft.)	Width (ft.)	Depth (ft.)	C.Y.	Extended Total	Extended Total O&P
1	N1	97.53	1	1.5	146.295	$ 150,977.90	$ 196,335.20
2	N2	97.53	1	1.5	146.295	$ 150,977.90	$ 196,335.20
3	N3	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
4	N4	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
5	N5	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
6	N6	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
7	N7	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
8	N8	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
9	N9	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
10	N10	97.53	1	2.5	243.825	$ 251,629.84	$ 327,225.34
11	Total					$ 2,314,994.51	$ 3,010,473.14

Table 7 Cast-In-Place Column Estimate

3. Foundation Renovation (Micro Piles)

The Micro Piles were installed to provide a more competent structural system capable of providing the new stair/elevator cores with a stable foundation. The Structural renovation estimate will include 78 micro piles. It will also include the pile caps/footings' quantity takeoff of rebar, concrete and formwork. Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate to find the amount of concrete, rebar and formwork used to construct the pile caps and footings. The pile caps vary in depth from 26" to 42".

Assumptions

- Assume that any pile cap/footing that does not have their depth labeled has a thickness of 36”
- Assume that footings have same rebar layout as pile caps unless designated otherwise
- Assume that there are 2 pieces of rebar per each square foot
- Assume that # 9 rebar is spaced 12” on center in each of the footers and pile caps east west, top and bottom rebar
- Assume that # 9 rebars weighs 3.4 lbs. /ft.
- Assume that uncoated reinforcing steel for footings between # 8-#18, # 9 rebar has a total O & P cost of $1578.87
- Assume that length and width takeoff was of all the pile cap/footings in order to provide a concise calculation
- Assume that the formwork for the footings and the pile caps are only used around the perimeter of the footing/pile cap and the earth is used as a form beneath. Forms will be required for only the four sides typically.
- Assume that RS Means cost works data price for concrete is $153.06/C.Y. which includes “Structural concrete, ready mix, normal weight, high early, 3000psi, includes local aggregate, Portland cement, sand and water, delivered excludes all additives and treatments
- Assume that formwork is applied to an average of three foot depth for most of the pile caps and footings
- Assume plywood modular prefabricate 2” x 8” buy with a unit type of Square Footage of Contact Area (SFCA) with a total O & P of $ 8.04
- Assume that formwork has three uses and dividing the square footage by three will give a more realistic value of the cost of the formwork

Figure 36 Pile Cap/Footing Quantity Takeoff

This extensive renovation of the building's structural system is exemplified in the costs associated with the concrete, rebar, and formwork shown below. Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate.

After conducting a thorough quantity takeoff of the area of each micro pile as well as the depth of each, it was discovered that there is precisely $63,913.57 of concrete that requires installation in order to construct the footing/pile caps in the cellar level in Table 8.

Table 8: Concrete in Pile Caps/Footings-3000 PSI					
Item No.	Area of Pile Cap/Footing (ft^2)	Thickness of Pile Cap/Footing (ft.)	Cubic yards of concrete	Total O & P ($/C.Y.)	Total Cost
1	2295.43	3	255.05	153.06	$ 39,037.61
2	82.84	2.17	6.65	153.06	$ 1,017.43
	665.29	3.5	86.24	153.06	$ 13,200.09
4	151.29	2.67	14.94	153.06	$ 2,287.06
5	122.96	2.33	10.63	153.06	$ 1,626.44
6	235.85	2.83	24.75	153.06	$ 3,788.19
7	208.63	2.5	19.32	153.06	$ 2,956.75
				Total	$ 63,913.57

Table 8 Concrete in Pile Caps/Footings-3000 PSI

A takeoff of the rebar was completed utilizing an understanding of the rebar layout to be # 9 bars spaced at 12" on center of east west and top bottom rebar. This layout clarified that there were 2 rebar. After finding the length and width it was found that there was a total length of 1591.62 ft. of rebar employed in the construction of the reinforcement for the footings/pile caps shown in table 9. The formwork estimate was conducted as well and is included in table 10.

Table 9: Rebar in Pile Caps/Footings-3000 PSI							
Item No.	Length of Footing/Pile Cap (ft.)	Width of Footing/Pile cap (ft.)	Total Rebar Length (ft.)	Weight of Rebar-(#9 @ 3.4 lbs. /ft.)(lbs.)	1 ton= 2000lbs. (tons)	Total Cost O & P ($)	Total ($)
1	367.74	428.07	1,591.62	5411.508	2.705754	$ 1578.87	$ 4,272.03
						Total	$ 4,272.03

Table 9 Rebar in Pile Caps/Footings-3000 PSI

Table 10: Formwork for Pile Caps/Footings							
Item No.	Length of Footing/Pile Cap (ft.)	Width of Footing/Pile cap (ft.)	Total Length (ft.)	Average Depth of Pile Caps/Footings (ft.)	SFCA (ft^2)	Total Cost O & P ($)	Total ($)
1	367.74	428.07	1,591.62	3	4,774.86	$ 8.04	$ 12,796.62
						Total	$12,796.62

Table 10 Formwork for Pile Caps/Footings-3000 PSI

Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate. The Micro Piles that were installed in the foundation of the structure are 7” in diameter which will be drilled to 11’-0” into the rock. Based on the geotechnical report water was discovered 8’-0” below the surface, this combined with a depth of 50 has resulted in choosing the item that most closely matched the requirements.

The item with a line item # 316326131300 and with a description of “Fixed end caisson piles, open style in wet ground, to 50’ deep, 18” diameter, 0.065 C.Y./L.F., machine drilled, pulled casing and pumping, includes excavation, concrete, 50 lb. reinforcing/C.Y. excludes mobilization, boulder removal, disposal”. This item came with an Extended Total of $41.01/V.L.F. as well as an Extended Total with O&P of $51.39/V.L.F.

The following estimate is not entirely accurate based on the fact that the holes are 7” in diameter and not 18” in diameter like the estimate from R.S. Means Cost works has. I am also assuming that the depth of each micro pile was to 50’ depth, this information has not yet been provided by Turner. Knowing the exact depth of each micro pile is a crucial piece of information that will help improve the accuracy of the estimate. This slight difference will not result in an accurate estimate; however it will help provide a reference to how much this work is likely to cost, details concerning the descriptions, measurements, quantities as well as the costs of these Micro Piles are listed below in table 11.

Table 11: Micro Piles				
Item	Description	Depth (ft.)	Extended Total	Extended Total O&P
1	78 Micro Piles	50'	$ 159,939.00	$ 200,421.00
2		Total	$ 159,939.00	$ 200,421.00

Table 11 Micro Pile Estimate

3. Concrete Slabs

The main elevator/stair core was removed from the structure so new slabs need to be formed, reinforced and poured to complete the installation of the new stair and elevator cores.

Cost data was taken from RS Means Cost works Data from the RS Means web source for this portion of the structural estimate. A structural estimate of the cast-in-place concrete slabs was completed using many assumptions due to lack of information provided by the Turner Construction Company. Some of the information that was not provided was the amount and type of rebar in each slab, the type of concrete used for the pour of the slabs and many other items that will be addressed in this portion of the estimate.

An analysis of the Structural cast-in-place concrete slabs was completed to estimate the cost of the Structural cast-in-place concrete slab. The line item that most closely matched this item was 033053401900 which has a description of “Structural concrete, in place, elevated slab (4000 psi), flat slab with drop panels , 125 psf superimposed load, 20’ span, includes forms(4 uses), reinforcing steel, concrete, placing and finishing”. With the concrete slab having an average thickness of 8” the structural concrete slab was estimated by taking a square foot take off of the area where the new concrete was to be poured from the ground level all the way to the high roof.

Details concerning the descriptions, measurements, quantities as well as the costs of the installation of these slabs are listed below in table 12.

Table 12: Slab Construction					
Item	Description	Area (ft^2)	C.Y.	Extended Total	Extended Total O&P
1	First Floor	330.23	220.26	$ 120,096.42	$ 153,426.68
2	Even Floors	1690	1127.23	$ 614,610.89	$ 785,183.33
3	Odd Floors	1352	901.78	$ 491,688.71	$ 628,146.66
4	Roof	338	225.44	$ 122,922.18	$ 157,036.67
5				$ 1,349,318.19	$ 1,723,793.34

Table 12 Slab Construction

General Conditions Estimate

The General Conditions Estimate can be broken down into 8 main areas: Temporary Facilities, Staffing Plans, Hoist Facilities, Temporary Utilities, Cleaning, Protection & Safety, and lastly the Fringes/Taxes/Insurance/Bonds. The Staffing Plan portion of the GC estimate includes all of the management and support staff on the Concordia project.

The GC estimate accounts for just over 5% of the project cost, this is a typical GC estimate and very accurate for this specific project.

Overall, GC costs account for approximately $27,721 a week. It is apparent that monitoring the project schedule is critical for maintaining the project budget and not incurring any additional GC costs. Any clarifications that are needed can be found in Tables 13-17.

Table 13: General Conditions (GC) Estimate		
Items	Description	Total
1	Temporary Facilities	$ 59,450.00
2	Staffing Plan	$ 522,000.00
3	Hoist Facilities	$ 100,300.00
4	Temporary Utilities	$ 113,900.00
5	Cleaning	$ 106,875.00
6	Protection & Safety	$ 18,600.00
7	General Expenses	$ 105,656.00
8	Fringes/Taxes/Insurance/Bonds	$ 303,829.00
	Total GC Estimate	$ 1,330,610.00

Table 13 General Conditions (GC) Estimate Summary

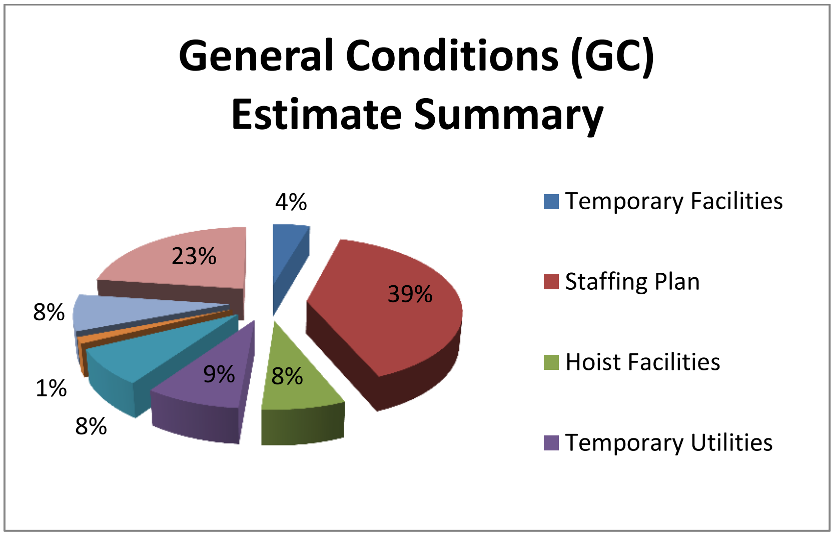


Figure 37 General Conditions (GC) Estimate Summary Pie Graph

1. Temporary Facilities

Table 14: General Condition (GC) Estimate-Temporary Facilities					
Items	Description	Cost	Unit	Qty.	Total
1	Misc. Tools and Supplies	$ 200.00	Month	12	$ 2,400.00
2	Trailers-2 sets	$ 500.00	Month	12	$ 6,000.00
3	Office set-up	$ 700.00	Month	1	$ 700.00
4	Deliver, Setup & Return Offices	$ 2,000.00	ea.	1	$ 2,000.00
5	Steps, Improvements	$ 500.00	ea.	1	$ 500.00
6	Utility Hook-ups	$ 2,500.00	ea.	1	$ 2,500.00
7	Move Office into Building (Walls/Phones/Etc.)	$ 15,000.00	ea.	1	$ 15,000.00
8	Vehicle Allowance (Inc. Maintenance and Mileage)	$ 1,950.00	Month	13	$ 25,350.00
9	Temporary Roof	$ 5,000.00	ea.	1	$ 5,000.00
	Temporary Facilities				$ 59,450.00

Table 14 General Conditions (GC) Temporary Facilities

2. Staffing Plan

Table 15: General Condition (GC) Estimate-Staffing Plan					
Items	Description	Cost	Unit	Qty.	Total
1	General Superintendent-Nicholas Vangeli	$ 11,000.00	Month	12	$ 132,000.00
2	Project Superintendent-Chuck McClellan	$ 8,200.00	Month	12	$ 98,400.00
4	Project Manager (Part time)-JT Armstrong	$ 3,500.00	Month	12	$ 42,000.00
3	Project Engineer-Bailey Wilson	$ 8,400.00	Month	12	$ 100,800.00
5	Project Executive (Part time)-Gary Ball	$ 4,000.00	Month	12	$ 48,000.00
6	MEP Engineer/Coordinator-Gregg West	$ 8,400.00	Month	12	$ 100,800.00
	Staffing Plan				$ 522,000.00

Table 15 General Conditions (GC) Staffing Plan

3. Hoist Facilities

Table 16: General Condition (GC) Estimate-Hoist Facilities					
Items	Description	Cost	Unit	Qty.	Total
1	Monthly rental, Inc. Maintenance	$ 5,500.00	Month	8	$ 44,000.00
2	Install and Remove	$ 7,500.00	ea.	2	$ 15,000.00
3	Gate Rental	$ 250.00	ea.	10	$ 2,500.00
4	Loading Platform	$ 2,000.00	ea.	1	$ 2,000.00
5	Operate Material Hoist	$ 2,600.00	Month	8	$ 20,800.00
6	Operate Material Hoist	$ 1,500.00	ea.	2	$ 3,000.00
7	Monthly Maintenance Charge	$ 1,500.00	Month	2	$ 3,000.00
8	Temporary Entrances Protection	$ 200.00	ea.	10	$ 2,000.00
9	Cab Protection	$ 1,000.00	ea.	1	$ 1,000.00
10	Operate Temp Elevators	$ 3,000.00	Month	2	$ 6,000.00
11	Overtime Operation	$ 500.00	Month	2	$ 1,000.00
	Hoist Facilities				$ 100,300.00

Table 16 General Conditions (GC) Hoist Facilities

4. Temporary Utilities

Table 17: General Condition (GC) Estimate-Temporary Utilities					
Items	Description	Cost	Unit	Qty.	Total
1	Operate Permanent System	$ 15,000.00	ea.	1	$ 15,000.00
2	Change A/C Filters on Permanent System	$ 2,000.00	Month	4	$ 8,000.00
3	Temporary Lighting	$ 15,000.00	ea.	1	$ 15,000.00
4	Electric Current Charge	$ 1,500.00	Month	12	$ 18,000.00
5	HVAC use	$ 7,000.00	Month	4	$ 28,000.00
6	Hoist Power	$ 2,000.00	Month	8	$ 16,000.00
7	Rental Toilets (1 toilet per 25 men	$ 110.00	ea.	60	$ 6,600.00
8	Job Office Toilet	$ 200.00	Month	12	$ 2,400.00
9	Setup Temporary Water and Sewer	$ 2,500.00	ea.	1	$ 2,500.00
10	Water Usage Charges	$ 200.00	Month	12	$ 2,400.00
	Temporary Utilities				$ 113,900.00

Table 17 General Conditions (GC) Temporary Utilities

5. Cleaning

Table 18: General Condition (GC) Estimate					
Items	Description	Cost	Unit	Qty.	Total
1	Cleaning Labor	$ 2,400.00	ea.	3	$ 7,200.00
2	Cleaning Materials	$ 1,500.00	ea.	1	$ 1,500.00
3	Glass Cleaning	$ 7,500.00	ea.	1	$ 7,500.00
4	Trash chute (Install/Remove, Rental-8 , Protection-10 floors)	$ 20,500.00	ea.	1	$ 20,500.00
5	Rubbish Removal	$ 425.00	ea.	91	$ 38,675.00
6	Final Cleaning	$ 0.35	GSF	90000	$ 31,500.00
	Cleaning				$ 106,875.00

Table 18 General Condition (GC) Estimate Cleaning

6. Protection & Safety

Table 19: General Condition (GC) Estimate-Protection & Safety					
Items	Description	Cost	Unit	Qty.	Total
1	Materials for Protection and Safety	$ 0.05	GSF	90000	$ 4,500.00
2	Drug Testing	$ 500.00	ea.	1	$ 500.00
3	Site Fence	$ 560.00	ea.	5	$ 2,800.00
4	Entrance Gate-Vehicle	$ 750.00	ea.	1	$ 750.00
5	Sidewalk Bridge	$ 7,500.00	ea.	1	$ 7,500.00
6	Fire Extinguisher	$ 35.00	ea.	30	$ 1,050.00
7	First Aid Supplies	$ 125.00	Month	12	$ 1,500.00
	Protection & Safety				$ 18,600.00

Table 19 General Condition (GC) Estimate Protection & Safety

7. Fringes/Taxes/Insurance/Bonds

Table 20: General Condition (GC) Estimate-Fringes/Taxes/Insurance/Bonds		
Items	Description	Total
1	Staff Employee Benefit Expense (EBE)	$ 253,607.00
2	S.S./U.I./Taxes	$ 44,297.00
3	WC Insurance	$ 5,925.00
	Fringes/Taxes/Insurance/Bonds	$ 303,829.00

Table 20 General Condition (GC) Estimate Fringes/Taxes/Insurance/Bonds

8. General Expenses

Table 21: General Condition (GC) Estimate-General Expenses

Items	Description	Cost	Unit	Qty.	Total
1	Copier (Purchase/Lease, Supplies & Maintenance)	$ 550.00	Month	12	$ 6,600.00
2	Office Supplies, Coffee/Water	$ 500.00	Month	12	$ 6,000.00
3	Monthly Phone Data Charges	$ 400.00	Month	12	$ 4,800.00
4	Fax Machine	$ 500.00	ea.	1	$ 500.00
5	Nextel-Phone & Service	$ 100.00	Month	48	$ 4,800.00
6	Main Office Phone Charges	$ 0.50	$ vol	22000	$ 11,000.00
7	Bid sets	$ 2,500.00	ea.	1	$ 2,500.00
8	Shop Drawing Production	$ 100.00	Month	13	$ 1,300.00
9	Plotter Service	$ 10.00	Sheet	200	$ 2,000.00
10	Laptops	$ 2,400.00	ea.	2	$ 4,800.00
11	System Setup	$ 1,500.00	ea.	1	$ 1,500.00
12	Maintain	$ 95.00	hr.	48	$ 4,560.00
13	Accounting Ledger Cost, Pay line	$ 11.50	Man Mo.	208	$ 2,392.00
14	Network Connectivity	$ 136.00	Man Mo.	24	$ 3,264.00
15	RFC Support Service, EDP	$ 1.12	Vol	22000	$ 24,640.00
16	Expediting Travel	$ 1,500.00	ea.	1	$ 1,500.00
17	Job Progress Photos	$ 200.00	Month	12	$ 2,400.00
18	Digital Camera & Media	$ 300.00	ea.	1	$ 300.00
19	Job Signs	$ 1,500.00	ea.	1	$ 1,500.00
20	Directional Signs	$ 500.00	ea.	1	$ 500.00
21	Postage/Overnight Express Service	$ 150.00	Month	12	$ 1,800.00
22	Record Document Storage	$ 2,000.00	ea.	1	$ 2,000.00
23	Existing Condition Laser Study	$ 10,000.00	ea.	1	$ 10,000.00
24	Layout Control Lines	$ 5,000.00	ea.	1	$ 5,000.00
	General Expenses				$ 105,656.00

Table 21 General Condition (GC) Estimate General Expenses

Construction Cost (CC) - $ 22,000,000.00 which does not include lands, site work or permitting. Resulting in $ 22,000,000.00/96,200SF=$228/SF

Total Project Cost (TC)-the total project cost was provided by the Turner Construction Company which was $23,000,000

- TC/SF=$23,000,000/96,200SF=$239.08/SF

Major Building Systems Costs- $ 10,200,00.00 which include the MEP systems and the renovation to the structural system. Resulting in $ 10,200,00.00/96,200SF=$106 /SF

Square Foot Estimate-a square foot estimate utilizing R.S. Means Cost Works Square Foot Cost Estimate Report has been completed. The square foot estimate is extremely close to the actual building total cost which is $23,000,000. The square foot estimate is $22,336,000 which is

($22,336,000/$23,000,000)*100=97.11) 97% accuracy. This square foot estimate is extremely close to the building estimate and may be off only due to precision and accuracy of the unit costs used. The square foot estimate detail and breakdown can be evaluated on the following pages of this technical report in table 18.

Square Foot Cost Estimate

Estimate Name:	**Untitled**	
Building Type:	**Hotel, 8-24 Story with Glass and Metal Curtain Walls / R/Conc. Frame**	
Location:	**National Average**	Costs are derived from a building model with basic components. Scope differences and market conditions can cause costs to vary significantly. **Parameters are not within the ranges recommended by RSMeans.**
Story Count:	**10**	
Story Height (L.F.):	**9**	
Floor Area (S.F.):	**96200**	
Labor Type:	**Union**	
Basement Included:	**No**	
Data Release:	**Year 2012**	
Cost Per Square Foot:	**$232.18**	
Building Cost:	**$22,336,000**	

		% of Total	Cost Per S.F.	Cost
A Substructure		**10.20%**	**$17.79**	**$1,711,000**
A1010	**Standard Foundations**		**$0.78**	**$75,000**
	Pile caps, 12 piles, 11' - 6" x 8' - 6" x 49", 40 ton capacity, 19" column size, 900 K column			
	Pile caps, 14 piles, 11' - 6" x 10' - 9" x 55", 80 ton capacity, 29"column size, 2155 K column			
A1020	**Special Foundations**		**$16.07**	**$1,546,000**
	Steel H piles, 100' long, 800K load, end bearing, 12 pile cluster			
	Steel H piles, 100' long, 1600K load, end bearing, 14 pile cluster			
	Grade beam, 30' span, 52" deep, 14" wide, 12 KLF load			
A1030	**Slab on Grade**		**$0.51**	**$49,000**
	Slab on grade, 4" thick, non industrial, reinforced			
A2010	**Basement Excavation**		**$0.02**	**$1,500**
	Excavate and fill, 30,000 SF, 4' deep, sand, gravel, or common earth, on site storage			

A2020	**Basement Walls** Foundation wall, CIP, 4' wall height, direct chute, .099 CY/LF, 4.8 PLF, 8" thick Foundation wall, CIP, 4' wall height, direct chute, .148 CY/LF, 7.2 PLF, 12" thick		**$0.41**	**$39,500**
B Shell		**22.10%**	**$38.77**	**$3,730,000**
B1010	**Floor Construction** Cast-in-place concrete column, 18" square, tied, 500K load, 10' story height, 315 lbs/LF, 4000PSI Flat plate, concrete, 9" slab, 20" column, 20'x25' bay, 75 PSF superimposed load, 188 PSF total load		**$16.10**	**$1,548,500**
B1020	**Roof Construction** Floor, concrete, beam and slab, 20'x25' bay, 40 PSF superimposed load, 18" deep beam, 8.5" slab, 146 PSF total load		**$1.44**	**$138,500**
B2020	**Exterior Windows** Aluminum flush tube frame, for insulating glass, 2" x 4-1/2", 5'x6' opening, no intermediate horizontals Glazing panel, insulating, 5/8" thick units, 2 lites 3/16" float glass, tinted		**$20.36**	**$1,958,500**
B2030	**Exterior Doors** Door, aluminum & glass, without transom, narrow stile, with panic hardware, 3'-0"x 7'-0"opening Door, aluminum & glass, without transom, narrow stile, double door, hardware, 6'-0" x 7'-0" opening Door, steel 18 gauge, hollow metal, 1 door with frame, no label, 3'-0" x 7'-0" opening		**$0.23**	**$22,000**
B3010	**Roof Coverings** Roofing, asphalt flood coat, gravel, base sheet, 3 plies 15# asphalt felt, mopped Insulation, rigid, roof deck, composite with 2" EPS, 1" perlite Roof edges, aluminum, duranodic, .050" thick, 6" face Flashing, aluminum, no backing sides, .019" Gravel stop, aluminum, extruded, 4", mill finish, .050" thick		**$0.62**	**$59,500**
B3020	**Roof Openings** Roof hatch, with curb, 1" fiberglass insulation, 2'-6" x 3'-0", galvanized steel, 165 lbs.		**$0.03**	**$3,000**
C Interiors		**19.90%**	**$34.94**	**$3,361,000**
C1010	**Partitions** Metal partition, 5/8"fire rated gypsum board face, 5/8"fire rated gypsum board base, 3-5/8" @ 24", 5/8"fire rated opposite face, 3.5" fiberglass insulation		**$6.18**	**$594,500**

	5/8" gypsum board, taped & finished, painted on metal furring			
C1020	**Interior Doors**		**$13.27**	**$1,276,500**
	Door, single leaf, kd steel frame, hollow metal, commercial quality, flush, 3'-0" x 7'-0" x 1-3/8"			
C2010	**Stair Construction**		**$2.77**	**$266,500**
	Stairs, steel, cement filled metal pan & picket rail, 16 risers, with landing			
C3010	**Wall Finishes**		**$3.50**	**$336,500**
	Painting, interior on plaster and drywall, walls & ceilings, roller work, primer & 2 coats			
	Vinyl wall covering, fabric back, medium weight			
	Ceramic tile, thin set, 4-1/4" x 4-1/4"			
C3020	**Floor Finishes**		**$5.26**	**$506,000**
	Carpet tile, nylon, fusion bonded, 18" x 18" or 24" x 24", 35 oz.			
	Vinyl, composition tile, maximum			
	Tile, ceramic natural clay			
C3030	**Ceiling Finishes**		**$3.96**	**$381,000**
	Gypsum board ceilings, 1/2" fire rated gypsum board, painted and textured finish, 7/8"resilient channel furring, 24" OC support			
D Services		**47.80%**	**$83.73**	**$8,055,000**
D1010	**Elevators and Lifts**		**$7.03**	**$676,500**
	Traction geared freight, 4000 lb., 15 floors, 10' story height, 200FPM			
	Traction, geared passenger, 3500 lb,15 floors, 10' story height, 2 car group, 350 FPM			
D2010	**Plumbing Fixtures**		**$16.69**	**$1,606,000**
	Water closet, vitreous china, bowl only with flush valve, wall hung			
	Water closets, battery mount, wall hung, back to back, first pair of closets			
	Water closets, battery mount, wall hung, each additional pair of closets, back to back			
	Urinal, vitreous china, wall hung			
	Lavatory w/trim, vanity top, PE on CI, 20" x 18"			
	Kitchen sink w/trim, countertop, stainless steel, 33" x 22" double bowl			
	Service sink w/trim, PE on CI, wall hung w/rim guard, 22" x 18"			
	Bathtub, recessed, PE on CI, mat bottom, 5' long			
	Shower, stall, baked enamel, terrazzo receptor, 36" square			
	Water cooler, electric, wall hung, wheelchair type, 7.5 GPH			

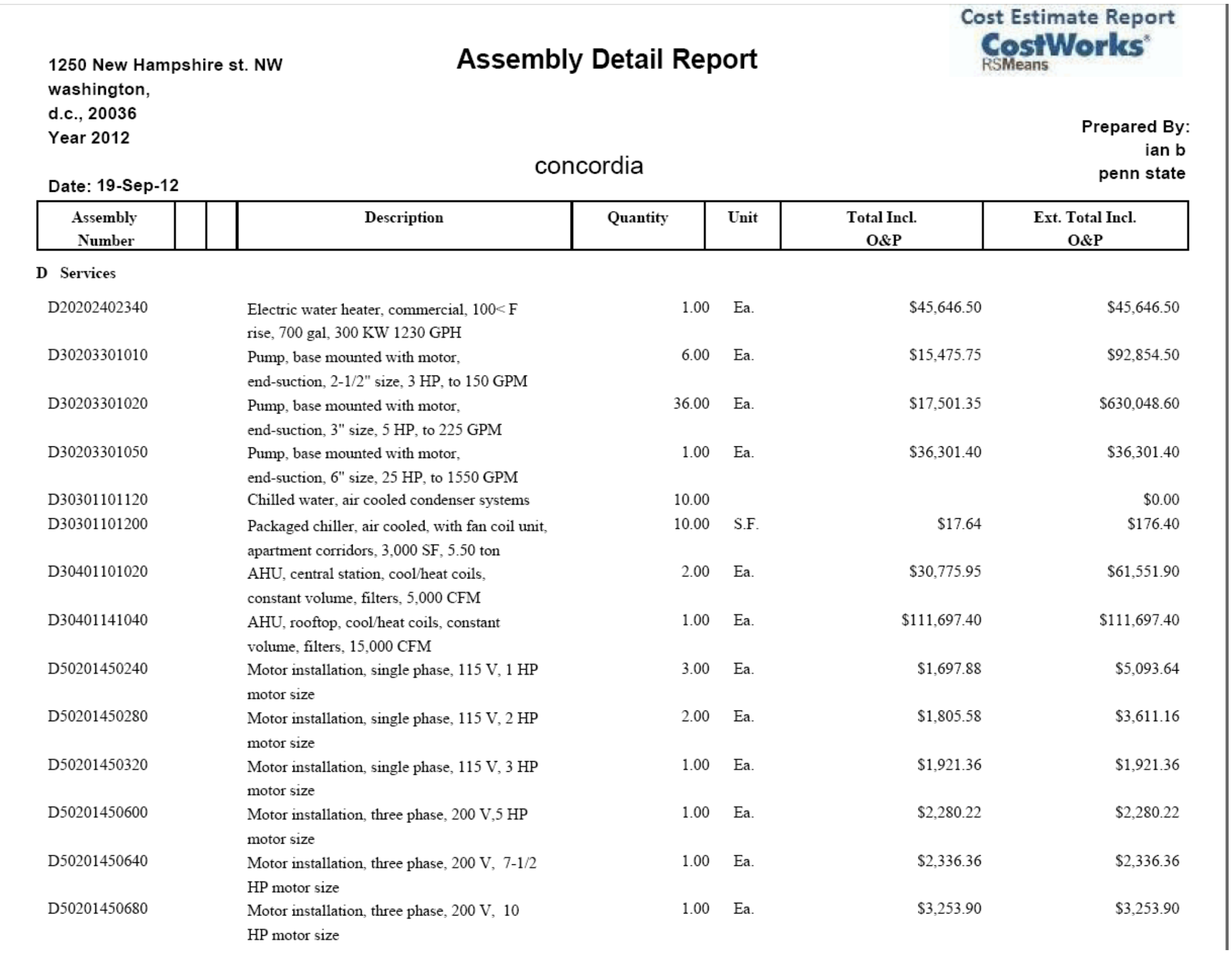
	Water cooler, elec, floor mounted, refrigerated compartment type, 1.5 GPH		
	Bathroom, three fixture, 1 wall plumbing, lavatory, water closet & bathtub share common plumbing wall *		
D2020	**Domestic Water Distribution**	**$14.37**	**$1,382,000**
	Electric water heater, commercial, 100< F rise, 1000 gal, 480 KW 1970 GPH		
	Gas fired water heater, commercial, 100< F rise, 500 MBH input, 480 GPH		
D2040	**Rain Water Drainage**	**$0.14**	**$13,500**
	Roof drain, CI, soil, single hub, 5" diam, 10' high		
	Roof drain, CI, soil, single hub, 5" diam, for each additional foot add		
D3010	**Energy Supply**	**$2.73**	**$262,500**
	Commercial building heating system, fin tube radiation, forced hot water, 1mil SF, 10 mil CF, total 5 floors		
D3030	**Cooling Generating Systems**	**$13.95**	**$1,342,000**
	Packaged chiller, water cooled, with fan coil unit, medical centers, 60,000 SF, 140.00 ton		
D4010	**Sprinklers**	**$4.34**	**$417,500**
	Wet pipe sprinkler systems, steel, light hazard, 1 floor, 50,000 SF		
	Wet pipe sprinkler systems, steel, light hazard, each additional floor, 50,000 SF		
	Standard High Rise Accessory Package 16 story		
D4020	**Standpipes**	**$3.80**	**$366,000**
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, 1 floor		
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, additional floors		
	Fire pump, electric, with controller, 5" pump, 100 HP, 1000 GPM		
	Fire pump, electric, for jockey pump system, add		
D5010	**Electrical Service/Distribution**	**$7.32**	**$704,000**
	Service installation, includes breakers, metering, 20' conduit & wire, 3 phase, 4 wire, 120/208 V, 2000 A		
	Feeder installation 600 V, including RGS conduit and XHHW wire, 60 A		
	Feeder installation 600 V, including RGS conduit and XHHW wire, 200 A		
	Feeder installation 600 V, including RGS conduit and XHHW wire, 2000 A		
	Switchgear installation, incl switchboard, panels & circuit		

	breaker, 2000 A			
D5020	**Lighting and Branch Wiring**		**$8.81**	**$848,000**
	Receptacles incl plate, box, conduit, wire, 10 per 1000 SF, 1.2 W per SF, with transformer			
	Wall switches, 5.0 per 1000 SF			
	Miscellaneous power, to .5 watts			
	Central air conditioning power, 4 watts			
	Motor installation, three phase, 460 V, 15 HP motor size			
	Motor feeder systems, three phase, feed to 200 V 5 HP, 230 V 7.5 HP, 460 V 15 HP, 575 V 20 HP			
	Motor connections, three phase, 200/230/460/575 V, up to 5 HP			
	Motor connections, three phase, 200/230/460/575 V, up to 100 HP			
	Fluorescent fixtures recess mounted in ceiling, 0.8 watt per SF, 20 FC, 5 fixtures @32 watt per 1000 SF			
D5030	**Communications and Security**		**$4.13**	**$397,000**
	Communication and alarm systems, fire detection, addressable, 100 detectors, includes outlets, boxes, conduit and wire			
	Fire alarm command center, addressable with voice, excl. wire & conduit			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, intercom systems, 100 stations			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, master TV antenna systems,100 outlets			
	Internet wiring, 2 data/voice outlets per 1000 S.F.			
D5090	**Other Electrical Systems**		**$0.42**	**$40,000**
	Generator sets, w/battery, charger, muffler and transfer switch, diesel engine with fuel tank, 500 kW			
E Equipment & Furnishings		**0.00%**	**$0.00**	**$0**
E1090	**Other Equipment**		**$0.00**	**$0**
F Special Construction		**0.00%**	**$0.00**	**$0**
G Building Site work		**0.00%**	**$0.00**	**$0**
Subtotal		**100%**	**$175.23**	**$16,857,000**
Contractor Fees (General Conditions,Overhead,Profit)		**25.00%**	**$43.81**	**$4,214,500**
Architectural Fees		**6.00%**	**$13.14**	**$1,264,500**
User Fees		**0.00%**	**$0.00**	**$0**
Total Building Cost			**$232.18**	**$22,336,000**

Table 22 Square Footage Estimate

Assemblies Cost Estimate

an assembly estimate of the major MEP systems such as AHU systems, Pump systems and major switchgear materials has been completed. Many of the major MEP systems are not listed in R.S. Means CostWorks database which has resulted in finding the nearest possible match to the MEP systems estimated. With this said, there will be a slight discrepancy with the assemblies and the assemblies cost. Unfortunately, being that the assemblies estimate has not been provided by the general contractor, Turner Construction Company, a proper assessment and comparison cannot be made. Concerning the assemblies estimate completed; many of the items associated with the MEP systems were not included. Items not included in the estimate are the Make-up Air Unit, all the transformers for the building, copper conductors, a cost for air cooled condensers, and many other systems that are simply not included in RS Means CostWorks. In order to achieve a more accurate assembly's estimate it will be optimal to price out specific equipment with vendors and to look back into historical data for previous projects. Below one will find the partial assemblies estimate which includes several items; AHU, pumps, several different motor types, electric water heater, and lastly packaged chiller which brings the total estimate of assemblies to $1,223,399.84.In consideration of these results ($1,223,399.84/$23,000,000)*100=5.3%, the assemblies account for only 5.3% of the total building cost. Based on the fact that the major MEP systems can account for 30-50% of the total cost of the building this shows that the completed assemblies estimate is only partial and does not accurately reflect the true cost of these substantial MEP systems. The following table, table 19, shows the breakdown of these details.



Cost Estimate Report
CostWorks®
RSMeans

1250 New Hampshire st. NW
washington,
d.c., 20036
Year 2012

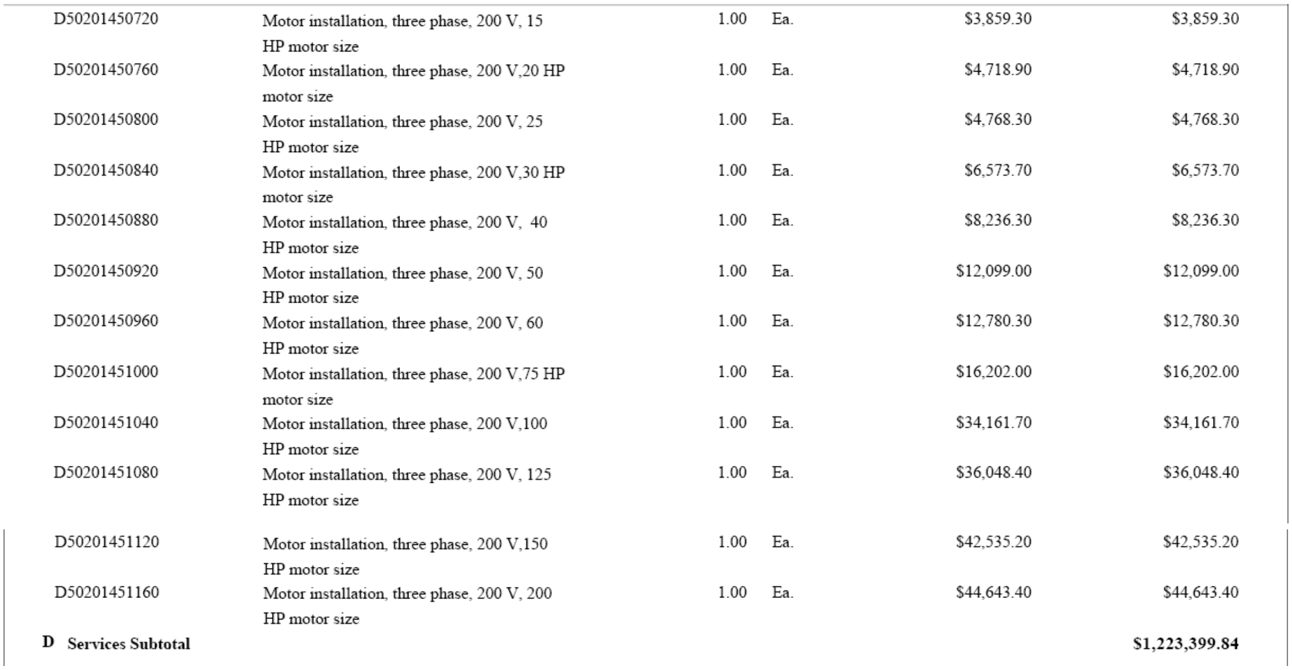
Assembly Detail Report

concordia

Prepared By:
ian b
penn state

Date: 19-Sep-12

Assembly Number			Description	Quantity	Unit	Total Incl. O&P	Ext. Total Incl. O&P
D Services							
D20202402340			Electric water heater, commercial, 100< F rise, 700 gal, 300 KW 1230 GPH	1.00	Ea.	$45,646.50	$45,646.50
D30203301010			Pump, base mounted with motor, end-suction, 2-1/2" size, 3 HP, to 150 GPM	6.00	Ea.	$15,475.75	$92,854.50
D30203301020			Pump, base mounted with motor, end-suction, 3" size, 5 HP, to 225 GPM	36.00	Ea.	$17,501.35	$630,048.60
D30203301050			Pump, base mounted with motor, end-suction, 6" size, 25 HP, to 1550 GPM	1.00	Ea.	$36,301.40	$36,301.40
D30301101120			Chilled water, air cooled condenser systems	10.00			$0.00
D30301101200			Packaged chiller, air cooled, with fan coil unit, apartment corridors, 3,000 SF, 5.50 ton	10.00	S.F.	$17.64	$176.40
D30401101020			AHU, central station, cool/heat coils, constant volume, filters, 5,000 CFM	2.00	Ea.	$30,775.95	$61,551.90
D30401141040			AHU, rooftop, cool/heat coils, constant volume, filters, 15,000 CFM	1.00	Ea.	$111,697.40	$111,697.40
D50201450240			Motor installation, single phase, 115 V, 1 HP motor size	3.00	Ea.	$1,697.88	$5,093.64
D50201450280			Motor installation, single phase, 115 V, 2 HP motor size	2.00	Ea.	$1,805.58	$3,611.16
D50201450320			Motor installation, single phase, 115 V, 3 HP motor size	1.00	Ea.	$1,921.36	$1,921.36
D50201450600			Motor installation, three phase, 200 V,5 HP motor size	1.00	Ea.	$2,280.22	$2,280.22
D50201450640			Motor installation, three phase, 200 V, 7-1/2 HP motor size	1.00	Ea.	$2,336.36	$2,336.36
D50201450680			Motor installation, three phase, 200 V, 10 HP motor size	1.00	Ea.	$3,253.90	$3,253.90



D50201450720	Motor installation, three phase, 200 V, 15 HP motor size	1.00	Ea.	$3,859.30	$3,859.30
D50201450760	Motor installation, three phase, 200 V,20 HP motor size	1.00	Ea.	$4,718.90	$4,718.90
D50201450800	Motor installation, three phase, 200 V, 25 HP motor size	1.00	Ea.	$4,768.30	$4,768.30
D50201450840	Motor installation, three phase, 200 V,30 HP motor size	1.00	Ea.	$6,573.70	$6,573.70
D50201450880	Motor installation, three phase, 200 V, 40 HP motor size	1.00	Ea.	$8,236.30	$8,236.30
D50201450920	Motor installation, three phase, 200 V, 50 HP motor size	1.00	Ea.	$12,099.00	$12,099.00
D50201450960	Motor installation, three phase, 200 V, 60 HP motor size	1.00	Ea.	$12,780.30	$12,780.30
D50201451000	Motor installation, three phase, 200 V,75 HP motor size	1.00	Ea.	$16,202.00	$16,202.00
D50201451040	Motor installation, three phase, 200 V,100 HP motor size	1.00	Ea.	$34,161.70	$34,161.70
D50201451080	Motor installation, three phase, 200 V, 125 HP motor size	1.00	Ea.	$36,048.40	$36,048.40
D50201451120	Motor installation, three phase, 200 V,150 HP motor size	1.00	Ea.	$42,535.20	$42,535.20
D50201451160	Motor installation, three phase, 200 V, 200 HP motor size	1.00	Ea.	$44,643.40	$44,643.40
D Services Subtotal					**$1,223,399.84**

Table 23 Assemblies Estimate Breakdown

Analysis 1: Building Information Modeling (BIM)

1.1 Problem Identification

The successful use of BIM in the 3D coordination of the MEP system clashes helps justify its application to other aspects of the project. The application of BIM to the other aspects of the project could have reduced the project costs and accelerated the project schedule. The use of the twenty-five BIM Uses will considered and analyzed in consideration to the greatest potential benefit to the project. The Pennsylvania State University BIM Execution Planning Guide will be utilized to aid in this thorough analysis of the alternate BIM Uses.

1.2 Research Goal

The goal of this analysis is to consider BIM’s applicability to renovations and not only new construction. Also, to explore and suggest the application of alternative BIM uses which might benefit the project’s completion. Upon completion of this analysis, the information discovered through research will be integrated throughout the other technical analyses.

1.3 Research Methods

- Acquire AutoCAD models from The Turner Construction Company
- Review model to consider accuracy and thoroughness of the building systems modeled
- Construct any missing systems with the utmost accuracy
- Research how BIM can be used to facilitate renovation project’s completion
- Determine how the generated 3D model will be beneficial to the alternative BIM applications
- Research the effect on construction means, methods, and logistics through the consideration of alternative BIM uses
- Gain a greater understanding of BIM’s applicability to demolition resequencing and prefabrication
- Interview project managers to determine all contributing factors to project delays

1.4 Resources &Tools to be Used

- The Turner Construction Company project team on the Concordia Hotel
- Dr. John Messner, Dr. Robert Leicht, Dr. Craig Dubler, Dr. Chimay J. Anumba
- The Pennsylvania State University AE Faculty
- Educational background from previous AE courses (such as AE 372, AE 475, AE 476, and AE 570)
- The Pennsylvania State University BIM Execution Planning Guide V2.0
- 3D Software (Revit, Navisworks)
- Applicable literature (books, websites, papers, etc.)
- Key industry members

1.5 Potential Solutions and Expected Outcomes

The possible solutions this BIM analysis will find is improvements to construction means and methods and potentially greater efficiency in construction. This research will hopefully have the effect of improving the schedule resulting in savings in overall construction costs. The solution will be that it will create a greater understanding of prefabrication of the main branches of the mechanical ductwork and in the sequence of demolition and construction efforts. Through the research of current construction industry trends it is expected that the information collected will provide accurate data to show positive cost and schedule impacts of implementing BIM methods on a renovation project of this magnitude.

1.6 The Concordia Renovation Project & BIM

The extent to which the Concordia renovation project used BIM was restricted to 3D coordination of the critical MEP systems. Due to the extensive amount of systems that were demolished it is believed that BIM could have been applied to not only 3D coordination but also to the phase planning of the demolition sequences and potentially prefabrication techniques of some of the MEP systems. The project team faced many issues with the demolition procedure which extended the schedule and caused delays in the initiation of other trades. A 3D model combined with a schedule would have likely reduced this delay by showing what work had to be done, when it needed to be completed and which systems were impacted at different times in the schedule. The installation of the MEP systems also caused delays which would likely have benefitted from the enactment of BIM in prefabrication efforts. In order to gain a greater understanding of the benefits of these techniques it is important to understand BIM's consideration in new construction and renovation projects.

1.7 New Construction

1.7 A: Acceptance

BIM has been found to be very beneficial to new construction projects. It has been widely adopted and applied to multiple new construction projects. The levels of BIM adoption over the last 6 years has drastically increased and is described in figure 38 the left image. "McGraw-Hill Construction predicted that BIM would reach a tipping point in North America in 2008, even though industry-wide adoption at the time was only 28%. Now in 2012, 71% of architects, engineers, contractors and owners report they have become engaged with BIM on their projects, a 75% growth surge over five years." (2012 Smartmarket report). This BIM adoption percentage is an industry-wide consideration of the acceptance of BIM. This level of acceptance is broken down even further into an analysis of BIM's prevalence by regions of North America. The west has a narrow lead while other regions are quickly gaining momentum. BIM is being applied more and more due to the clear and accurate description of key benefits to project teams, owners and projects. The breakdown of BIM use is shown in figure 38 the right image. The embracing of BIM was not prevalent with all parties and some acquired skills in BIM earlier on than others.

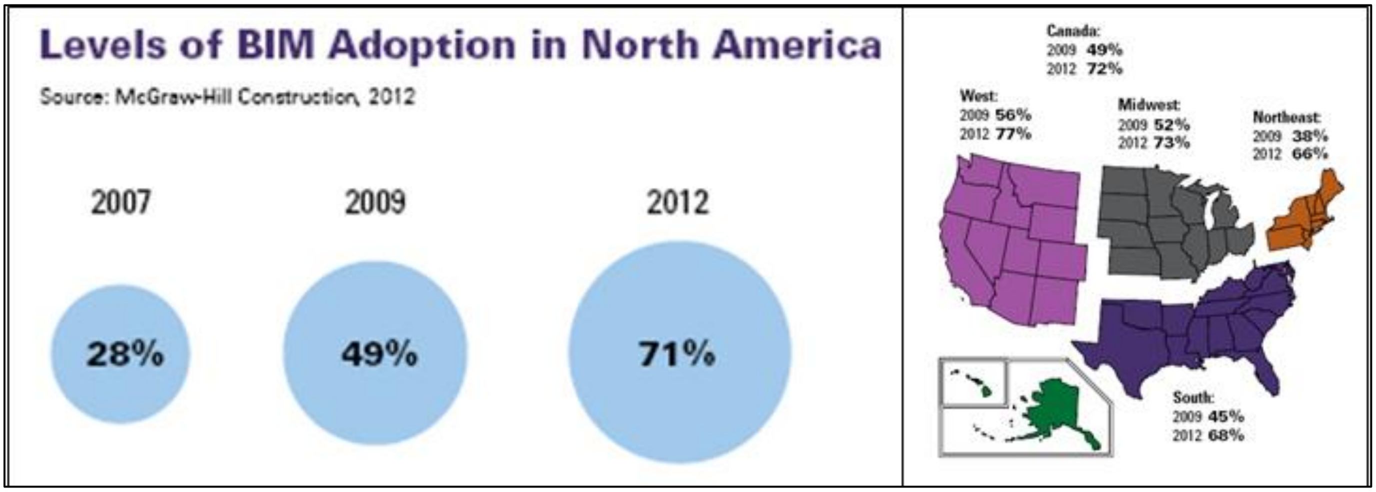


Figure 38 BIM Adoption in North America & Region

1.7 B: Key Players

Not everyone has acquired BIM into their arsenal there are still a large amount of skeptics. Just a few years ago it was not considered a valuable asset to some architects and an even greater amount of contractors and engineers. The current trends show that 74% of contractors use BIM while 70% of architects and 67% of engineers use it as well; unfortunately, owners are still the lightest user of BIM as shown in figure 39. While 38% of architects say they will not use BIM at all there are fewer and fewer non-users each year. More companies are getting involved with BIM and this is primarily attributed to the fact that many of the benefits associated with BIM are being documented and catalogued for all to see.

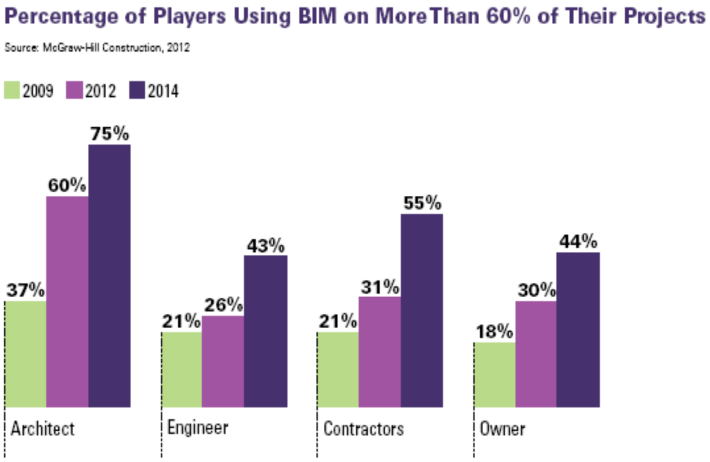


Figure 39 Percentages of Key Players Using BIM

1.7 C: Return on Investment (ROI)

The benefits associated with BIM can be extensive and a great deal of consideration is placed on understanding and calculating ROI. "Almost two thirds (62%) of all BIM users' perceive positive ROI, although not evenly across firm types or BIM engagement levels". (Smartmarket report). It is critical to formulate comparisons of ROI based on the level of engagement of a company due to the strong correlation between the two. Positive ROI is strongly correlated with high levels of engagement due to the fact that high levels of engagement typically result in higher skill, experience and implementation levels. When it comes to ROI approximately 74% of the contractors reported a positive ROI whereas only 37% of engineers reported a positive ROI. Figure 40 shows the strong correlation between ROI and levels of engagement. While a great deal of analysis is being placed on the correlation between ROI and levels of engagement it has been much harder to validate as credible and repeatable.

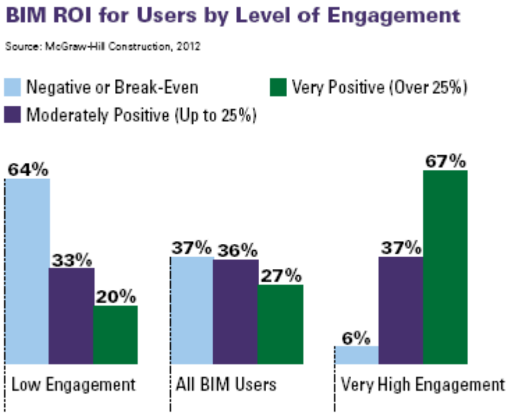
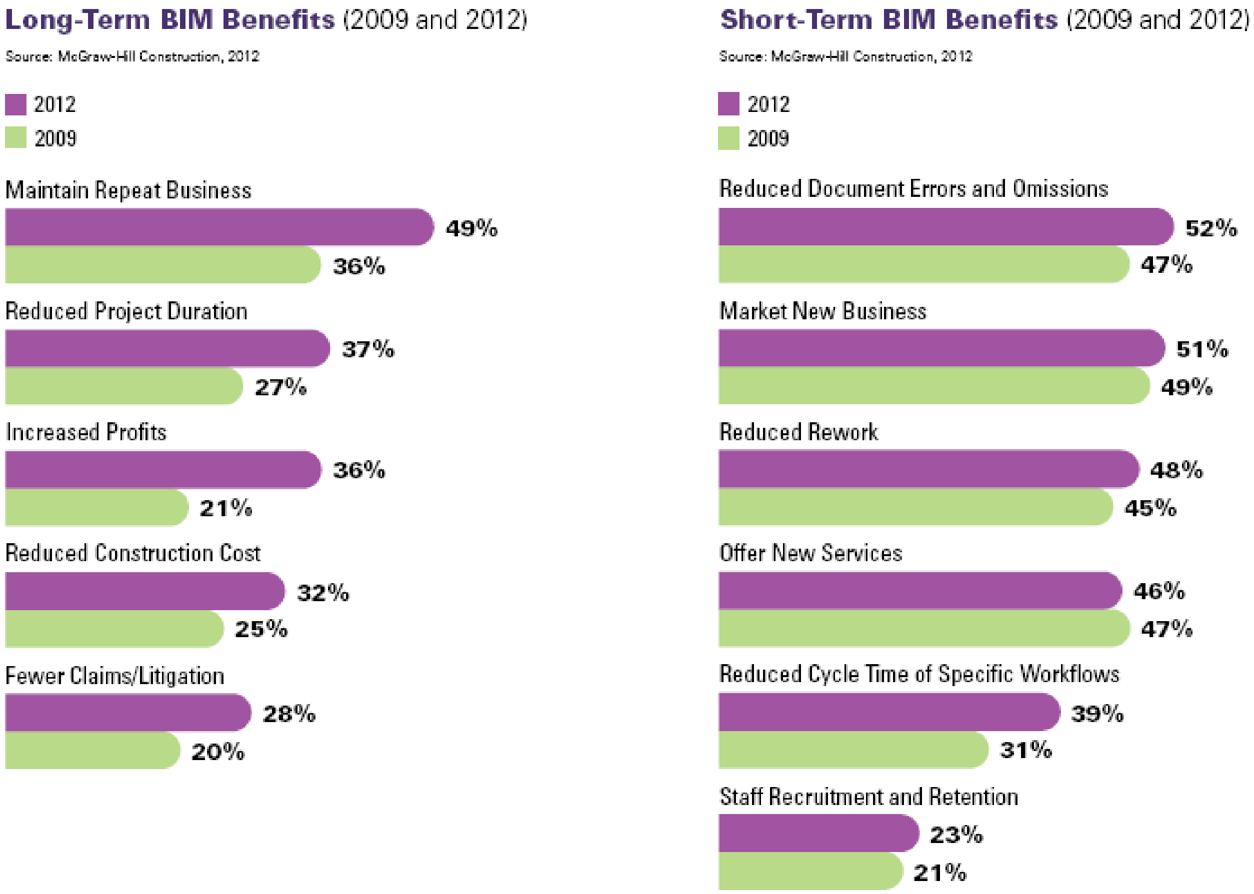


Figure 40 ROI Based on Levels of Engagement

1.7 D: Long-term & Short-term Benefits

Some of the long-term and short-term benefits include increased profits, fewer claims and litigation, and a reduction in overall project duration. Increased profits could drive the future use of BIM in the construction industry as BIM processes become more standardized and the initial costs of adoption and implementation of BIM are remunerated. One of the key benefits of BIM usage is that there are fewer claims and litigations, this benefit grew from 20% in 2009 to 28% in 2012. The strong increase in percentage shows that as more problems are avoided by the project team during the construction the number of claims is reduced. Reducing overall project duration is an apparent benefit once again due to the growth from 27% in 2009 to 37% in 2012; this growth will be a key quantifiable justification to apply BIM to more and more projects. Many of the other long-term and short-term benefits are listed below in figure 41 based on their importance.



Long-Term BIM Benefits (2009 and 2012)

Source: McGraw-Hill Construction, 2012

Short-Term BIM Benefits (2009 and 2012)

Source: McGraw-Hill Construction, 2012

Figure 41 The Long-term and Short-term Benefits of Applying BIM

1.7 E: Benefits to Key Players

The top benefits that 51% of architects believe is a major benefit of BIM is reduced document errors and omissions. This benefit typically results in a more accurate set of design documents. The top benefit that 65% of contractors believe is an attribute of BIM is reduced rework. This reduced rework is likely attributed to 3D coordination and more accurate design documents from the architect. This close collaboration reduces errors and waste. When it comes to engineers their greatest benefit was for repeat customers through engineering analysis. Lastly owners experience the greatest benefit from reduced document errors and omissions. These top benefits to each major player are displayed in figure 42.

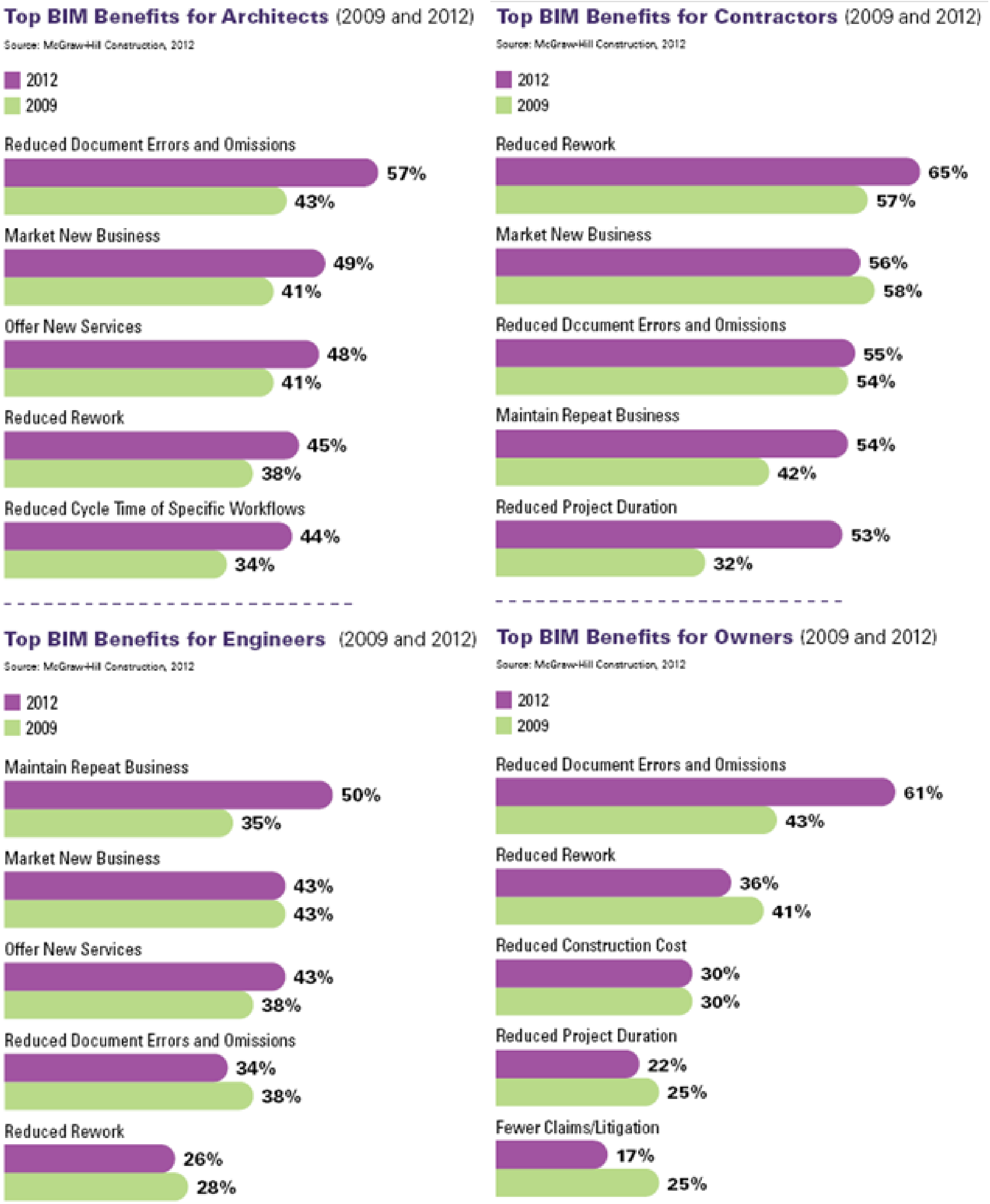


Figure 42 Top Benefits for Each of the Key Players

1.8 Renovation Projects

With a greater focus being placed on LEED and sustainable construction methods more owners are choosing to renovate existing structures rather than constructing new buildings on green space. Renovations are becoming more prevalent these days especially in overly developed regions of the United States. While BIM has not been applied as drastically to renovation projects as it has to new construction projects it is picking up momentum and becoming more common with advancements in techniques of its application. The reason for this lack of application is due to several key issues that must be addressed by the project team and other key players involved in a project's completion. These key issues can play a critical role in the successful application of BIM to a project. The most critical issue is the existence and accuracy of the 2D drawings for the structure. This issue can be compounded depending on the level at which the building is being renovated.

1.8 A: Partial Renovation

A partial renovation includes only a limited removal of key systems which is more likely to result in a break –even or potentially a negative ROI. It is important to consider which systems will be replaced; the extent to which they will be replaced and the potential benefits that can be gained from the implementation of BIM. For instance, if the fire protection system is being brought up to code it may not be as beneficial to the owner or the contractors involved to employ BIM. The cost of modeling the other systems and conducting coordination efforts will likely be more expensive then to follow typical design/planning/coordination efforts. It is likely that contractors will resort to their typical methods of designing the system and coordinating its installation around surrounding systems in order to prevent these additional modeling costs. The installation of a new mechanical system to an older structure is likely to benefit more from 3D modeling and 3D coordination than the previously mentioned system. Replacing such a substantial system in an older building is likely to benefit, in the design, coordination and construction efforts, from a BIM product. The extent to which BIM is used can be another critical issue after there is a clear interest and of course a great potential to gain a positive ROI. There are essentially two techniques which can be applied to model existing conditions, the first would be relying on the existing as-built drawings to compose 2D drawings that could then be used to produce and accurate 3D model. This method is time consuming and requires extensive verification of the drawings compared to the current construction. The 2D drawings may not show any new construction that has been completed in the last five or more decades resulting in highly inaccurate 2D reference drawings. The second method is the utilization of a laser scanner to accurately locate all existing systems and conditions for the structure. Laser scanning can be a rather expensive process requiring qualified personnel to conduct the scans, vast amounts of storage space for the terabytes of data, advanced computers and lastly personnel to analyze and model the data is not a useable model.

1.8 B: Full Renovation

A full renovation would be considered as a demolition and replacement of all major systems and potentially a partial replacement of key structural systems. Some of the key systems may include the MEP components some interior finishes like drywall partitions and other casework possibly. These more extensive renovation projects are where BIM is most likely to result in the greatest positive ROI. Employing BIM to model existing conditions will be very beneficial to future design, coordination, construction efforts and renovation efforts further down the road. Modeling these existing conditions can once again be complicated especially with outdated and inaccurate 2D drawings. Fortunately, laser scanning is very applicable to these project types resulting in a more efficient and effective delivery of a 3D model.

1.8 C: Conclusion of BIM Research

BIM has taken a few decades to become a widely accepted and practiced technique in the construction industry. Its use is gaining momentum thanks to the application of many of its methods by major players in the industry to many different and complex structures around the world. The key players in a project's development are investing their time, energy and money hoping for a positive ROI and more often than not they are experiencing a very positive return. These returns are resulting in multiple short-term and long-term benefits which facilitate a project's completion and result in benefits to the major players involved with a project's development. These benefits are more beneficial to some of the key players more than others, a detailed consideration of these potential benefits should be considered. Requests from owners for contractors to involve themselves in BIM may only benefit the owner resulting in inadequate support for investment in time or energy. BIM needs to be a feasible option accepted and promoted by the owner, contractor and the subcontractors in order for it to be very effective. BIM is becoming applied more and more to projects both small and big and of varying levels of complexity especially since these benefits are being measure in greater details and precision. While BIM is predominantly applied to new construction it is being applied in greater frequency to renovation projects. Methods have been produced to facilitate these accurate 3D models of existing conditions. With these advancements it is likely that BIM will become a standard application to not only new construction but also complex renovation projects. In order to experience greater benefits from applying BIM to renovation projects it is crucial to understand the issues associated with its application to renovation projects.

After analyzing current industry trends and assessing alternative BIM uses it is likely that this information will provide sufficient support for these alternative applications to this renovation project.

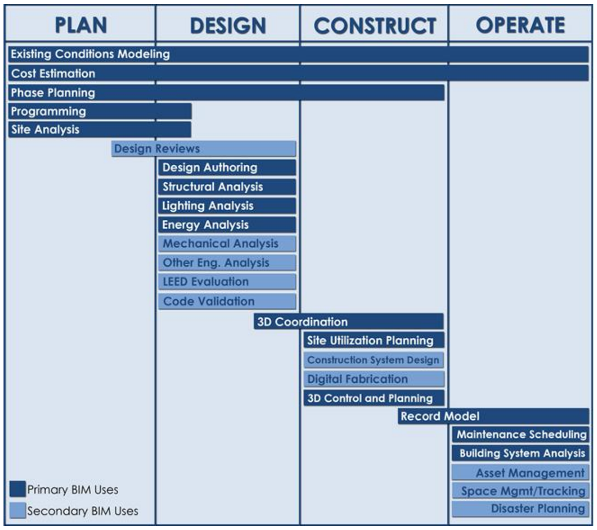


Figure 43 Project Development Phases

There are exactly twenty-five BIM Uses that facilitate a project's development. Phase planning is found in the Planning, Design and Construction phase of the four project development phases. Phase Planning, more commonly known as 4D Modeling is a Primary BIM use which is frequently used and often highly beneficial to a project's timely completion under budget. The alternative uses and the project phases they are associated with are displayed in figure 43.

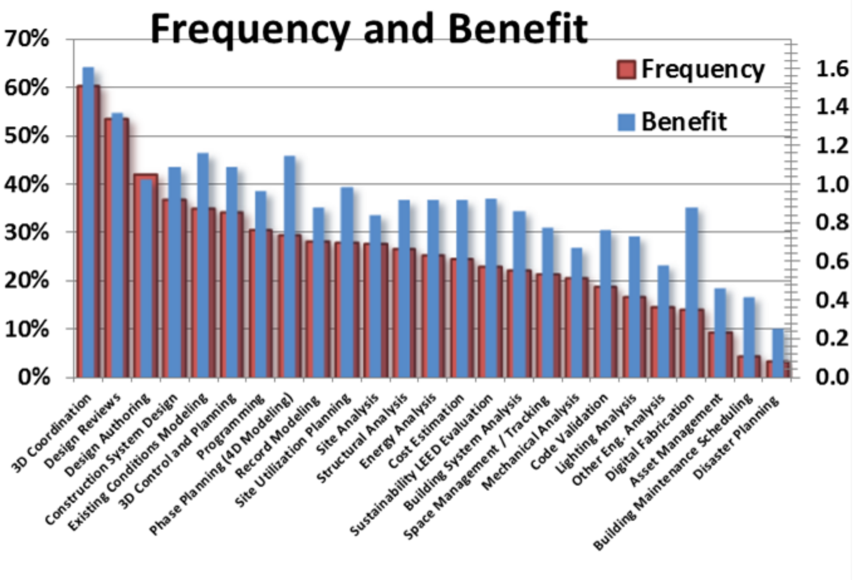
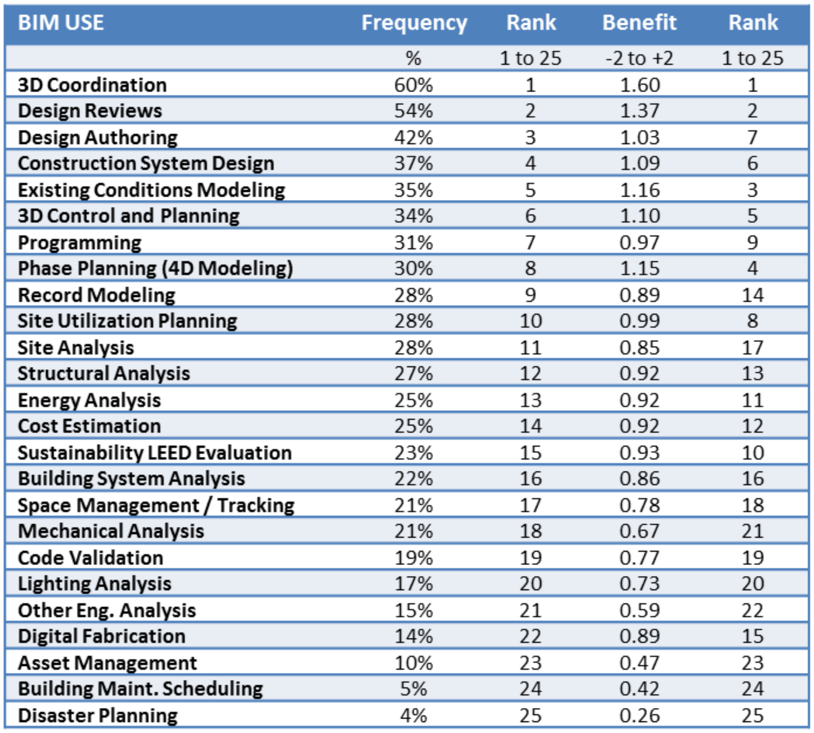


Figure 44 Frequency and Benefits of Each Use



BIM USE	Frequency	Rank	Benefit	Rank
	%	1 to 25	-2 to +2	1 to 25
3D Coordination	60%	1	1.60	1
Design Reviews	54%	2	1.37	2
Design Authoring	42%	3	1.03	7
Construction System Design	37%	4	1.09	6
Existing Conditions Modeling	35%	5	1.16	3
3D Control and Planning	34%	6	1.10	5
Programming	31%	7	0.97	9
Phase Planning (4D Modeling)	30%	8	1.15	4
Record Modeling	28%	9	0.89	14
Site Utilization Planning	28%	10	0.99	8
Site Analysis	28%	11	0.85	17
Structural Analysis	27%	12	0.92	13
Energy Analysis	25%	13	0.92	11
Cost Estimation	25%	14	0.92	12
Sustainability LEED Evaluation	23%	15	0.93	10
Building System Analysis	22%	16	0.86	16
Space Management / Tracking	21%	17	0.78	18
Mechanical Analysis	21%	18	0.67	21
Code Validation	19%	19	0.77	19
Lighting Analysis	17%	20	0.73	20
Other Eng. Analysis	15%	21	0.59	22
Digital Fabrication	14%	22	0.89	15
Asset Management	10%	23	0.47	23
Building Maint. Scheduling	5%	24	0.42	24
Disaster Planning	4%	25	0.26	25

Figure 45 Frequency and Benefits of Each Use Cont'd

After analyzing the many alternative BIM Uses 4D Modeling was found to be ranked 8/25 as frequency of use and a score of 1.15 with 2 being the highest for most benefit to a project. After this careful consideration of the alternative BIM uses and considering which use would be most beneficial to the project, a decision was made to analyze the application of 4D Modeling. These values can be further observed in Figures 44 & 45.

BIM PROJECT EXECUTION PLAN

Version 2.0

FOR

Concordia Hotel

DEVELOPED BY

Ian Bower

Turner Construction Company

This template is a tool that is provided to assist in the development of a BIM project execution plan as required per contract. The template plan was created from the buildingSMART alliance™ (bSa) Project "BIM Project Execution Planning" as developed by The Computer Integrated Construction (CIC) Research Group of The Pennsylvania State University. The bSa project is sponsored by The Charles Pankow Foundation (http://www.pankowfoundation.org), Construction Industry Institute (CII) (http://www.construction-institute.org), Penn State Office of Physical Plant (OPP) (http://www.opp.psu.edu), and The Partnership for Achieving Construction Excellence (PACE) (http://www.engr.psu.edu/pace). The BIM Project Execution Planning Guide can be downloaded at http://www.engr.psu.edu/BIM/PxP.

Section A: BIM Project Execution Plan Overview

To successfully implement Building Information Modeling (BIM) on a project, the project team has developed this detailed BIM Project Execution Plan. The BIM Project Execution Plan defines uses for BIM on the project (e.g. design authoring, cost estimating, and design coordination), along with a detailed design of the process for executing BIM throughout the project lifecycle

Section B: Project Information

1. **Project Owner:** Private
2. **Project Name:** Concordia Hotel
3. **Project Location and Address:** Washington D.C. (specific address is to remain confidential)

4. **Contract Type / Delivery Method:** Renovation: Brief Project Description: The IMF Concordia is a 10-story plus cellar and underground parking garage extended stay facility with two main structures connected at the ground floor. While the entire building is composed of 178 rooms the bond building has 78 while the Concordia houses the other 100. It was designed in by Berla & Able.

5. **Additional Project Information:** The BIM execution process for this project details the strengths and weaknesses of BIM implementation in the varying stages of the project.

6. **Project Numbers:**

PROJECT INFORMATION	NUMBER 2010-035

7. **Project Schedule / Phases / Milestones:**

PROJECT PHASE / MILESTONE	ESTIMATED START DATE	ESTIMATED COMPLETION DATE	PROJECT STAKEHOLDERS INVOLVED
PRELIMINARY PLANNING	8/21/11	9/20/11	Owner, GC, Architects
DESIGN DOCUMENTS	9/20/11	7/15/12	Owner, GC, Architects
CONSTRUCTION DOCUMENTS	11/8/11	12/1/11	Owner, GC, Architects, Subcontractors
CONSTRUCTION	12/12/11	2/18/13	Owner, GC, Architects, Subcontractors, Occupants
OPERATION	12/15/11	Ongoing	Owner, Occupants

Section C: Key Project Contacts

Role	Contact Name	Location	E-Mail	Phone
Project Manager(s)	JT Armstrong	Washington D.C.	jtarmstrong@tcco.com	301-509-2823
BIM Manager(s)	Yet to be provided	Washington D.C.	Yet to be provided	Yet to be provided
Operations Manager	Ben Short	Washington D.C.	Not Provided	Not Provided
Project Executive	Gary Ball	Washington D.C.	gball@tcco.com	703-200-1972
Project Engineer	Bailey Wilson	Washington D.C.	bawilson@tcco.com	571-527-1128
General Superintendent	Nicholas Vangeli	Washington D.C.	Not Provided	Not Provided
Assistant Superintendent	Chuck McClellan	Washington D.C.	cpmcclellan@tcco.com	202-330-9873
MEP Engineer/Coordinator	Gregg West	Washington D.C.	Not provided	Not Provided

Section D: Project Goals / BIM Uses

1. Major BIM Goals / Objectives:

PRIORITY (HIGH/ MED/ LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES
High	Increase effectiveness of Design	Record Model, 3D Coordination, Asset Management, Space Management/Tracking
High	Eliminate Field Conflicts	3D Coordination
Med	Increase Field Labor Productivity & Quality Through Large Amounts of Prefabrication	3D Design Coordination
High	Identify Concerns Associated With Phasing On-Campus	Phase Planning
Medium	Quickly asses cost associated with design changes	Cost Estimation
High	Review design progress	Design Reviews
Med	Accurate 3D Record Model for Construction Team	Record Model, 3D Coordination,
Med	Track progress during construction	4D Modeling
High	Re-phasing of demolition efforts	Phase Planning (4D Modeling)

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			
Existing Conditions Modeling	MED	Contractor	HIGH	2	3	2	3D model manipulation, review and assessment	Accurate assessment of existing conditions for demolition and construction	**YES**
		Facility Manager	MED	1	1	1			
		Designer	HIGH	3	3	3			
Cost Estimation	HIGH	Contractor	HIGH	3	3	3	Model-based estimating software, design authoring software and cost data	Ability to define specific design modeling procedures which yield accurate quantity take-off information, identify quantities for the appropriate estimating level (ROM,SF, etc..) upfront	**NO**
		Owner	HIGH	3	2	3			
		Designer	MED	1	2	2			
Phase Planning (4D Modeling)	HIGH	Contractor	HIGH	3	3	3	3D Modeling Manipulation, Design authoring software, 4D Modeling Software	knowledge of scheduling and phasing of construction, manipulate, navigate and review 3D Model and knowledge of 4D Scheduling Software	**YES**
		Subcontractor	HIGH	1	2	2	Software Training	Phasing complications	
		Owner	MED	1	1	1		Use for Phasing & Construction	
Programming	HIGH	Contractor	HIGH	3	3	3			**MAYBE**
		Subcontractors	HIGH	1	3	3	conversion to Digital Fab required	Modeling learning curve possible	
		Designer	MED	2	3	3			
Site Analysis	MED	Engineer	HIGH	2	2	2			**MAYBE**
		Designer	MED	2	2	2			
		Contractor	MED	3	2	2			
Design Reviews	HIGH	Designer	HIGH	2	3	3		Reviews to be from design model	**NO**
		Contractor/DA Subs	HIGH	3	3	3			
		Owner	HIGH	3	3	3			
Design Authoring	HIGH	Designer	HIGH	2	2	2	Coordination software required	BMC to facilitate Coord.	**MAYBE**
		Engineer	MED	2	2	1			
		Contractor	HIGH	2	2	2			

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			
Structural Analysis	MED	Designer	HIGH	3	3	3			**MAYBE**
		Engineer	MED	3	3	3			
		Contractor	HIGH	3	3	3			
Lighting Analysis	MED	Contractor	LOW	2	2	2			**NO**
		Engineer	HIGH	2	3	3			
		Designer	MED	2	2	3			
Energy Analysis	MED	Contracter	LOW	2	3	3			**NO**
		Engineer	LOW	2	2	2	Additional Software Training		
Mechanical Analysis	HIGH	Contractor	LOW	2	2	2	Requires training and software		**NO**
		Engineer	HIGH	3	3	3			
		Designer	MED	3	3	3			
Other Eng. Analysis	HIGH	Contractor	LOW	2	1	1			**MAYBE**
		Designer	MED	3	3	3			
		Engineer	HIGH	3	3	3			
LEED Evaluation	HIGH	Contractor	MED	3	2	2		High vlaue to owner, require LEED accredidation	**MAYBE**
		Designer	MED	2	2	2			
		Owner	HIGH	3	3	3			
Code Validation	LOW	Contractor	HIGH	3	3	3			**NO**
		Subcontractors	HIGH	1	3	3			
		Designer	MED	2	3	3			
3D Coordination	HIGH	Engineer	MED	2	2	2	Coordination Software Training	Reduction of clashes	**YES**
		Subcontractor	HIGH	2	2	2	3D model manipulation, review and assessment	Ability to deal with multiple trades, project challenges	
		Contractor	HIGH	3	3	3			
Site Utilization Planning	MED	Designer	LOW	1	2	1	Additional Training		**NO**
		Contractor	HIGH	3	3	3			
Construction System Design	MED	Designer	MED	2	2	2			**NO**
		Engineer	HIGH	2	2	1			
		Contractor	MED	2	2	1			

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			
Digital Fabrication	HIGH	Designer	MED	2	2	2			**NO**
		Engineer	LOW	1	2	2			
		Contractor	HIGH	3	3	3			
Record Model	MED	Facility Manager	MED	3	3	3	Model Manipulation	Need to have the ability to navigate, review and manipulate the BIM product and 3D Model, use the product for updates to the facility, and to maintain a thorough understanding of site processes in order to assure correct input	**MAYBE**
		Owner	HIGH	3	3	3			
		GC & Subs	MED	2	3	2			
Maintenance Scheduling	MED	Facility Manager	HIGH	1	1	1	Design reviewing software to allow FM to view BIM product components, Building Automation Systems linked to the construction model/actual model, user ready interface and friendly user operational abilities	Be capable of understanding and manipulating Maintenance Management System and many of the MEP systems within the structure as well as the control systems	**NO**
		Owner	MED	2	1	1	Software Training		
Building System Analysis	HIGH	Facility Manager	HIGH	3	3	3			**MAYBE**
		Owner	HIGH	3	3	2			
		Designer	MED	2	3	2			
Asset Management	MED	Facility Manager	HIGH	3	2	2			**MAYBE**
		Owner	HIGH	3	2	3			
Space Mgmt/Tracking	HIGH	Facility Manager	HIGH	3	2	2			**NO**
		Owner	HIGH	3	3	3			
Disaster Planning	HIGH	Contractor	LOW	3	3	3			**MAYBE**
		Owner	HIGH	1	3	3			
		Designer	LOW	2	3	3			

2. BIM USES

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING MAINTENANCE SCHEDULING
	SITE ANALYSIS	X	DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN		BUILDING SYSTEM ANALYSIS
		X	3D COORDINATION	X	3D COORDINATION		ASSET MANAGEMENT
			STRUCTURAL ANALYSIS		DIGITAL FABRICATION		SPACE MANAGEMENT / TRACKING
			LIGHTING ANALYSIS		3D CONTROL AND PLANNING		DISASTER PLANNING
			ENERGY ANALYSIS	X	RECORD MODELING	X	RECORD MODELING
			MECHANICAL ANALYSIS				
			OTHER ENG. ANALYSIS				
			SUSTAINABLITY (LEED) EVALUATION				
			CODE VALIDATION				
X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)
	COST ESTIMATION		COST ESTIMATION		COST ESTIMATION		COST ESTIMATION
	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

After a reanalysis of the goals of the project a decision was made to pursue a greater application of Phase Planning (4D Modeling) beginning in the planning phase and continuing into the construction phase. This BIM application was considered, however, based on the GC's wishes it was not applied to the key phases of the project's development. It was decided that a more critical analysis of the demolition and construction efforts could be facilitated via the application of 4D Modeling. This analysis will be included into analysis 2 & 3. It will be applied to exactly three alternative demolition sequences and MEP prefabrication techniques.

1.9 Analysis Summary

- It was determined that the project team did in fact use BIM for the 3D coordination of the MEP systems throughout the structure.
- Based on the benefits and ROI potential that 4D Modeling can offer it was determined that it would be feasible to use the 3D model created for the resequencing of the demolition efforts.
- It is based on this conclusion that the next analysis area will utilize a 4D model to show the resequencing of demolition efforts to discover a more efficient manner of conducting these demolition efforts.

Analysis 2: Re-Sequencing of Demolition Efforts

2.1 Problem Identification

The demolition of the Concordia project consisted of the removal of MEP systems, drywall partitions, CMU walls, concrete columns, interior finishes and several interior slabs. The demolition initiatives which took place throughout the structure were extensive and repetitious on several floors. Even though demolition of the interior slabs and structural columns were repetitious, this activity still delayed concurrent and succeeding activities from being completed. These delays resulted in the project being completed behind schedule just less than two months. The goal of this analysis is to consider alternate sequences to demolish the structural slabs and columns in order to accelerate the schedule and to result in overall savings to the project.

2.2 Research Goal

The goal of this analysis is to perform an in depth schedule re-sequencing in order to make it possible for the owner to turnover floors to construction in a more efficient manner. The ultimate goal is to accelerate the schedule by considering alternative demolition sequences that will allow succeeding activities to begin on-time or ahead of schedule therefore improving the likelihood of the project meeting the require project completion date. There were inefficient means of demolition, mobilization and demobilization, this analysis will consider alternatives that will eliminate inefficient methods of demolition.

2.3 Research Methods

- Interview project managers to determine all contributing factors to project delays
- Conduct interviews of demolition contractor ACEco to understand actual demolition technique as well as potential alternative demolition methods to consider
- Research the effect on construction means, methods, and logistics through the consideration of alternative BIM uses
- Research how BIM can be used to facilitate demolition efforts
- Gain a greater understanding of BIM’s applicability to demolition resequencing and prefabrication
- Acquire AutoCAD models from The Turner Construction Company
- Review AutoCAD models to consider accuracy and thoroughness of the building systems modeled
- Construct any missing systems with the utmost accuracy
- Determine how the generated 3D model will be beneficial to the alternative BIM applications
- Compose a 3D model of the cast-in-place concrete structural system
- Export the 3D model into Navisworks as a DWG and create a detailed schedule of each of the alternate demolition techniques
- Assess the schedule impact as a result of re-sequencing Analyze potential schedule and cost savings associated with each demolition method

2.4 Resources & Tools to be Used

- The Turner Construction Company project team on the Concordia Hotel
- Nathan Lytle with ACEco-Demolition Contractor
- The Pennsylvania State University AE Faculty

- Educational background from previous AE courses (such as AE 372, AE 475, AE 476, and AE 570)
- 3D Software (Revit, Navisworks)
- Applicable literature (books, websites, papers, etc.)
- Other key industry members

2.5 Potential Solutions and Expected Outcomes

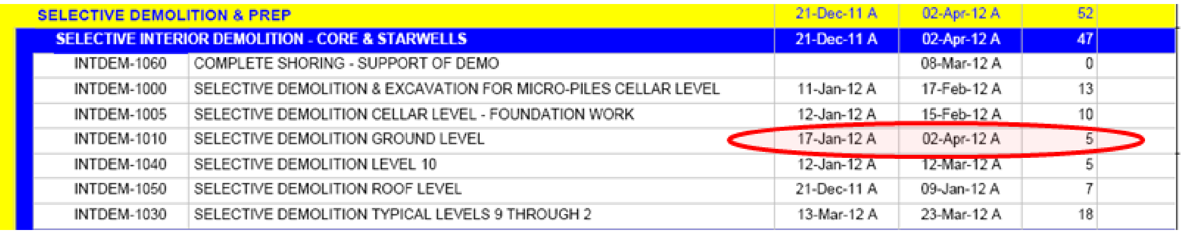
Upon completion of this analysis, it is expected that a more efficient phasing sequence can be implemented for the demolition and renovation phases through the use of the BIM use; phase planning. Through an in-depth analysis of the schedule, it is expected that the owner can turnover floors to construction sooner and more efficiently with less constructability and logistical issues. The organized floor turnover sequence is expected to reduce the overall duration of the schedule, thus reducing overall general conditions costs and durations of the project.

2.6 Demolition Efforts

There were essentially two phases of demolition the first involved extensive removal of interior finishes and expensive asbestos abatement, a removal of the outdated MEP systems and lastly a demolition of the façade. The second phase involved the demolition of the interior slabs and elevator/stairwell core. The second phase experienced many construction issues and it will be the key area of analysis. *"Phase 2 performed for Turner Construction is very difficult to give a schedule on as there was problem after problem and we have been in and out to complete our scope starting last March. We completed that work in the last 2 weeks" (Nathan Lytle of ACEco Feb. 11, 2013).*

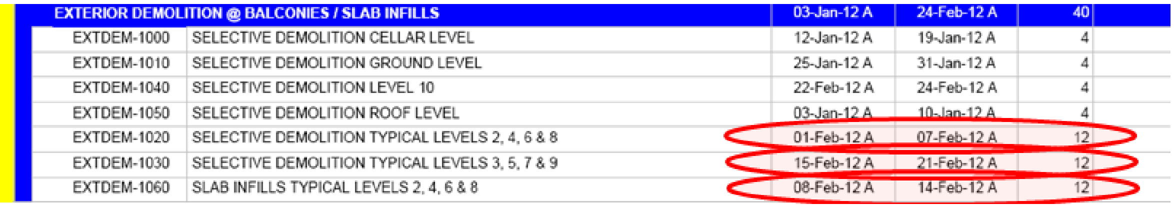
2.7 Re-sequencing the Demolition Project Schedule

In a complexly phased project, it is essential to understand the project schedule and which trades are affected when making changes to the demolition sequence. There were several trades which were affected by this delayed schedule specifically the key activities associated with the installation of the new Micro Pile & MEP systems for the structure. The areas of slabs which required demolition were repetitious starting from the second floor continuing up to the ninth level. The cellar and roof level involved non-repetitious demolition. The roll-out schedules and Gantt charts describing the demolition initiatives and the sequence in which they were completed are shown below in figures 46 & 47.



SELECTIVE DEMOLITION & PREP		21-Dec-11 A	02-Apr-12 A	52
SELECTIVE INTERIOR DEMOLITION - CORE & STARWELLS		21-Dec-11 A	02-Apr-12 A	47
INTDEM-1060	COMPLETE SHORING - SUPPORT OF DEMO		08-Mar-12 A	0
INTDEM-1000	SELECTIVE DEMOLITION & EXCAVATION FOR MICRO-PILES CELLAR LEVEL	11-Jan-12 A	17-Feb-12 A	13
INTDEM-1005	SELECTIVE DEMOLITION CELLAR LEVEL - FOUNDATION WORK	12-Jan-12 A	15-Feb-12 A	10
INTDEM-1010	SELECTIVE DEMOLITION GROUND LEVEL	17-Jan-12 A	02-Apr-12 A	5
INTDEM-1040	SELECTIVE DEMOLITION LEVEL 10	12-Jan-12 A	12-Mar-12 A	5
INTDEM-1050	SELECTIVE DEMOLITION ROOF LEVEL	21-Dec-11 A	09-Jan-12 A	7
INTDEM-1030	SELECTIVE DEMOLITION TYPICAL LEVELS 9 THROUGH 2	13-Mar-12 A	23-Mar-12 A	18

Figure 46 Demolition Schedule



EXTERIOR DEMOLITION @ BALCONIES / SLAB INFILLS		03-Jan-12 A	24-Feb-12 A	40
EXTDEM-1000	SELECTIVE DEMOLITION CELLAR LEVEL	12-Jan-12 A	19-Jan-12 A	4
EXTDEM-1010	SELECTIVE DEMOLITION GROUND LEVEL	25-Jan-12 A	31-Jan-12 A	4
EXTDEM-1040	SELECTIVE DEMOLITION LEVEL 10	22-Feb-12 A	24-Feb-12 A	4
EXTDEM-1050	SELECTIVE DEMOLITION ROOF LEVEL	03-Jan-12 A	10-Jan-12 A	4
EXTDEM-1020	SELECTIVE DEMOLITION TYPICAL LEVELS 2, 4, 6 & 8	01-Feb-12 A	07-Feb-12 A	12
EXTDEM-1030	SELECTIVE DEMOLITION TYPICAL LEVELS 3, 5, 7 & 9	15-Feb-12 A	21-Feb-12 A	12
EXTDEM-1060	SLAB INFILLS TYPICAL LEVELS 2, 4, 6 & 8	08-Feb-12 A	14-Feb-12 A	12

Figure 47 Demolition Schedule

Upon further analysis of this schedule breakdown; there seemed to be discrepancies between dates and durations. Based on these potential mistakes it was assumed that the start date was correct and that the durations were as well, therefore, the finish dates are indeed incorrect.

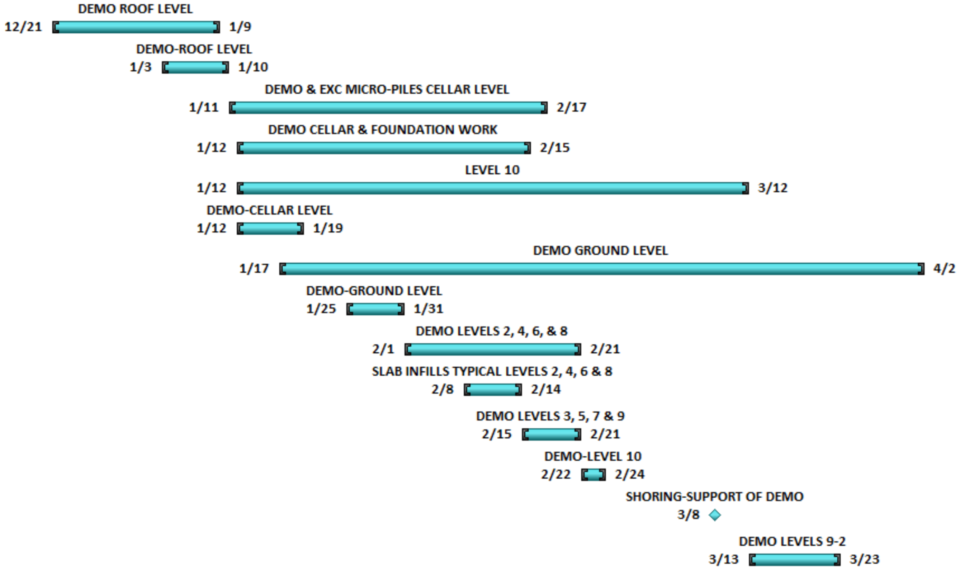


Figure 48 Demolition Gantt Chart (52 days)

Figure 48 shows the schedule for demolition efforts of the structural slabs beginning at the cellar level and extending up to the roof of the Concordia hotel. The Gantt chart above follows the start and finish dates shown above in the inaccurate schedules in figure 46 and 47. After conducting further analysis of this discrepancy a new schedule was constructed in order to accurately consider the correct start date with the correct durations. This new Gantt chart is included below in figure 49 and is a more accurate representation of the actual demolition efforts and their durations.

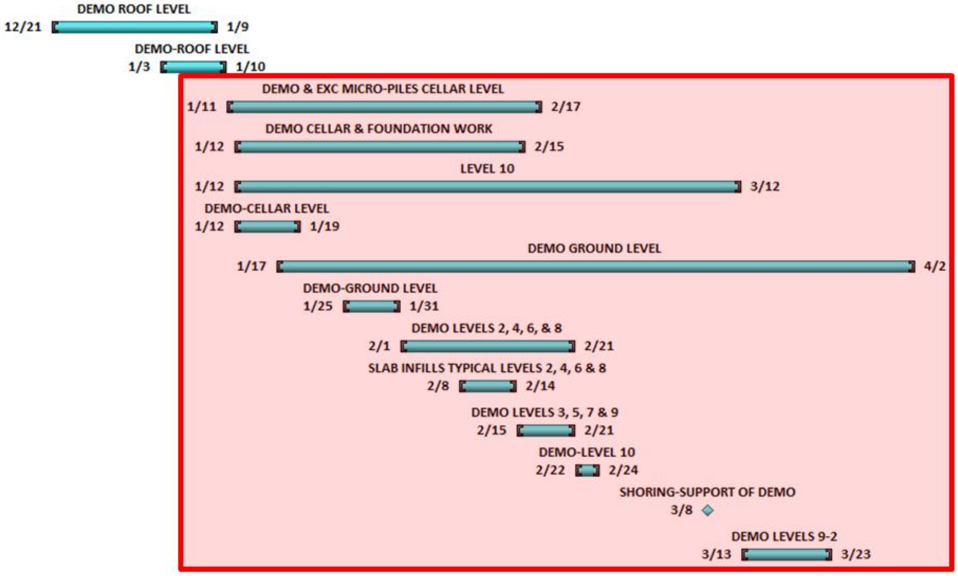


Figure 49 Corrected Gantt Chart of Demolition Efforts

After completing this correction, the schedule was further analyzed in order to discover any inefficiency that existed in the demolition efforts and to gain a greater understanding of the techniques applied to this renovation project and how they might be improved. After conducting interviews with the project team, demolition contractor and carefully considering the schedule it was discovered that there were several inefficient methods applied to the demolition sequence. After careful observation of the schedule it is clear that the movement back and forth from each of the floors is very inefficient and results in lost productivity and time. This loss is due to the constant mobilization and demobilization efforts required to set up on each floor. It would be more effective to start and finish demolition on each floor before moving to the next floor. This technique also utilized one Brokk 50 demolition robot and a crew of 8 laborers (2 laborers prepped the floor and removed demolished debris, 2 competent laborers operated the demo bot, and the 4 other laborers operated jackhammers to support demolition efforts on each floor).

Figure 50 Detailed Analyses of Inefficiencies

Figure 50 shows the inefficient movements that occurred for transporting equipment and personnel between the multiple floors. This repeated movement caused lost productivity due to mobilization and demobilization requirements of the demolition contractor. In figure 50 highlighted in red shows the discontinuation of demolition on the 10th level and highlighted in green shows the discontinuation between levels 2-9.

The purpose of this analysis will be to consider and observe the effects of alternate sequences specifically considering their effects on schedule, cost and project logistics. This analysis will be performed utilizing phase planning (4D Modeling), a key BIM use, introduced and recommended previously in Analysis 1 Building Information Modeling (BIM). After conducting this analysis and proposing more feasible demolition techniques a more efficient and productive method will be analyzed in terms of its potential to accelerate the schedule and reduce project overall costs and delays. Highlighted in red in figure 49 is the area of the schedule which will be analyzed in greater detail. For the purposes of this analysis the roof level will be excluded and will not be considered. This analysis will consider three alternative demolition sequences, a catch-plate demolition sequence, a staggered demolition and finally an extended demolition sequence. The following proposed sequences will be analyzed in order to eliminate the inefficiencies associated with the actual demolition process in order to save time and money to the renovation of the Concordia project.

2.8: Alternative Demolition Sequences:

2.8 A: Actual Demolition-(2 crews composed of 8 laborers/crew, 1 demolition bot for the above floors and one small excavator for the cellar level demolition, and lastly other typical demolition equipment like jackhammers for the floors above) Nathan Lytle with ACEco provided limited details concerning the demolition efforts that actually occurred on-site, however, during our conversations he described the countless delays and lack of coordination that caused inefficiencies in the demolition schedule. While figure 46, 47 & 48 suggests that demolition was planned to only take a total of 60 days, due to multiple schedule delays and conflicts, the demolition actually took much longer than had originally predicted. A representation of this schedule was created in order to formulate a baseline schedule accompanied by a 4D model to help represent the actual technique applied shown in figure 48. The 4D model of the actual demolition schedule was used to compare alternatives to this baseline in order to infer the potential opportunities for improvements that may save time and money.

2.8 B: Catch-Plate Demolition-A catch plate demolition sequence is a technique commonly applied to areas where large expanses of slabs are being removed from a building. A catch plate system is used to capture any falling debris and to prevent any potential safety risks while still maintaining bearing capacity for materials, equipment and personnel. This system would allow demolition efforts to be conducted on the floor below to proceed while demolition was being completed on the floor above. This system would be applied to every other floor starting at the 9th floor and working its way down to the 7th, 5th and lastly the 3rd floor. There are some critical issues associated with implementing this system, while it would allow for simultaneous demolition efforts on multiple floors it will result in extra costs. These costs will be a result of added design, personnel, and other logistical issues like assembling, relocating and reassembling of the system from each floor. Employing a “catch plate system” would involve extensive design in order to withstand the dead loads associated with the demolished materials, equipment and personnel conducting the demolition. This system’s implementation would include expensive design and design approval from a qualified engineer which would likely result in an additional expense of $2500.00-$3000.00. The system would also require qualified personnel to be enrolled in its construction resulting in increased labor costs. Applying this method to the demolition of the structure would considerably hinder the schedule due to constructability and material flow issues related to the system. The method would consist of demolition efforts beginning on the 10th level while the catch plate system was being installed below the core of the 9th level. Next, the demolition team would move down to the 8th level while the system’s installation was being completed on the 9th level. Once the system’s construction was complete the crew and their equipment would return to the 9th level to complete demolition efforts. This back and forth movement would inevitably and unfortunately result in loss of productivity due to mobilization requirements. The only way to eliminate this loss of productivity would be to employ two crews with two pieces of demo equipment. Utilizing two crews would consist of one crew doing all of the even floors and set up of the catch plate devices for the odd floors and the other crew would move down through all of the odd floors demolishing the cores and other openings as they moved down through the structure. Once again the added cost of the application and movement of the catch plate system is likely to result in an inefficient demolition method. This will be compounded additionally due to the increased manpower and equipment used to conduct the demolition of the core and other slab openings. This was the first alternative demolition technique to be considered and compared to the actual technique applied to the project. After careful consideration of this technique it was considered that it would not result in considerable cost savings and would only result in constructability issues associated with the movement of materials and equipment and in the end would result in greater costs.

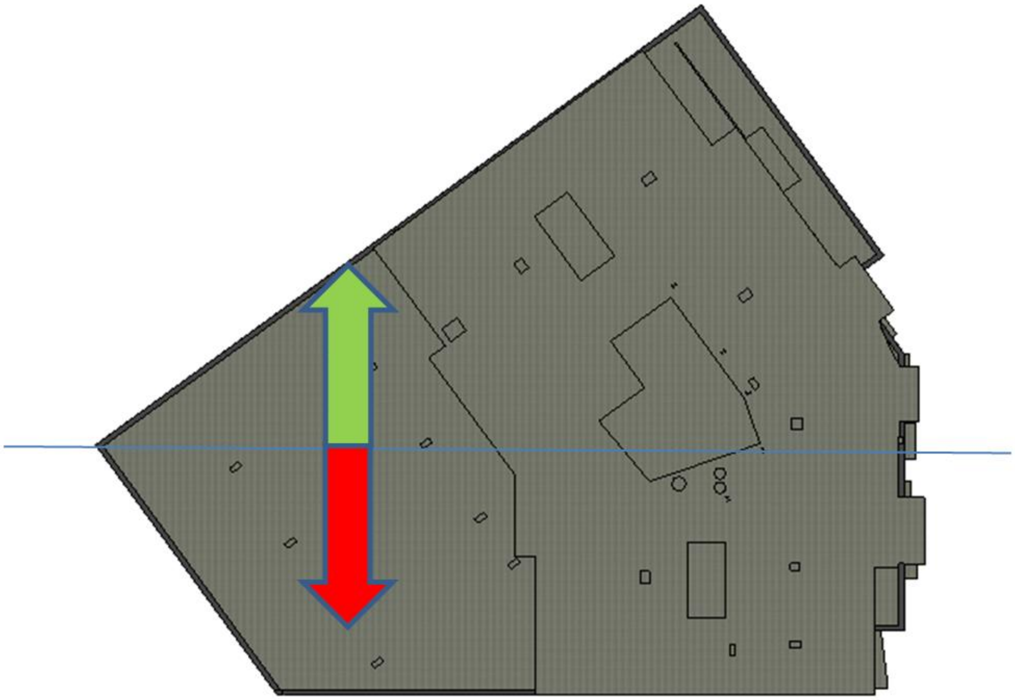


Figure 51 Demolition Layout Green Arrow=North Openings, Red Arrow=South Openings

2.8 C: Staggered Demolition-(30 days under schedule when compared to actual demolition) The second alternative demolition technique to be considered consists of demolition initiatives being conducted on multiple levels on opposite sides of the structure simultaneously on the upper floors and working their way down through the structure. While demolition efforts are being conducted on the floors above the small excavator will be conducting demolition procedures in the cellar level to prepare for the micro-pile installation. Each floor would be broken up into two areas, the north and the south sides as shown in figure 51. Demolition efforts would begin on the 10th level north with crew # 1 while a second crew, crew # 2 would conduct demolition of the 9th level south simultaneously, shown highlighted in blue in figure 58. The two crews would switch only when both crews have completed the demolition on that floor so as to prevent any injuries due to falling debris. So, to clarify crew # 1 would move to 10th level south and crew # 2 would move to the 9th level north, shown highlighted in red in figure 58. Once the 10th level south is complete and the 9th level north is completed crew # 2 will move down to the 8th level north to begin demolition while crew # 1 will demolish the 10th level core. Once the crew # 1 has completed the 10th level core they will be responsible for demolishing the rest of the cores throughout the structure from the 9th floor to the cellar level. Crew # 2 will have the responsibility of demolishing only the north and south openings on each floor excluding the cores. During these demolition efforts crew # 1 will be conducting demolition overhead of the second crew, the cores will be taped off so as to decrease the likelihood of injuries due to falling debris. This method will continue on all the way down to the cellar level of the structure. This method will result in a greater efficiency in demolition efforts.

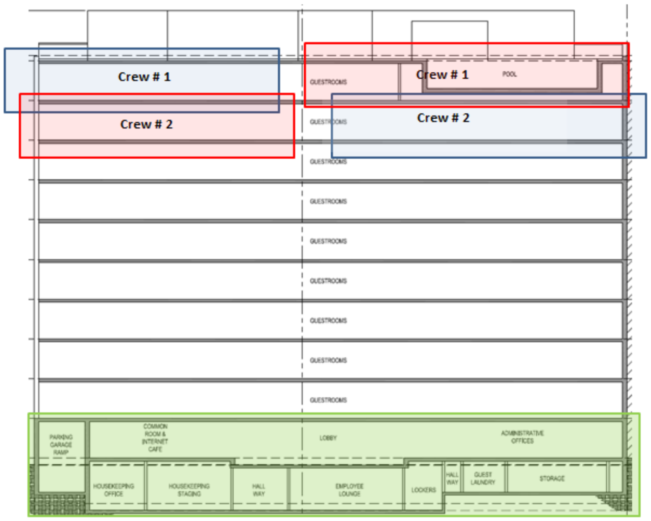


Figure 52 Building Section (Staggered Demolition)

2.8 D: Extended Demolition-The third and final alternative demolition technique to be analyzed was the standard practice of demolition which is to move down through the structure with the completion of one floor at a time utilizing a limited crew and equipment to save overall costs. This technique will involve the use of one crew and one set of demolition equipment on the floors above and while it might have saved money it will not result in any significant schedule savings. It is for these reasons that the extended demolition sequence was not analyzed any further than composing a 4D model due to its failure to accelerate the schedule. After a thorough analysis of this sequence it resulted in going over the planned demolition finish date a total of approximately 17 days over schedule. This would result in added costs that would not be overcome by the reduced cost of equipment and laborers. It is based on these details that this method not be applied to the project by the project team.

2.9 Alternative Demolition Sequence Impacts:

2.9 A: Staggered Demolition Impacts

A further analysis of the staggered demolition sequence has been considered below in relation to schedule and other related general conditions costs. The focus was placed on the staggered demolition effort due to the fact that this resulted in the greatest schedule savings potential compared to the other proposed alternatives. A 4D model was combined with a detailed demolition schedule created to help justify the application and feasibility of this method. Implementing this technique will result in several key impacts to constructability concerns, schedule and finally the overall project cost.

2.9 B: Construction Impact

Re-sequencing the project schedule to conform to the proposed staggered demolition sequence, will result in increased productivity and efficiency. Beginning and finishing demolition on each floor will accelerate the turnover of each floor to the succeeding trades and would have helped the project meet its schedule. This method will not require constant mobilization and demobilization efforts until each floor is completed. While each crew will have to conduct these mobilization and demobilization efforts, it will not be as extensive as was previously proposed. This accelerated turnover of each floor will allow subcontractors to mobilize and demobilize in a more efficient and organized manner. This sequence will not affect the micro pile installation in the cellar level because it will follow a similar sequence and demolition for this area. A small excavator with demolition attachments as well as a bucket attachment will be used in the cellar level to demolish existing slabs and walls. The same shoring devices will be used to alleviate the weights of dead loads and construction loads just as previously proposed.

2.9 C: Schedule Impacts

After conducting a thorough analysis of the schedule and the increased productivity through the utilization of a second Brokk demolition robot and crew substantial schedule savings were noted. The durations for each floor were maintained and one crew's responsibility only included the stairwell/elevator cores, after completing the north and south roof level openings, while the other crew's responsibility included the other openings on both the north and south side. This allowed for a greater standardization and focus of tasks which would result in greater productivity due to the contractor overcoming the learning curve. As laborers and contractors move through the floors conducting repetitious demolition on the slabs and cores they will become more efficient and reduce their typical durations. In this analysis this was not considered to influence the durations, therefore the durations in this analysis are an over compensation and in reality these durations would have likely been reduced. Through an analysis of a 4D model it was discovered that a significant amount of workdays would be saved as a result of applying this staggered demolition method. Demolition efforts would be completed on 2/17/12 rather than 3/23/12 resulting in the schedule being reduced to 28 days instead of 56 days a savings of 28 days.

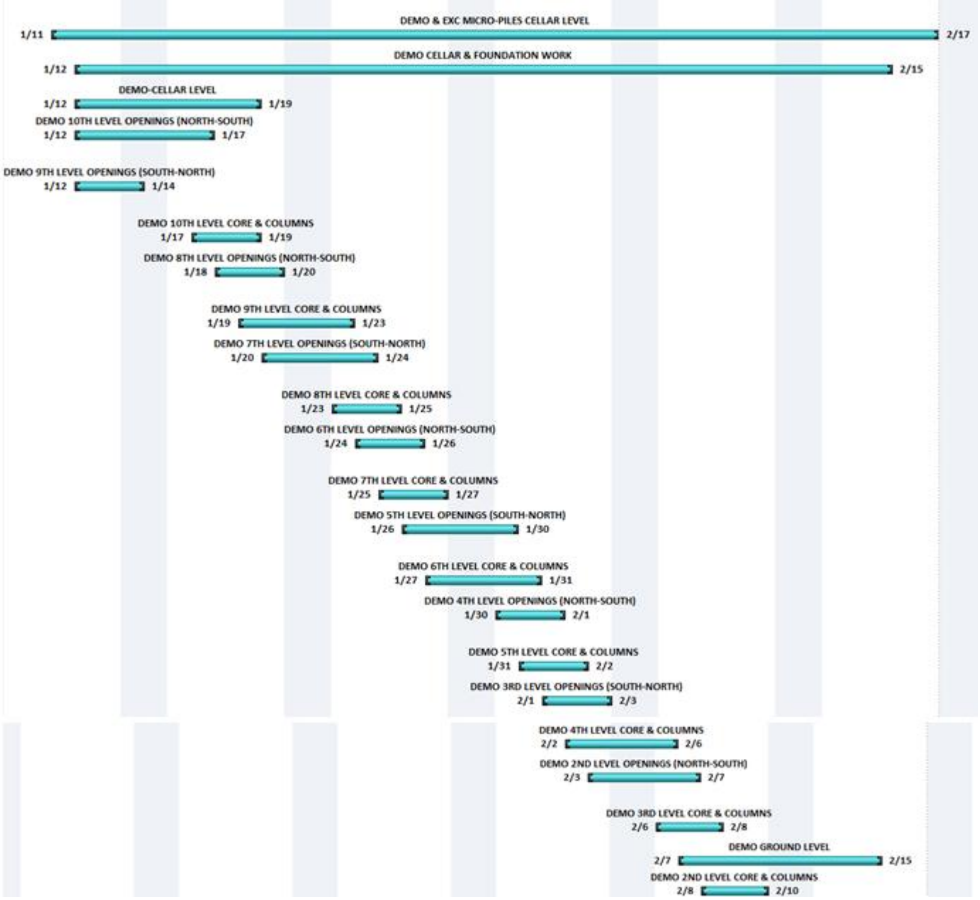


Figure 53 Staggered Demolition Schedule

2.9 D: Project Cost Impact

The owner required the project to be completed and ready for the New Year to welcome prospective guests to the hotel. The hotel will charge $30,260/day as a penalty for every day that the contractor is late and over schedule for the project's delivery. This is likely an overestimate of the penalty due to the fact that several change orders were submitted prior to these delays occurring, however, this is a great consideration of the worst case scenario to the contractor and to the owner. It was assumed that the contractor would be penalized the average cost of hotel rooms for all of the 178 rooms for each day past the preoject's completion date. The average hotel room in this area is approximately $170.00. The project was to conduct a final punch list and turnover on the 18th of December when in fact the project is still being turned over at the moment and should be completed by March 1st. The original demolition duration was 56 days which resulted in the project being handed over exactly 53 working days which does not include weekends. This unfortunately would result in a penalty of $1,603,780.00. The implementation of a staggered demolition sequence will result in schedule savings since the staggered demolition sequence only took 28 days to complete, which resulted in 28 days saved. Since the project was over schedule 53 days with the original demolition efforts and there was a schedule reduction of 28 days we can see that approximately 25 days were saved. This reduced the penalty from $1,603,780.00 to a penalty of only $756,500.00, a savings of $847,280.00. This cost analysis is shown in greater detail below in table 24.

Table 24: Penalty Savings-Staggered Demolition

Item	Schedule (Days)	Over Schedule	Total # of Rooms	Cost/ Room	Penalty Costs
Original Duration	56	53	178	$ 170.00	$ 1,603,780.00
New Duration	28	53-28=25	178	$ 170.00	$ 756,500.00
				Savings	$ 847,280.00

Table 24 Penalty Savings-Staggered Demolition

The General conditions costs, as noted previously in this report are a total sum of $1,330,610.00 which is just under 6% of the overall project cost of $23,000,000.00. The project's construction duration was to be 246 days, which gives a general conditions breakdown per day of $5,408.98/day ($1,330,610.00/246 days). The original method of demolition had a duration of 56 days and resulted in the project being delivered 53 days over schedule. The application of a staggered demolition sequence will result in schedule savings since the staggered demolition sequence only took 28 days to complete, which resulted in 28 days saved from the past due project therefore it was theoretically only days over schedule (53-28=25 days over schedule). The new demolition technique will deliver the project 28 days sooner resulting in the project only being 25 days over schedule. This will result in a general conditions cost of only $135,224.50 which is a savings of $151,451.44 from the original GC cost of $286,675.94. This cost analysis is displayed in greater detail below in table 25.

Table 25: Schedule Savings-Staggered Demolition

Item	Schedule (Days)	General Conditions Cost Savings ($/Day)	Over Schedule	General Conditions Cost
Original Duration	56	$ 5,408.98	53	$ 286,675.94
New Duration	28	$ 5,408.98	53-28=25	$ 135,224.50
		Savings		$ 151,451.44

Table 25 General Conditions Savings-Staggered Demolition

In order to consider the precise extent of savings that a demolition technique of this nature can save to the project an analysis of the extra cost of laborers and equipment. Equipment and laborers will result in extra costs due to a second Brokk robot at $2,000/month and an additional crew. The original demolition technique was to take 56 days which is approximately 1.87 months while the staggered demolition method is approximately 28 days or 0.93 months. After receiving a quote from a reputable equipment rental company it was found that the Brokk 50 Demolition Robot would cost $2,000/month while the mini-excavator would cost $2200/month, this rental cost includes the attachments and delivery and retrieval of the equipment from the site. Assuming that skilled demolition laborers receive $100/hr and laborers receive $30/hr this will result in a cost of $2,480/day for a crew of 8 with 1 skilled laborer and 7 non-skilled laborers. The use of this equipment and crew will result in a cost of $139,128.00 for the 56 day duration. The new sequence will utilize an extra Brokk robot, and a second crew which will include 2 skilled laborers and 14 non-skilled laborers which will result in a labor cost of $4,960.00/day which is $138,880.00 for the 28 day duration which is an increased labor cost of $248.00.

Table 26: Equipment Cost-Actual Demolition				
Equipment	Number	Duration (month)	Cost ($/month)	Total Cost ($)
Brokk 50 Demo Bot	1	1.87	$ 2,000.00	$ 3,733.33
Mini Excavator	1	1.87	$ 2,200.00	$ 4,106.67
Laborers	8	1.87	$ 74,400.00	$ 139,128.00
				$ 146,968.00

Table 26 Equipment Cost-Actual Demolition

Table 27: Equipment Cost-Staggered Demolition				
Equipment	Number	Duration (month)	Cost ($/month)	Total Cost ($)
Brokk 50 Demo Bot	2	0.93	$ 2,000.00	$ 3,720.00
Mini Excavator	1	0.93	$ 2,200.00	$ 2,046.00
Laborers	16	0.93	$ 148,800.00	$ 138,880.00
				$ 144,646.00

Table 27 Equipment Cost-Staggered Demolition

Overall, the implementation of a staggered demolition sequence will result in an overall decrease in cost of $2,322.00 for additional laborers and equipment.

2.9 E: Contractor Concerns

This demolition re-sequence will enable mobilization efforts on the upper floors and in the cellar level to prepare for construction much sooner than original demolition technique. Since the building's foundation required extensive micro pile installation it is critical to maintain the schedule for this procedure so that construction throughout the structure can continue on schedule. Resequencing the demolition will require a greater consideration of the schedule of succeeding activities and delivery requirements in order for things to run smoothly on the construction site. It will be beneficial for a confident BIM leader to be present from The Turner Construction Company to update the 4D model as work is completed to provide baseline updates to the owner and to the subcontractor. This will also allow an efficiency and productivity analysis to be conducted. Training the subcontractor to utilize the 4D BIM model for demolition efforts will facilitate the efficiency and maintenance of the schedule.

2.10 Analysis Summary

- Through re-sequencing the demolition of the project schedule for the cellar level to the tenth floor, a more efficient operation was created which allowed for an overall schedule reduction from the original 56 duratiion to the new 28 day duration.
- Penalty costs were reduced from $1,603,780.00 to $756,500.00 which resulted in a savings of $847,280.00 to the project's overall cost.
- General conditions costs were reduced from $286,675.94 to $135,224.50 which resulted in a savings of $151,451.44 to the project's overall cost.
- The new sequence will utilize an extra Brokk robot, and a second crew which will include 2 skilled laborers and 14 non-skilled laborers which will result in an equipment and laborer cost of $144,646.00 as compared to the original $146,968.00 cost of equipment & labor related to the original demolition sequence. This is a decreased cost of $2,322.00 for the additional laborers and equipment.
- A cost of the BIM requirements was not considered due to the fact that completing a 3D model took no more than a day and minor adjustments were made to each model to consider the alternate demo sequences and methods.
- Overall it is feasible based on the schedule reduction of 28 days and the cost savings of $1,001,053.44 to penalties, general conditions, labor and equipment costs. Based on these savings it is my recommendation to re-sequence the project schedule and implement the alternate staggered demolition technique.

Analysis 3: Implementation of MEP Prefabrication

3.1 Problem Identification

The site logistics of this project served as a major challenge for the project team due to the restrictive site and its limited space and potential for material laydown. The extensive construction and installation of the MEP systems caused numerous delays to the project. Duct banks, electrical bus ways, conduit, telecommunications, and various other components were constructed using an on-site, stick-built method which failed to achieve schedule and cost savings potential. The project team has gone over schedule approximately two months resulting in accrued penalty costs. In order to stay on schedule and prevent penalties, The Turner Construction Company has decided to bring in more tradesmen and employing extra crews during the week and even on weekends. These overtime crews include mechanical piping installers and plumbing trim-out crews which resulted in an additional cost of approximately $40,000. These delays and added costs could have been avoided if the MEP systems were fabricated at an off-site facility and then transported to the construction site rather than applying the typical stick-built on-site method. These components can be manufactured offsite with the proper lengths, sizes and with all the required bends. After each designated component is prefabricated offsite, they can be delivered, placed on the proper floor, and then installed together in order to simplify the installation process. This application will result in several benefits which include cost savings from reduced labor and prevention of overtime, greater productivity, safety, quality and efficiency of materials which will result in greater material savings.

3.2 Research Goal

The main goal of this analysis is to perform an in-depth research by exploring options for a lean and green construction approach to material construction, delivery and material storage for the project in order to prevent the requirement for overtime. Another goal for this analysis topic is to explore the feasibility of implementing prefabricated MEP systems for the construction project. This analysis will consider the impacts on constructability of these systems.

3.3 Research Methods

- Acquire AutoCAD models from The Turner Construction Company
- Review model to consider accuracy and thoroughness of the building systems modeled
- Construct any missing systems with the utmost accuracy
- Research how BIM can be used to facilitate prefabrication techniques
- Contact Mr. Matt Corrigan with Pierce Associates Inc.
- Contact Mr. Rhodes with Southland Industries
- Contact mechanical contractor responsible for the installation of key MEP systems
- Determine which components of the MEP system can be easily fabricated to fit together as an assembly within the
- Assess the time required to fabricate and then install assemblies
- Locating and choosing the best prefabrication facility in terms of value not limited to distance and cost
- Research lean practices such as Just-In-Time delivery and production in order to eliminate waste on-site and improve quality and safety

3.4 Resources & Tools to be Used

- The Turner Construction Company project team on the Concordia Hotel
- Contact Greg West with Turner and WSP Flack + Kurtz
- The Pennsylvania State University AE faculty
- Owner representatives and construction team
- Prefabrication facilities
- Key industry members
- Contact Mr. Matt Corrigan with Pierce Associates Inc.
- Contact Mr. Rhodes with Southland Industries
- The Pennsylvania State University AE Faculty
- Educational background from previous AE courses (such as AE 372, AE 475, AE 476, and AE 570)
- 3D Software (Revit, Navisworks)
- Applicable literature (books, websites, papers, etc.)
- Other key industry members

3.5 Potential Solutions and Expected Outcomes

Upon completion of this analysis, it is likely that a more efficient method of construction will be discovered which will facilitate the project meeting the project completion date with less penalty and loss of revenue to the owner. Since the construction site is highly restrictive, this analysis will propose Just In Time (JIT) delivery methods. Upon completion of the analysis it is expected that prefabricated MEP systems can reduce site congestion, eliminate waste, improve efficiency and improve site logistics. This analysis will be integrated with the research performed related to Analysis 1 BIM. It is expected that there will be substantial efficiencies associated with applying prefabrication techniques to this project. While there may be additional costs these will likely be overcome by potential cost savings through schedule reductions a result of the prefabrication of these key systems.

3.6 MEP System Prefabrication

In an attempt to attain a more lean and green approach to the renovation of the Concordia hotel the implementation of the prefabricated mechanical duct branches will be considered. This approach will utilize just-in-time production and delivery in order to reduce site congestion and create greater efficiencies. Prefabrication techniques have been applied to many projects and after extensive research it has been found to improve safety, quality and to reduce waste compared to the typical on-site, stick-built method.

- Reduced Schedule & Cost Savings
- Increased Safety
- Enhanced Productivity
- Overall Improvements to Facility
- Elimination of Construction Waste

The process of applying prefabrication methods to the building's highly repetitive MEP systems, typically found in a hotel, has great potential to allow the construction project to be delivered in a more efficient manner. It will result in schedule, cost savings and overall improved safety to the project. The potential for these savings is shown in the visual process map below in figure 63. "HVAC Ductwork laborers can install 20-25 LF/Man Day, an electric pipefitter can install 8-12 LF/ManDay and a Plumber Pipefitter can install 18-23 LF/Man Day these numbers include the entire installation. For example, for ductworkthat number includes installing duct hangers, racks, installing fittings etc.. the whole deal. Not just slamming in the ductwork once those pieces are already in place. This productivity can be affected by weather, union vs. non-union, new work vs. reno and of course the complexity and amount of fittings.” (Andrew Rhodes Southland Industries).

3.6 A: Prefabrication Acceptance

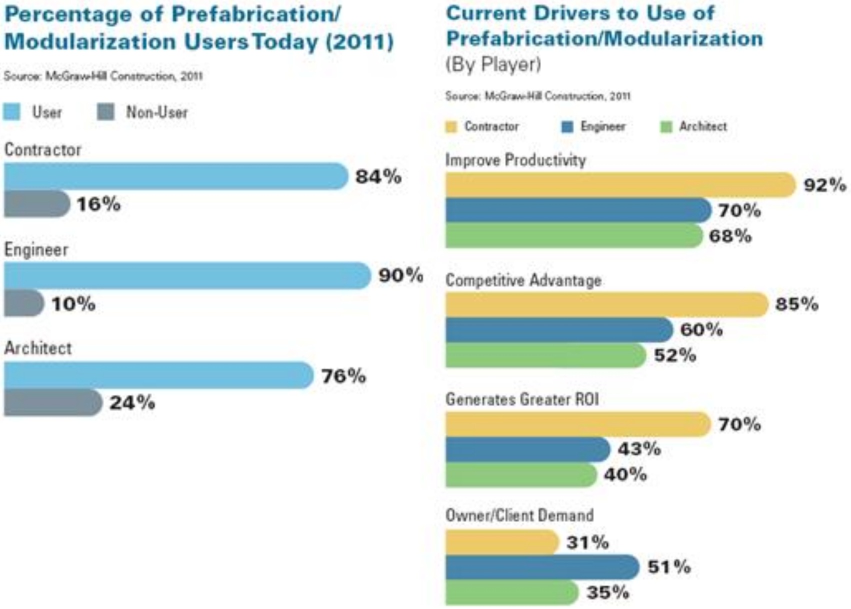
Prefabrication and modular building design is not a new method and was introduced to the construction industry many years ago. Prefabrication was seen as early as 1851 with the structure that contained the Great Exhibition in Britain. The structure was erected in a very short period of time utilizing light and inexpensive materials like iron, wood and glass. Once the exhibition had ended the structure was disassembled and moved to an alternative location. Prefabrication began with small housing when designers realized the advantages with prefabricating a house and transporting it to the site of construction. Sears and Roebuck Company and Aladdin marketed prefabricated houses that were delivered to customers as a mail-order home. Designers found that applying this method to residential house construction could save time, money and improve quality. During WW2 a greater drive for prefabricated facilities was seen due to the extensive requirement for military personnel. Prefabrication and modularization techniques were introduced to larger scaled buildings once these advantages were reinforced with clear examples. The technique has been further refined and progressed over the years resulting in a 500-room Hilton Placio Del Rio to be constructed in-time for the Texas World’s Exposition of 1968 to capitalize on revenues due to guests for the fair. The core of the structure was constructed while each of the wings were erected as modular units. It took only 46 days to complete the hotel’s construction. With a greater push for lean, green construction, improvements in BIM application, and improved manufacturing methods this technique is becoming more and more common on many projects. Recent studies have found that this technique has been widely accepted and applied by many industry members for quite some time now. This is clear due to the fact that 63% of the individuals utilizing prefabrication and modularization for the past five years or more. Forecasts have been made based on current industry trends and most believe that prefabrication and modularization techniques will be utilized by approximately 98% of all players.

Figure 54 Prefabricated Exhibition Center, Great Britain 1851

Figure 55 Hilton Placio Del Rio Modular Hotel 1968

3.6 B: Prefabrication Key Players

While prefabrication and modularization is widely used by many of key industry members it has not been accepted by all. Fortunately owners, contractors, engineers, and architects are realizing that in order to remain competitive in this economy they will have to adopt these new techniques in order to capitalize on these savings. Figure 56 shows the current drivers for the adoption of prefabrication and modularization. Projects are being delivered cheaper, in less time and with less waste resulting in a highly competitive market that challenges all industry members to continually adopt these new methods. In order for a project to be more likely to succeed in the application of prefabrication and modularization it is critical for the architect to design systems and architectural components that are easier to prefabricate. While most architects are interested in utilizing prefabricated and modular building elements they base the lack of application on owner’s resistance. This is likely attributed to owner’s belief in the rumor that prefabricated structures are cheap or of poor quality. The key players involved with prefabrication are very high with engineers and are consistently increasing with architects and contractors as owners become more aware of the advantages associated with the application of prefabrication and modularization to their facility as shown in figure 56. As prefabrication becomes more common these advantages will become more apparent.


Percentage of Prefabrication/ Modularization Users Today (2011)

Source: McGraw-Hill Construction, 2011

Current Drivers to Use of Prefabrication/Modularization (By Player)

Source: McGraw-Hill Construction, 2011

Figure 56 Key Users & Current Drivers of Prefabrication

3.6 C: Benefits of Applying Prefabrication

While prefabrication can present multiple benefits to an owner and a project team there are several key benefits that support the application of prefabrication and modularization to commercial structures. The most notable benefit is improved productivity which includes impacts on the project cost, schedule, quality and safety. Productivity is increased not only due to concurrent construction but also because employees have easy access to tools and materials saving them time consuming trips for locating tools, equipment and materials. Prefabrication contains the potential to accelerate the schedule compared to the typical stick-built method which is clearly described in the visual process map. Key building systems can be constructed in a warehouse concurrently as construction is being completed on-site, a visual process map shown in figure 57 helps convey this idea. These systems can be transported to the site and placed directly into the proper location. 72% of the contractors surveyed believe that the use of prefabrication & modularization decreases the project by a week or more. 79% of mechanical contractors agree that it has the ability to reduce the schedule as shown in figure 58.

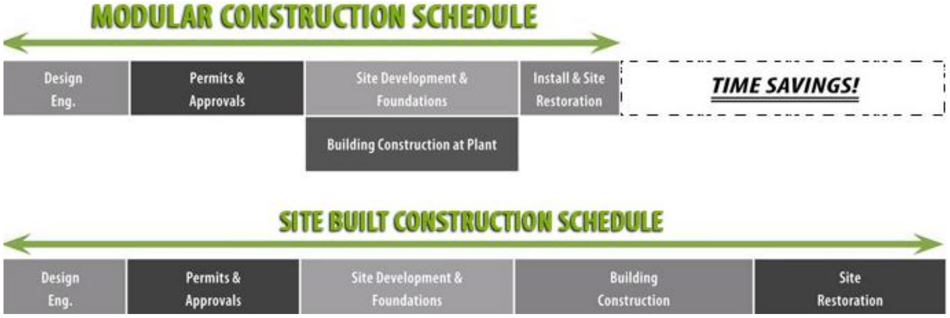


Figure 57 Visual Process Map of Prefabrication vs. Typical Stick-Built Method

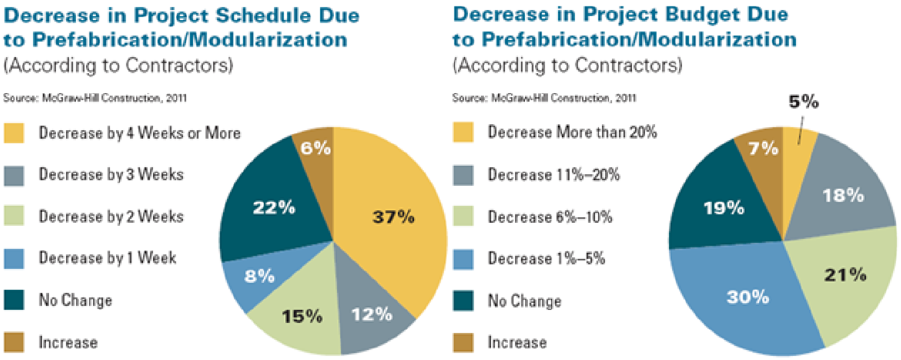


Figure 58 Decreases in Project Schedule & Budget Potential (According to Contractors)

Prefabrication has the capability of reducing costs, improving site safety and reducing waste. 74% of contractors believe that prefabrication can help decrease project budgets and 85% of mechanical contractors agree. Quality is improved, waste is reduced and site safety is increased as a result of the implementation of BIM to a project. Constructing these critical systems in a warehouse helps create a product that is of better quality because they are constructed in a controlled environment by employees that have a greater comfort level then they would if they were stick building the system out in the field. Waste is reduced for this same reason; since employees have easy access to materials that are the precise shape and length requirements. Working in a controlled environment also protects employees and others from potential dangers associated with construction projects. With these many benefits prefabrication is gaining greater popularity and application to multiple sectors of the industry.

3.6 D: Sectors Where Prefab is Increasing in Application

Building system prefabrication is increasing in applicability to other building sectors. While it has been most common to apply this method to healthcare facilities, due to the repetitious MEP and casework, it is becoming more popular in other sectors. Hotels and commercial warehouses are less likely to be prefabricated which is likely due to owners believing the rumor of cheapness and poor quality are associated with prefabricated products. This sector is likely to see the greatest increase in prefabrication due to commercial warehouses and hotels having typical and repetitive design. Hotels often are highly repetitious in their systems and finishes and it is for this reason that it is tied in second on the list for having the greatest opportunity for prefabrication. While this sector has remained untouched by the long arm of prefabrication it has the greatest opportunity for growth for the next decade. Some of these other areas like high-rise and low-rise office buildings are likely next to experience the greatest increase in prefabrication techniques. When focusing on the parties involved and their future opportunities to apply prefabrication, hotels appear much higher on the list at 13%. The building sectors which are more than likely to have prefabrication applied to are outlined below in figure 59 & 60. The main influence will not only be the repetition of the architectural, structural and building systems but it will also be influenced by the jobsite conditions.

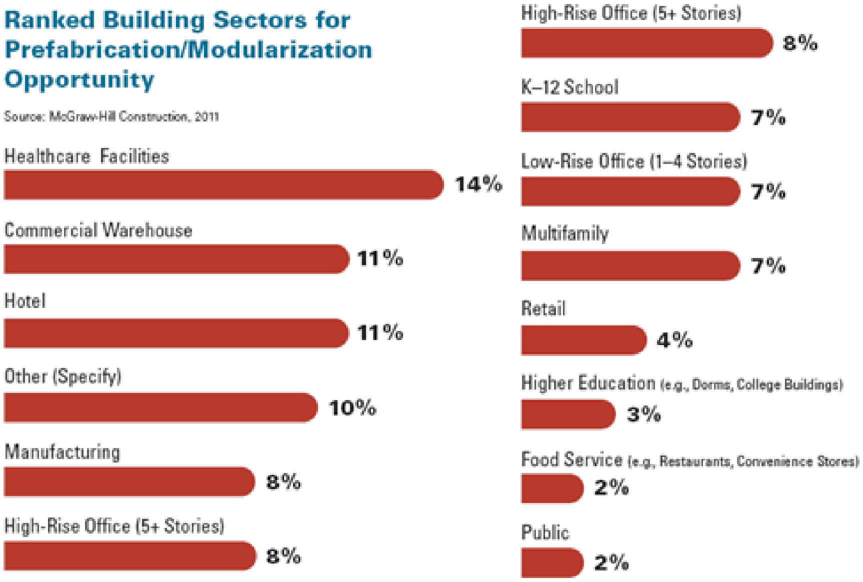


Figure 59 The Building Sectors Most Likely to Have Prefabrication Methods Applied

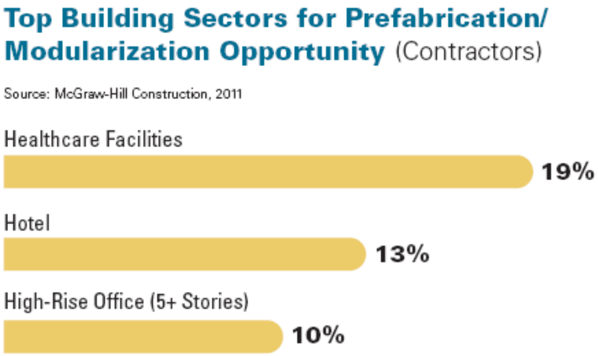


Figure 60 Top Sectors for Prefab Application

3.6 E: Influence of Job Site Conditions

The type of project and its design is a critical influence on whether or not prefabrication methods can and will be applied, this influence is also joined by critical issues associated with site logistics. In order for a project to successfully apply prefabrication initiatives to the construction it is important to carefully analyze some of the conditions surrounding a jobsite. Some of the most influential conditions include site accessibility, number of stories, type of building exterior, and lastly the layout of the building's interior. Job site accessibility is critical due to the fact that the prefabricated systems require numerous trips in order to be successfully to the construction site. This requirement makes the location and accessibility of the site critical for trucks to be capable of accessing the construction site for deliveries. The number of stories is the next greatest influence due to the lifting requirements associated with high-rise structures. High-rise buildings will require greater coordination with deliveries and crane lifting capacities. Depending on the size and weight of the modules and prefabbed equipment this lifting activity can become a logistical nightmare. The structures exterior can be prefabbed and depending on the type of exterior some prefabrication may be easier than others. The layout of the interior can also play a critical role due to whether or not the layout is highly repetitious or not. The jobsite conditions which influenced are shown in figure 61. Obviously a layout that is highly repetitive is a lot easier to create modular units for than a less repetitive layout.

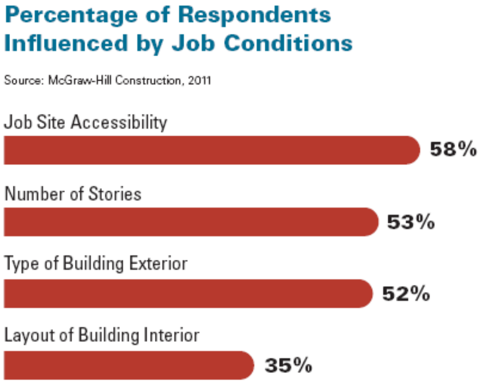


Figure 61 Influences of Job Site Conditions on Prefabrication

3.6 F: Most Commonly Prefabricated Systems

The most often prefabricated systems include the prefabrication of the building superstructure, exterior walls and MEP building systems. Ranked at 27% the prefabrication of building superstructure is the highest ranked prefabbed building element. The other two most likely prefabbed building elements are exterior walls ranked 20% and MEP building systems at 21%. Prefabrication of the building superstructure consists of fabricating all of the building above the foundation with prefabricated or modular units. Prefabrication of the MEP building systems can consist of the construction of complicated MEP systems including but not limited to conduit, duct banks, fittings, dampers, elbows and other key components. Prefabbing the exterior wall systems includes the construction of the exterior finishes and façade in a controlled environment which can then be transported to the site. The areas where prefabrication is commonly applied is shown in Figure 62. These key systems all have great opportunities for prefabrication and contain the likelihood of saving time and cost to the overall project.

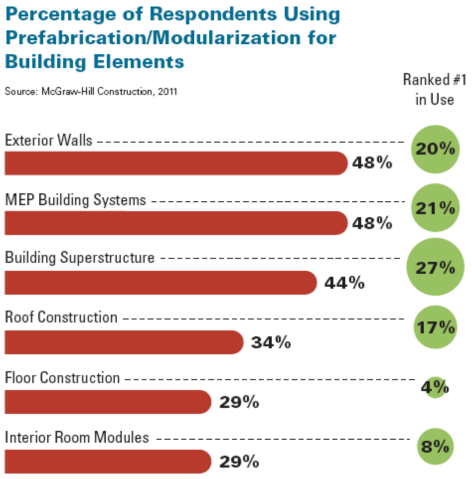


Figure 62 Building Systems favorable of Prefab

3.6 G: Conclusion of Prefabrication Research

Prefabrication is becoming more and more widely accepted and this acceptance is likely attributed to the positive results and benefits associated with its successful implementation. These results are becoming more accurately considered and recorded as prefabrication and modularization is more widely accepted and applied. Prefabrication is a great opportunity for cost, schedule savings and many other benefits. The successful application of prefabrication methods to a construction project can be dependent on a number of issues and while it may be very successful in completion of one project type it may not be applicable to another. The success of prefabrication is dependent on jobsite logistics associated with the complexity of the project and the site which it resides. Many building systems which compose a structure have the opportunity to be prefabricated; some systems are more capable and likely to be prefabricated than others. In order to successfully apply this method, whether it is a new construction project or a renovation project, it is critical to understand all of these influences and the impact they might have. After conducting thorough research of prefabrication techniques and its applicability further pursuit of this analysis will be conducted.

3.7 The Concordia Renovation Project & Prefabrication

The Concordia Renovation Project required the complete demolition of the existing MEP systems. The project presented many logistical issues associated with the construction of the MEP systems which included but were not limited to a restrictive site with limited material laydown, complicated delivery logistics and many other issues. All of these issues combined to result in excessive schedule delays, complications and increased costs. The project's construction of the extensive MEP systems would have benefitted from prefabrication of the mechanical ductwork for both the main branches and the duct risers. In order to gain a greater understanding of this opportunity a few of the project's issues were considered and analyzed to assess the potential success of the application of this method to this project.

3.7 A: Key Project Considerations

A. Job-site accessibility

When considering job-site accessibility one will quickly notice that there is little to no laydown area for equipment and materials. The renovation project is located in the congested metropolitan area of Washington D.C. right near Dupont circle. The site is surrounded by narrow one-way streets and alleyways. It will be crucial to conduct Just-In-Time (JIT) delivery from the prefab shop and to understand any transportation restrictions and requirements that might complicate deliveries to the site. In order to improve productivity and on-site production there must be a considerable lead time for the ductwork to be fabricated assembled into feasible lengths and then delivered to the construction site. Two fabrication shops were considered based on their experience with the prefabrication of the mechanical ductwork. The two shops which were considered were the Southland Industries Prefabrication shop and Pierce Associates, Inc. These shops will be further analyzed based on quality added to the project.

Southland Industries

Southland is a nationwide mechanical engineering, construction and service firm with offices in California and the midatlantic region. Southland offers a 30,000 SF prefabrication shop which is capable of construction of all of the MEP systems in one shop. The shop is located in Lorton Virginia at 8307 Terminal Road; it is approximately 18.9 -19.5 miles from the construction site depending on which route is taken as shown in figure 63. They have the capability of prefabricating the specified lengths and sizes and delivering them to the construction site on their vehicles. Southland Industries is a high quality company which is very familiar with the logistical issues associated with applying prefabrication to a construction project. Employing Southland Industries to be responsible for the prefabrication of the mechanical ductwork and duct risers will be beneficial to the project based on their experience and potential to add quality to the project.

Pierce Associates, Inc.

Pierce Associates is a specialty mechanical contractor which provides mechanical construction services for the greater metropolitan Washington D.C. Pierce Associates, Inc. The company offers a 35,000 SF prefabrication shop responsible for the construction of the mechanical ductwork. The shop is located at Wheeler Avenue in Alexandria, Virginia 22304-9050. The shop is approximately 13.7-14.2 miles from the construction site depending on which route is taken as shown in figure 64. Pierce Associates, Inc. has the capability of prefabricating the specified lengths and sizes and delivering them to the construction site on their vehicles. Pierce Associates, Inc. is also a company of high caliper and also very familiar with the logistical issues associated with applying prefabrication techniques to a construction project. Employing Pierce Associates, Inc. to be responsible for the prefabrication of the mechanical ductwork and duct risers will be beneficial to the project team and the owner of the project.

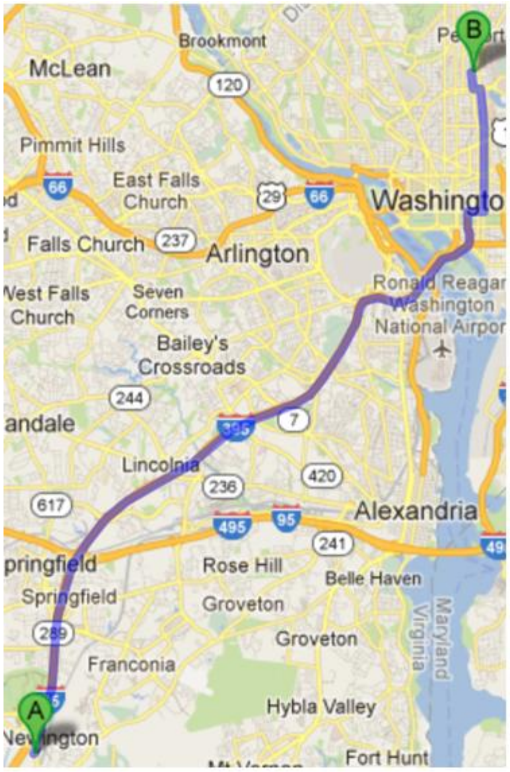


Figure 63 Southland Industries Route to Site

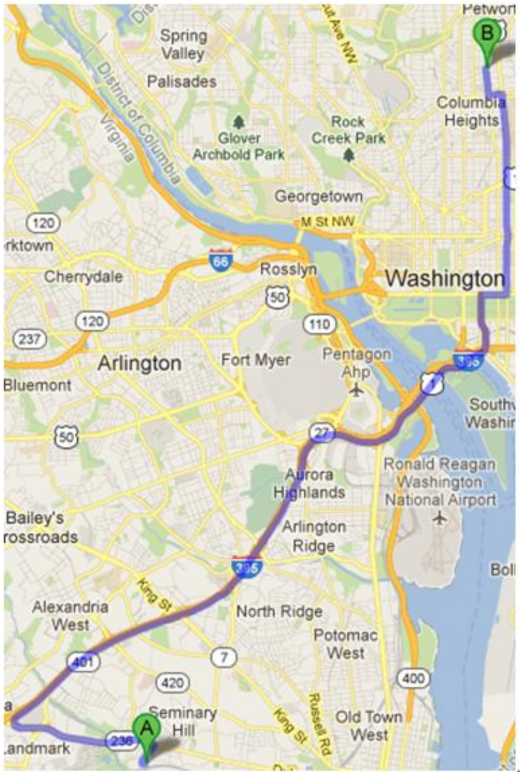


Figure 64 Pierce Associates, Inc. Route to Site

Pierce Associates, Inc. has been chosen to be responsible for prefabricating the mechanical ductwork for this project based on their competency and resources. The company has several shops one for sheet metal fabrication, one for small pluming piping and the last shop is responsible for prefabricating large plumbing piping. The main mechanical ductwork shop is 35,000 SF and capable of prefabricating the mechanical ductwork to the required specifications, their shop is shown in image 65. The company is capable of taking the 2D drawings from the design engineers, they verify their accuracy, feasibility, make any design changes based on their mechanical background and then they proceed to conduct 3D coordination with the design engineers. They then consider what areas of the project can be prefabricated based on ease and facilitation of construction. Once they understand which systems will be prefabricated they create what are called “spooling documents” which are then used to prefabricate the specific duct based on the sizing and material requirements. Pierce Associates’ prefab shop has regular deliveries of raw materials which are then shaped in their large presses, assembled and then prepared delivery to the construction site. Figure 66 shows this organized process of the prefabrication of the mechanical ductwork.

Figure 65 Pierce Associates, Inc. Mechanical Ductwork Prefab Shop

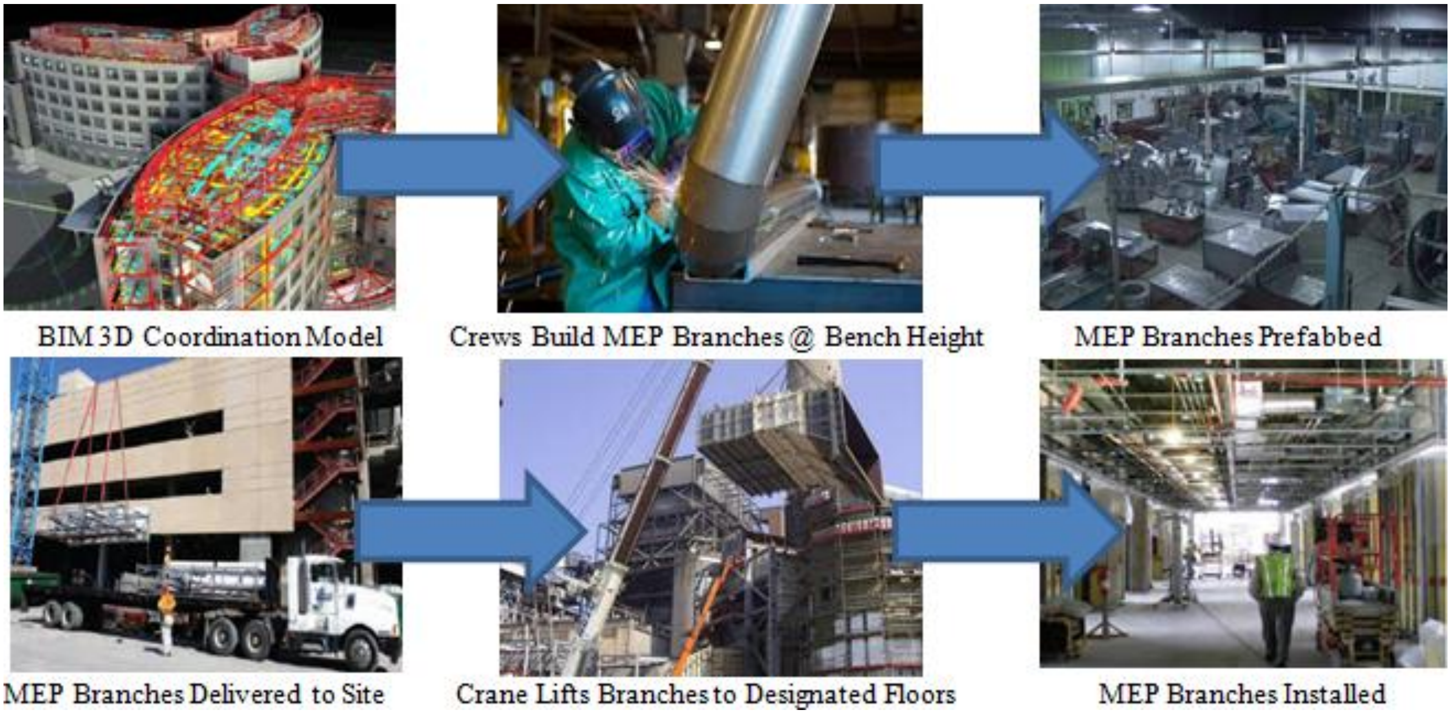


Figure 66 Visual Process Map of Prefabrication

B. Number of stories

Once the branch & riser lengths are transported to the construction site they will require a crane to lift them to the floor where they will be installed. The number of stories has a critical influence concerning the feasibility of applying this method based on additional crane related expenses. Fortunately, this will not be an issue due to the fact that The Turner Contracting Company employed a mobile crane on-site for the duration of the renovation project capable of lifting these loads to the required heights.

C. Type of building exterior

The type and complexity of the building exterior will play a critical role in the success or failure of applying prefabrication as well. Since the exterior is typically constructed prior to the interior fit-out it will be crucial to create a plan to leave openings on the façade in order to prepare for deliveries and hoisting of materials to each floor. These openings can be temporarily sealed with wooden paneling and plastic to protect employees and materials from the elements.

D. Layout of building interior

Since the main duct branches are installed and then the smaller branches are installed soon after it is not a critical issue to consider the layout of the interior since we are focusing on the prefab of the ducts. Once the branches are installed, the interior finishes are typically built around these systems. The interior layout has been extensively coordinated with the MEP systems through the application of BIM so no further consideration will be placed on this influence. These concerns have brought light to some key complications to this project, however, based on the potential for this method to create schedule and cost savings a much more in-depth analysis of this potential opportunity will be conducted. The areas which will be considered for the prefabrication efforts are highlighted in blue in the figures below starting with figure 73 and ending with figure 80. The focus will be primarily placed on the main duct branches and potentially the duct risers.

3.8 Area of Implementation

3.8 A: Area of Implementation-Mechanical

In determining the areas of the structure well suited for the application of prefabrication it was crucial to first gain a greater understanding of the logistical issues associated with applying this construction technique to this particular project. Some of the most critical issues, which were discussed previously in section 3.6 F, are the accessibility of the job site which can also include the project's geographical location. The number of stories, the type of building exterior and the layout of the building interior are all critical issues which can impact whether or not the project is successful in applying prefabrication to critical building systems.

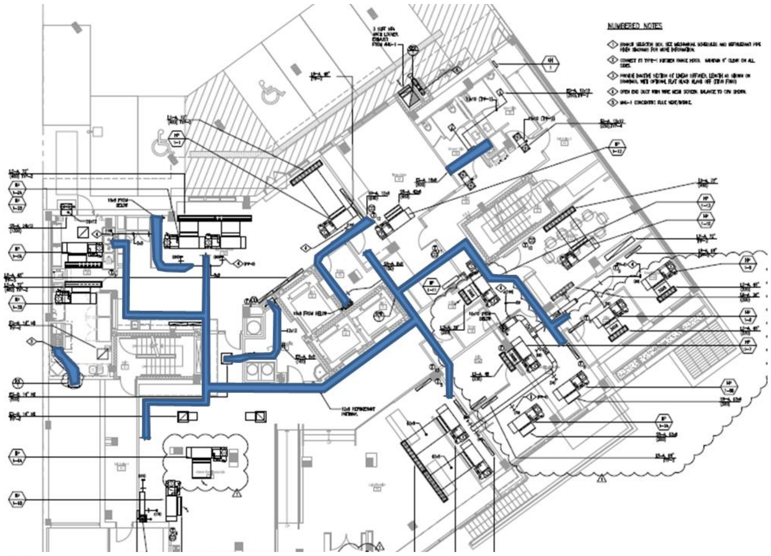


Figure 67 Ground Level

Figure 67 shows the ductwork that will be considered for prefabrication located on the cellar level. Duct sizes range anywhere from 12x12 up to 24x12. These branches will be fabricated to the greatest length possible while still facilitating construction and maintaining practicality.

Figure 68 shows the ductwork that will be considered for prefabrication located on the ground level. Duct sizes range anywhere from 10x10 up to 42x6. Once again great emphasis will be placed on having these branches fabricated to the greatest length possible without negatively affecting constructability.

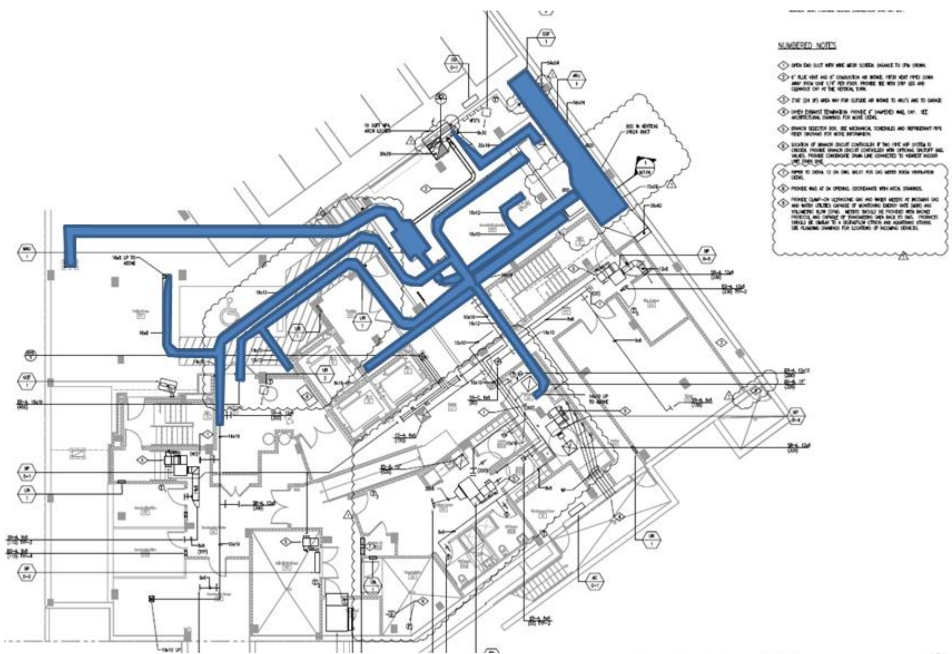


Figure 68 Cellar Level

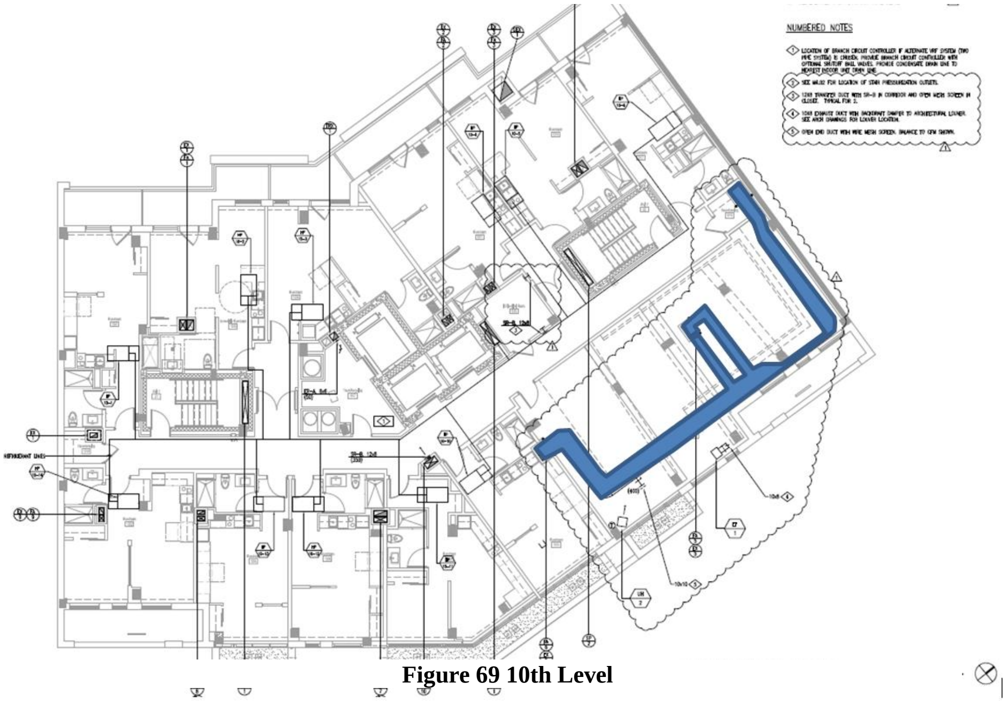


Figure 69 10th Level

Figure 69 shows the ductwork that will be considered for prefabrication located on the 10th level. The duct sizes range anywhere from 12x18 up to 12x26.

Figure 70 shows the ductwork that will be considered for prefabrication located on the Roof Level. The duct sizes range anywhere from 14x8 up to 24x12

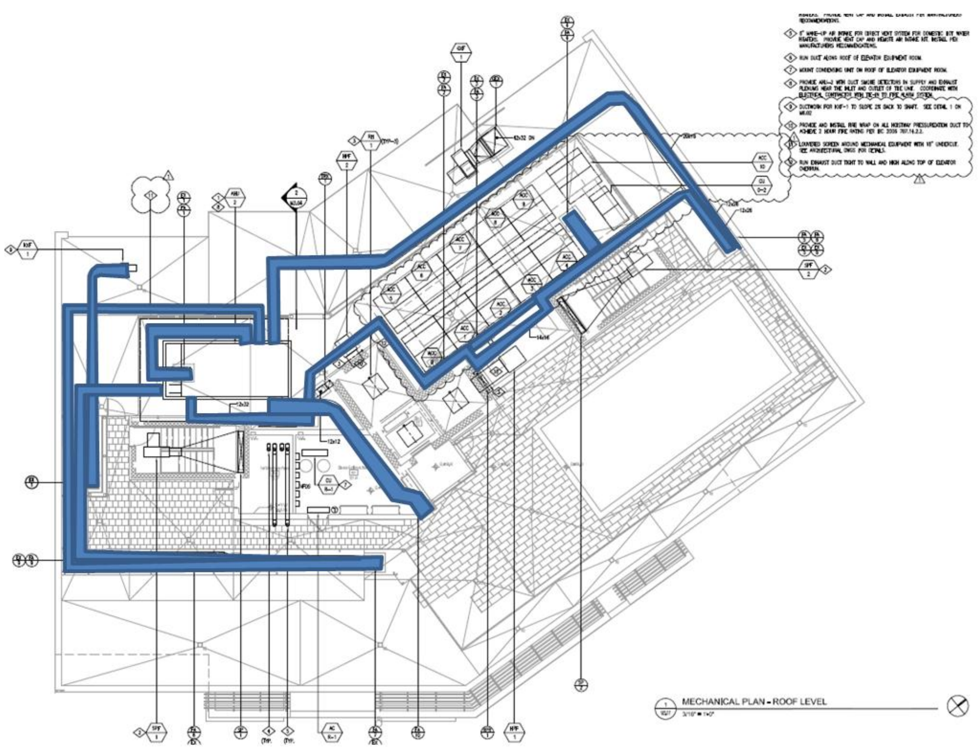


Figure 70 Roof Level

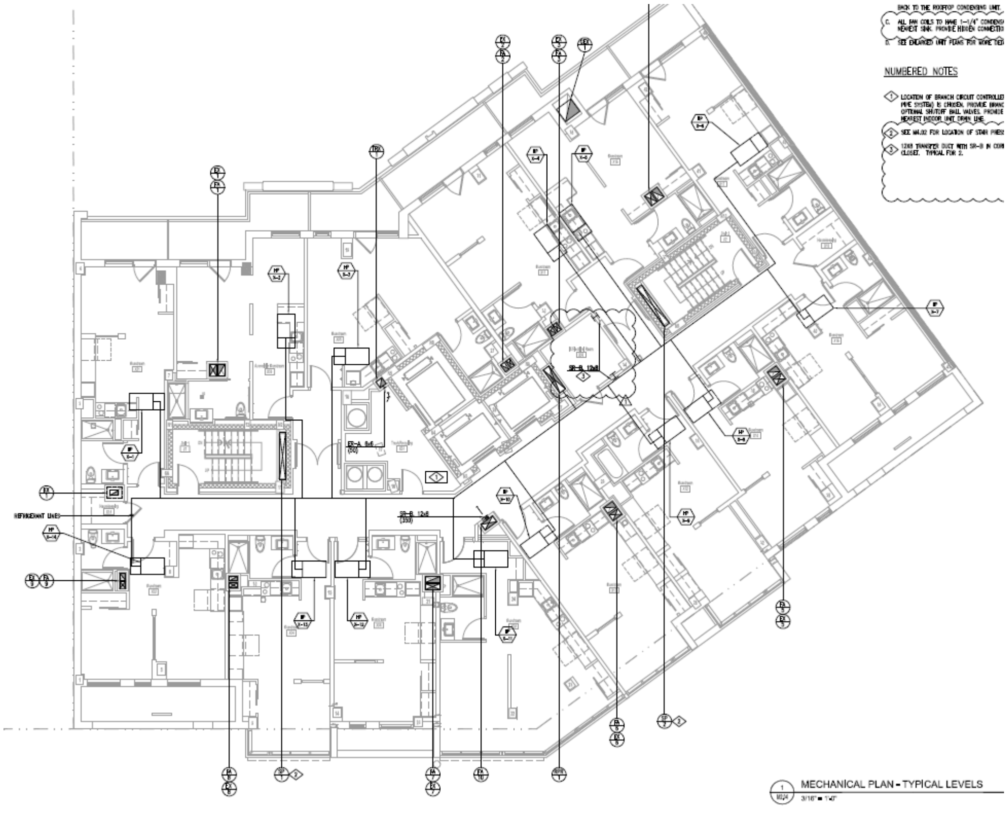


Figure 71 Mechanical Ducts for Typical Floors

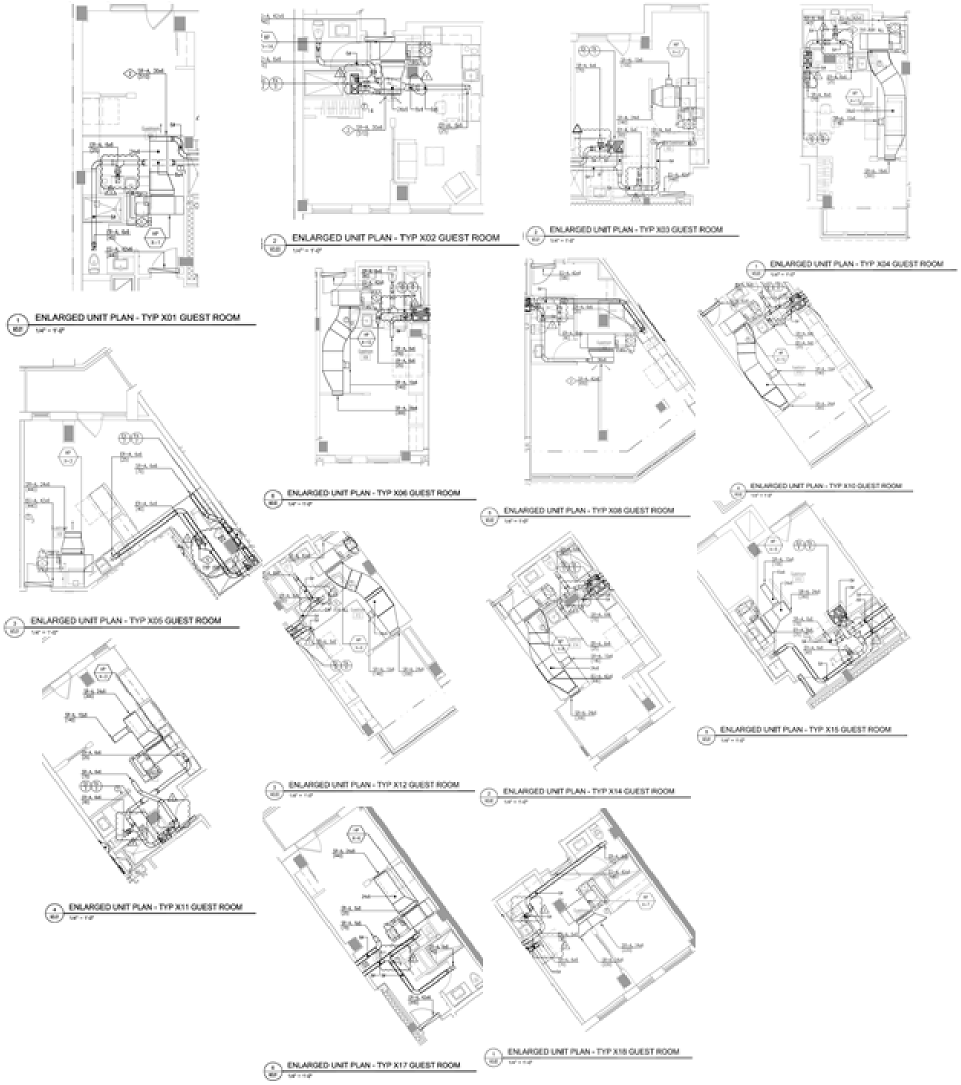


Figure 72 Mechanical Ducts for Rooms on Floors 2-9

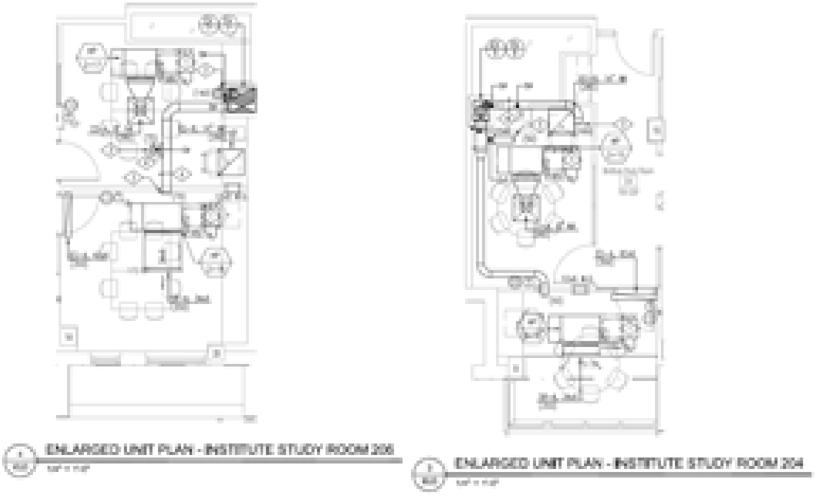


Figure 73 Mechanical Ducts for Rooms on Floors 2-9

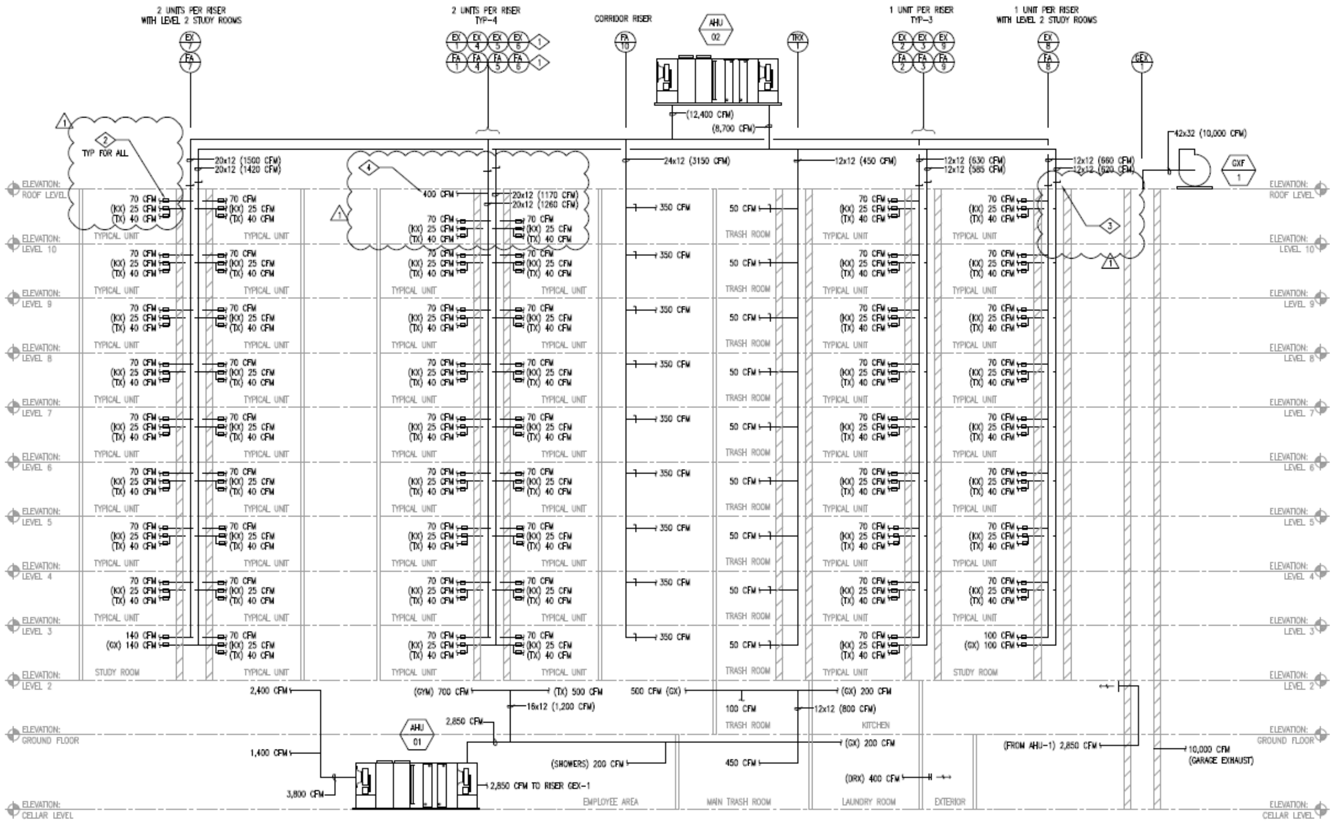


Figure 74 Riser Diagrams

There is a great potential to not only prefabricate the main duct branches but also to potentially consider prefabricating, 12 ft. lengths or more, the mechanical duct risers. There will be several constructability issues associated with applying prefabrication initiatives to the duct branches as well as the duct risers, however, these can be easily overcome with careful planning and consideration of the issues. Figure 74 shows the Duct Risers all of which will potentially be considered for prefabrication.

3.8 B: Area of Implementation-Electrical

Since many of the interior spaces will utilize Metal Clad (MC) cable; the primary focus of prefabrication techniques to the electrical system will be focused on the conduit located in the cellar level as well as the risers running throughout the structure. While there are other areas where prefabrication can be highly beneficial the primary focus will be placed on these areas where the size of conduit is >1".

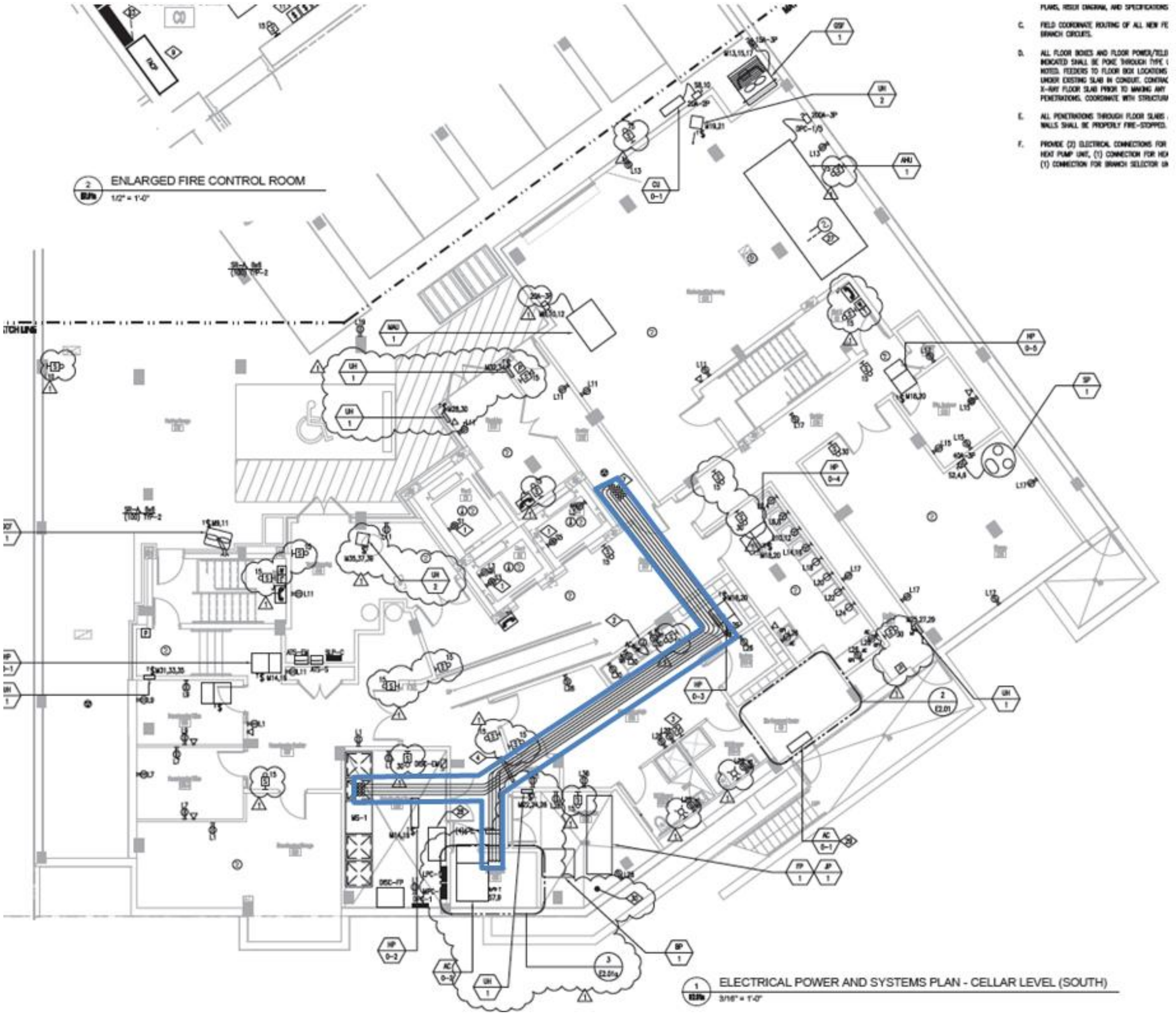


Figure 75 Electrical Systems-Cellar Level

3.8 C: Area of Implementation-Plumbing

In wall plumbing will be prefabricated along with the risers running up and throughout the structure. Prefabrication techniques will be applied to the Sanitary, domestic water, storm water and natural gas piping throughout the structure. Since there are a great deal of repetitious kitchenettes and bathrooms the entire wet walls will be assembled in the shop and transported to the site for installation.

3.9 Material Staging

As stated before the jobsite is very congested being that it is located in the Metropolitan DC area which will require JIT delivery. Utilizing a JIT approach implies that materials will be manufactured, delivered to the site upon completion, brought to the location of installation, and then immediately installed by the construction crews. This method of construction eliminates the need for off-site material storage or on-site space consumption on the floors through material laydown and staging areas. The JIT method of construction and delivery is particularly beneficial to projects where site logistics is challenging for the project staff as is present with The Concordia renovation project. In order to prevent or eliminate challenges of site access related to material laydown and storage related to the mechanical ductwork, a JIT technique will be applied to the project.

3.9 A: Material Staging-Mechanical Ductwork

In order to efficiently utilize JIT manufacturing and delivery to the Concordia Renovation project it is important to have the construction of the ductwork lengths to lead the installation of these lengths on-site. The following lengths of ductwork will be prefabricated and delivered to the construction site for installation.

- 21-10 ft lengths 8x4
- 375-12 ft lengths 6x6
- 14-5ft lengths 10x6
- 4-12 ft lengths 10x8
- 1-12 ft lengths 12x8
- 2-12ft length 12x10
- 18-12ft lengths 12x12
- 6-12ft lengths 12x26
- 3-12 ft lengths 12x32
- 5-8ft lengths 14x8
- 2-12ft lengths 14x10
- 4-12ft lengths 14x16
- 2-12 ft lengths 14x20
- 4-12ft lengths 16x8
- 5-12 ft lengths 16x12
- 5-12 ft lengths 16x16
- 28-12 ft lengths16x20
- 2-12ft length 18x10
- 5-12ft lengths 18x12
- 2-12ft lengths 20x16
- 21-12 lengths 20x12
- 3-12ft lengths 20x20
- 14-5 ft lengths 24x6
- 18-12ft lengths 24x12
- 56-12 ft lengths 34x6
- 1-8ft lengths 36x42
- 1-5ft length 72x24
- 1-10 ft length 54x2

3.9 B: Material Staging-Plumbing

Prefabrication techniques will be applied to the Sanitary, domestic water, storm water and natural gas piping throughout the structure.

- Sanitary Risers
    - 70-10 ft lengths 2”
    - 178-10 ft lengths 3”
    - 147-10 ft lengths 4”
    - 60-10 ft length 5”
    - 15-10ft lengths 6”
    - 40-5 ft lengths 8”
- Domestic Water Risers
    - 108-10 ft lengths ½”
    - 77-10 ft lengths ¾”
    - 59-10 ft lengths 1”
    - 57-10 ft lengths 1-1/4”
    - 51-10 ft lengths 1-1/2”
    - 47-10 ft lengths 2”
    - 33-10ft lengths 2-1/2”
    - 14-5 ft lengths 9”
- Storm Water Risers
    - 40-10 ft lengths 3/4”
    - 60-10 ft lengths 1-1/4”
    - 29-10 ft lengths 1-1/2”
    - 30 ft lengths 1”
    - 73-10 ft lengths 4”
    - 64-10 ft lengths 5”
    - 54-10 ft lengths 6”
    - 56-5 ft lengths 8”
- Natural Gas Risers
    - 10-10 ft lengths 3/4”
    - 11-10 ft lengths 1-1/4”
    - 20-10 ft lengths 1-1/2”
    - 20-10 ft lengths 1”

A standard flatbed trailer ranges from 45’-53’ in length, 8’-8.5’ in width and can accommodate a maximum load height of 8.5’. Figure 76 shows the length of typical transport trailers. Pierce Associates, Inc. has its own transport vehicles and trailers; they have 45’, 48’, and 53’ trailers that are available. The size of trailer chosen will be dependent on the most efficient transport of the materials to the jobsite.

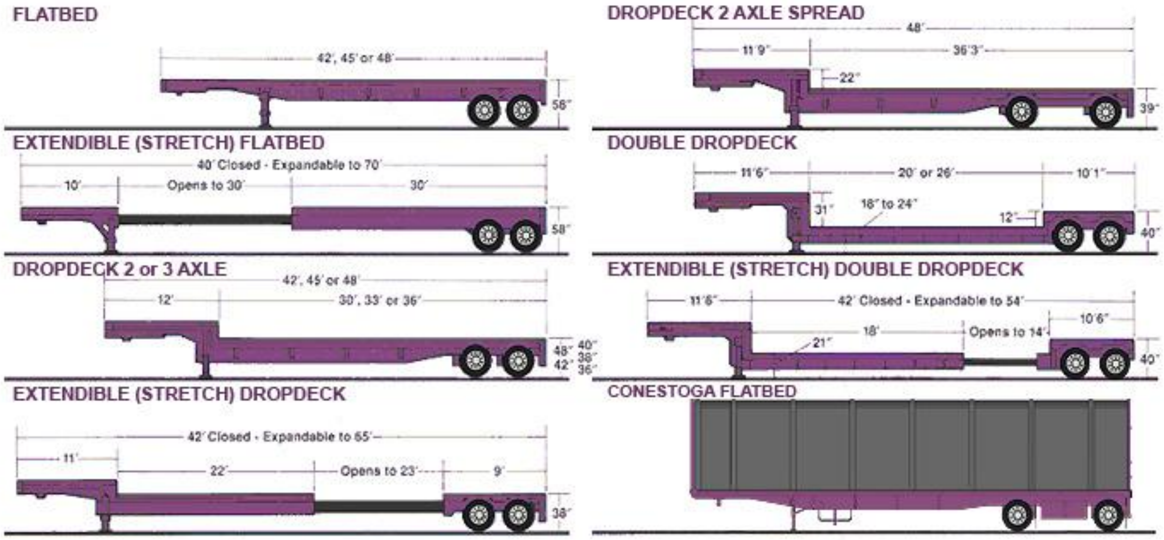


Figure 76 Typical Specifications of Transport Trailers

3.10 Cost and Schedule Analysis

The primary driving force behind utilizing prefabrication methods of construction is to achieve a higher quality of construction, reduced overall project schedule and project cost, and lastly a safer work environment. Most if not all of the cost savings will be a direct result of schedule reductions and potentially reduced compensation requirements for laborers working off-site compared to the on-site compensation requirements. The reduction in schedule will be analyzed through a detailed consideration of the installation of the MEP systems that run throughout the structure. Through the use of prefabrication with laborers working at bench height in a temperature controlled environment laborers are likely to increase the average production rates and reduce on-site installation rates. Due to the repetitious nature of the floors it will be assumed that the prefabrication installation rates can reduce the labor durations for this area of work by a conservative one quarter. Table 28 shows the breakdowns of the schedule reductions that are a result of the implementation of prefabrication.

Table 28: MEP Prefabrication Summary of Duration Reduction

Location	Installation Activity	Original Installation Duration (Days)	Prefabrication Installation Duration (Days)	Duration Reduction (Days)
Cellar Level	Mechanical	12	9	3
	Electrical	10	7.5	2.5
	Plumbing	12	9	3
	Fire Protection	5	3.75	1.25
Ground Level	Mechanical	12	9	3
	Electrical	10	7.5	2.5
	Plumbing	12	9	3
	Fire Protection	5	3.75	1.25
2nd Level	Mechanical	10	7.5	2.5

	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
3rd Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
4th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
5th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
6th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
7th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
8th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
9th Level	Fire Protection	5	3.75	1.25
	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
10th Level	Mechanical	10	7.5	2.5
	Electrical	10	7.5	2.5
	Plumbing	10	7.5	2.5
	Fire Protection	5	3.75	1.25
Roof Level	Mechanical	15	11.25	3.75
	Electrical	7	5.25	1.75
	Plumbing	15	11.25	3.75
	Fire Protection	7	5.25	1.75
Risers	Mechanical	15	11.25	3.75
	Electrical	35	26.25	8.75
	Plumbing	100	75	25
	Fire Protection	15	11.25	3.75
Total		602	451.5	150.5

Table 28 Mechanical Ductwork Prefabrication Summary of Duration Reductions

Through the implementation of prefabrication of the mechanical ductwork for the Concordia Hotel approximately 150.5 days were saved. This duration means that it will take 150.5 less days to install the mechanical, electrical, plumbing, and fire protection throughout the building. In order to determine the total cost savings through implementing this prefabrication initiative a detailed analysis was performed in consideration of the labor costs and general conditions which are shown in table 29. This analysis will study the typical wages associated with on-site and off-site construction efforts as well as the other potential cost savings. Table 30 shows the total labor savings resulting from prefabrication off-site as opposed to on-site The general conditions were also analyzed showing that approximately $814,051.49 were saved as a result of the implementation of prefabrication to the MEP systems this breakdown of savings is shown in table 32.

Table 29: Hourly & Daily Labor Rates For Prefabrication					
Trade	Hourly Wages		Quantity of Laborers	Daily costs	
	On-site ($/hr)	Off-site ($/hr)		On-site ($/hr)	Off-site ($/hr)
Mechanical	$ 108.67	$ 65.74	6	$ 5,216.16	$ 3,155.52
Electrical	$ 102.00	$ 61.00	4	$ 3,264.00	$ 1,952.00
Plumbing	$ 104.04	$ 62.14	4	$ 3,329.28	$ 1,988.48
Fire Protection	$ 135.10	$ 81.00	5	$ 5,404.00	$ 3,240.00
Total Daily Labor Costs				$ 17,213.44	$ 10,336.00
Total Labor Savings					$ 6,877.44

Table 29 Hourly & Daily Labor Rates for Prefabrication

Table 30: Total Labor Savings			
Contractor	Original Labor Costs	Prefabrication Labor Costs	Total Cost Savings
Mechanical	$ 751,127.04	$ 340,796.16	$ 410,330.88
Electrical	$ 496,128.00	$ 222,528.00	$ 273,600.00
Plumbing	$ 762,405.12	$ 341,521.44	$ 420,883.68
Fire Protection	$ 416,108.00	$ 187,110.00	$ 228,998.00
Total	$ 2,425,768.16	$ 1,091,955.60	$ 1,333,812.56

Table 30 Total Labor Savings

Table 31: Total Schedule Savings Summarized			
Installation Activity	Original Duration	Prefabrication Duration	Duration Reduction
Mechanical Installation	144	108	36
Electrical Installation	152	114	38
Plumbing Installation	229	171.75	57.25
Fire Protection Installation	77	57.75	19.25
Total			150.5

Table 31 Total Schedule Savings Summarized

Table 32: Schedule Savings-Staggered Demolition			
Item	Schedule (Days)	General Conditions Cost Savings ($/Day)	General Conditions Cost
Original Duration	602	$ 5,408.98	$ 3,256,205.96
New Duration	451.5	$ 5,408.98	$ 2,442,154.47
Total Savings			$ 814,051.49

Table 32 General Conditions Savings-Staggered Demolition

3.11 Analysis Summary

- With the application of prefabrication techniques to the project there was an overall schedule reduction of 113 days from the original 602 day duration to the new 451.5 day duration.
- General conditions costs were reduced from $3,256,205.96 to $2,442,154.47 which resulted in a savings of $814,051.49 to the project's overall general conditions cost.
- There were savings in labor as well due to the off-site prefabrication, it went from $17,213.44/8-hour day to $10,336.00/8-hour day which resulted in a labor wage savings of $6,877.44/8-hour day
- This will also likely prevent the need for additional labor crews and overtime hours which would eliminate the $40,000.oo changeorder submitted for getting the project back onto schedule.
- Overall, it is feasible and highly beneficial to use prefab on this project based on the cost, schedule savings and intangible benefits.

Analysis 4: Alternate Roof System

4.1 Problem Identification

The Concordia Hotel employs two different roofing systems, a green roof and a Thermoplastic Polyolefin (TPO) in different areas. This difference in roofing systems caused constructability issues and inefficiencies in ordering of materials. The roofing system could have been optimized by utilizing one system over the other in order to capitalize on bulk order savings and labor efficiencies with repetitive tasks. Utilizing one system for the entire roofing area could have also optimized the potential to earn a greater amount of LEED credits.

4.2 Research Goal

The goal of this analysis is to perform an in-depth study related to implementing a sustainable cool roof, over the green roof system The ultimate goal is to determine the benefits to the owner and occupants of the facility, as well as the effect on cost, the project schedule, and the issues of constructability. Additionally, out of option breadths will arise with this analysis of the applicability of a sustainable cool roof over a green roof system. These other breadths will include; structural and mechanical analyses that will influence the performance and overall functionality of the structure.

4.3 Research Methods

- Research various sustainable roofing system technologies and compare the advantages and disadvantages of each of the systems
- Analyze current designs and the energy efficiency associated with each type of roofing system
- Analyze how each different roof type will influence mechanical and structural systems.
- Determine constructability issues and schedule impacts.

4.4 Resources

- The Turner Construction Company project team on the Concordia Hotel
- Bailey Wilson-Project Engineer
- AE Faculty, Key Industry Members
- Product manuals and Reviews
- Project Drawings and Specifications
- Educational Background from Previous AE Courses, Internship with Dr. Riley

- Knowledge from undergraduate courses (AE 308 and E 404)
- Educational background from previous AE courses (such as AE 372, AE 475, AE 476, and AE 570)
- Applicable Literature
- The Pennsylvania State University AE faculty
- Key industry members
- Applicable literature (books, websites, papers, etc.)

4.5 Potential Solutions and Expected Outcomes

It is believed that applying a single roof system throughout the entire roofing surface will result in greater efficiencies in cost, schedule and construction. The application of a green roof system will cost more and require greater structural reinforcement; however, it will allow the building to qualify for greater LEED credits through reductions in the Heat Island Effect and the reduction of storm water runoff. The system will also have increased savings due to its thermal efficiency. Installing the cool roof system to all of the roof's surfaces will likely result in similar LEED qualifications and cost savings due to reduced structural needs. Unfortunately, the cool roof system will not be as thermally efficient as the green roof system will be in terms of thermal efficiency, however, this will likely be outweighed by the savings in structural reinforcement to support the green roof system.

4.6 LEED Roofing Systems

Unfortunately, buildings are responsible for approximately 40% of the total energy consumption in the United States. They are also responsible for 16% of the total water consumption. These are significant figures and in order to reduce the use of fossil fuels and other energy resources as well as protecting water resources new construction methods are being applied to create more environmental conscientious structures. There are essentially two types of "Green Roof" systems, one employs a roof garden another employs materials that are highly refelective which has coined the term "Cool Roof". A Green roof is a roof system which is covered with vegetation and a growing medium over a waterproofing membrane. While these types of roofs are becoming more and more popular they have been around for centuries. These living roofs have been seen all across the world in places such as Australia, Canada, Egypt, France, Germany and many others. A Cool Roof is a system that utilizes the same materials as a typical roof, however, the only difference between the two is that a cool roof's materials are highly reflective in order to reduce solar gain. As sustainable awareness and design is being applied to more projects these roof systems are becoming more and more prevelant which is likely attributed to the many benefits associated with them. "Green roofs" provide great opportunities for accomplishing reductions in the use of these natural resources. These environmentally conscientious roofing types have the ability to gain many short term and long term benefits to the owners and the occupants of a structure. Each Roofing type will be described in terms of their benefits, LEED credits, and lastly their structural and mechanical influences below.

4.6 A: Green Roof Benefits

Green Roof Systems have many benefits which include environmental impacts, and great energy savings. These green roof systems have many great environmental impacts that really create appeal to owners and many environmental advocates. Some of these environmental benefits include absorbing rainwater, filtering pollutants and absorbing CO_2, improving insulation, creating a habitat for wildlife, and most importantly reducing the urban heat island effect. A green roof will reduce stormwater runoff when the plants and the plant medium absorb the water which is a critical issue in urbanized areas. Not only will it reduce the stormwater runoff but it also filters pollutants and absorbs CO_2 commonly found in abundance in highly populated and over developed areas. Implementing this roof type reduces the thermal loss of a building resulting in energy savings related to heating and cooling the interior of the building. A green roof can also extend the life of the roof because it protects the roof from weather, therefore reducing maintenance costs. The appeal of installing a green roof is also due to the idea that it creates a natural habitat for birds and insects which is great for these highly populated areas where wildlife is sparce. Many cities are plagued with higher temperatures which is a direct result of many building materials which absorb a great deal of heat and release it as the surroundings cool; this phenomenon is referred to as the heat island effect. The green roof system reduces this extensive absorption of heat minimizing the heat island effect which is the cause of cities increased temperatures.

4.6 B: LEED Influences

Green roof systems have the ability to gain LEED credits as well as local and government incentives. Applying a green roof to a structure enables the owner to potentially receive 20 points in LEED credits depending on the amount of area to which the green roof is applied. These points will be outlined and described below:

Sustainable Sites

- SS Credit 5.1: Site Development: Protect or Restore Habitat (1 point)
- SS Credit 5.2: Site Development: Maximize Open Space (1 point)
- SS Credit 6.1: Stormwater Design: Quantity Control (1 point)
- SS Credit 6.2: Stormwater Design: Quality Control (1 point)
- SS Credit 7.2: Heat Island Effect: Roof (1 point)
- ID 1.1 Vegetated Roof for Exemplary Performance

Water Efficiency

- WE Credit 1.1: Water Efficient Landscaping: Reduce by 50% (1 point)
- WE Credit 1.2: Water Efficient Landscaping: No Potable Water Use or No Irrigation (1 point)

Energy & Atmosphere

- EA 1.1 to 1.19 Optimize Energy Performance

Materials & Resources

- MR Credit 4.1-4.2: Recycled Content
- MR Credit 6: Rapidly Renewable Materials
- MR Credit 5.1-5.2: Regional Materials

In addition to the LEED credits an owners in certain regions can benefit from federal and local tax incentives and potentially even funding to support implementation of such a system.

Tax Incentives

Clean Energy Stimulus & Investment Assurance Act-Bill which allows property owbners who install green roofs to recoup 30% of their cost in federal tax credit. There is no limit on commercial roofs, however, the green roof must cover at least 50% of the total roof surface in order to qualify.

Energy Policy Act of 2005-Federal tax credits of up to $1.80 per sq. ft. are available for green buildings that meet ASHRAE standards.

Grants

Chesapeake Bay Foundation-has $300,000 in funds to provide green roof grants. Individual grants may fund up to 20% of the total cost of a green roof installation.

4.6 C: Green Roof Mechanical Influences

Many different materials are rated based on their thermal resistance, this rating is called the "R-Value". The R-values, also known as the thermal resistance of a materials, is a guage of a material's insulating properties. As outlined previously as some of the benefits green roofs have, it has been shown that they can improve thermal efficiency, and they have the ability to decrease costs associated with the heating and cooling of a structure. Unfortunately the R-value of a green roof is not always consistent and therefore is not easily defined. Conservative assumptions are often made to define this value for green roofs that utilize typical materials.

4.6 D: Green Roof Structural Influences

Based on the fact that a green roof has twice as many materials as a typical roof these can often be 2-4 times the weight of a typical single-ply hot asphalt roof type. Depending on the size of the plant medium, the desired appearance and plant sizes these roofs can be anywhere from 10 psf to as much as 150 psf. These roof types often require extensive and often expensive structural requirements in order to support the increased dead load to the structure from the roofing materials.

4.6 E: Cool Roof Benefits

A cool roof system has similar benefits that a green roof will have with a few exceptions. A cool roof will reflect sunlight and reradiate absorbed heat as light energy back to the atmosphere, rather than transferring absorbed heat to the building below. Figure 77 shows how the cool roof works when it comes to reflection. Cool roof's reflect the solar radiation back into the earth's atmosphere instead of transferring it to the building's interior. This reduction in solar gain can result in reduced cooling costs which typically outweighs the increased heating costs for the winter seasons. Similar to green roofs, a cool roof will reduce the urban heat island effect, essentially due to the high reflectance of the construction materials. The life cycle of a cool roof is much greater than a typical roof because while a typical roof will absorb ultraviolet (UV) radiation and infrared (IR) radiation a cool roof will not.

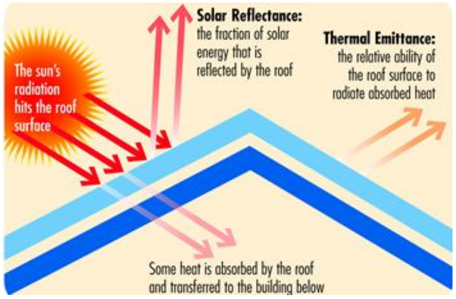


Figure 77 How a Cool Roof Works

4.6 F: LEED Influences

Cool roof systems have the ability to gain LEED credits as well as local and government incentives. Applying a cool roof rather than a typical roofing system enables the owner to potentially receive 1 point in LEED credits depending on the amount of area to which the green roof is applied. 1 point would be awarded for “using roofing materials having a Solar Reflectance Index (SRI) equal to or greater than the values in the table below for a minimum of 75% of the roof surface.

Sustainable Sites

- SS 7.2 Heat Island Effect, Roof

In addition to the LEED credits an owners in certain regions can benefit from federal and local tax incentives and potentially even funding to support implementation of such a system.

Rebate Programs

Commercial Building Tax Deduction Coalition-The deduction is limited to $1.80 per square foot of the property, with allowances for partial deductions for improvements in the building envelop systems.

4.6 G: Cool Roof Structural and Mechanical Influences

A cool roof is very similar to a typical roof and therefore each manufacturer lists the R-value and other specifications of the roofing materials. When it comes to structural influences the cool roof is very similar to typical hot asphalt roofing and therefore no extra structural considerations need to be made. These two roofing types are highly beneficial to both occupants of the facility as well as the surrounding environment. While a green roof was applied to the structure in order to gain several LEED credits it might have been more beneficial to apply a cool roof system instead of the green roof.

4.7 The Concordia Renovation Project’s Roofing

The roof on the Concordia project is an 8” Flat-Plate 2-way slab system which supports a multitude of amenities for hotel guests. Prior to the renovation, the roof of the structure was composed of a pool, and patio/seating area. With the renovation of the building the owner is hoping to acquire a Gold LEED rating for the new construction, and the owner is hoping to improve the odds of meeting this goal by installing a green roof system on the south east corner of the structure as well as several smaller sections of the roof. The green roof is applied to 2000sq. ft./8597.80 sq. ft. of roof, which is only 23% of the total roof area these areas are highlighted in blue in figure 78. The newly constructed green roof system will be accompanied by the newly renovated pool and highly reflective patio area as well. There are several key logistical issues associated with installing a green roof system on a structure built in 1965. The most critical concern was the structure’s ability to support the new loading requirements of a green roof system. Installing this roof type inevitably caused the installation of extensive reinforcing for the bottom and top of the slabs in locations in order to support the loading of a new green roof system. The extent of the CFRP to be applied to both the bottom and top of the slab is shown in greater detail in figures 79.

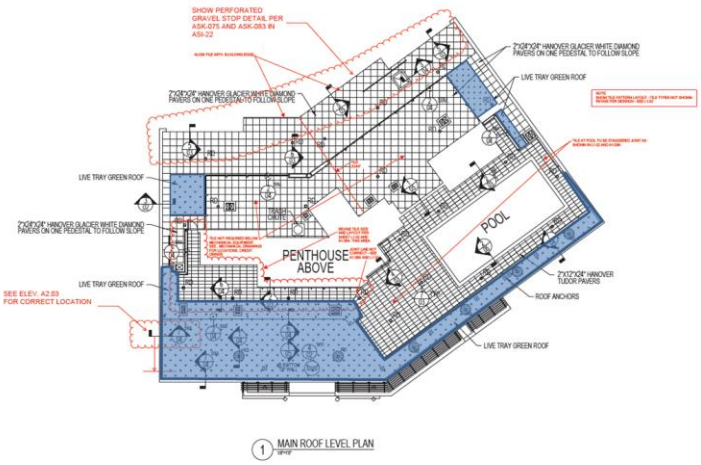


Figure 78 Roofing Components

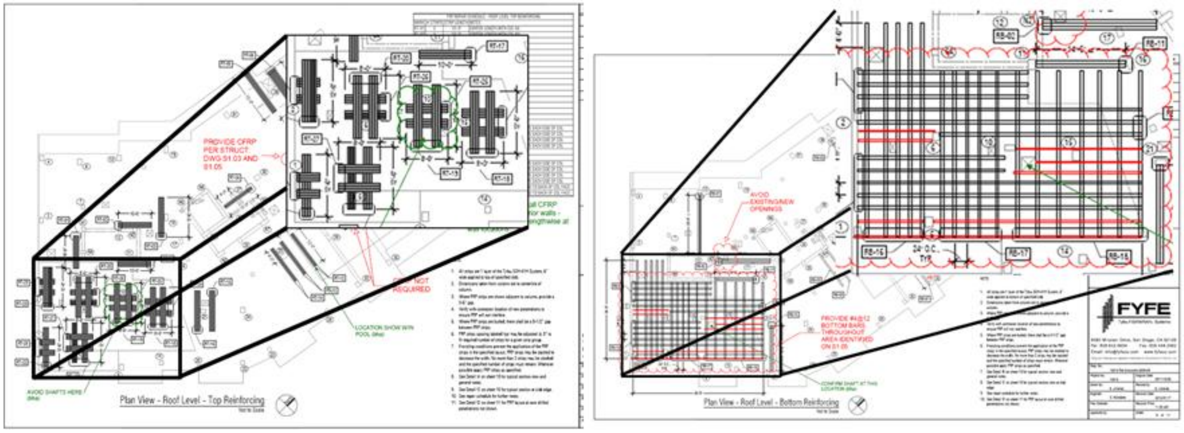
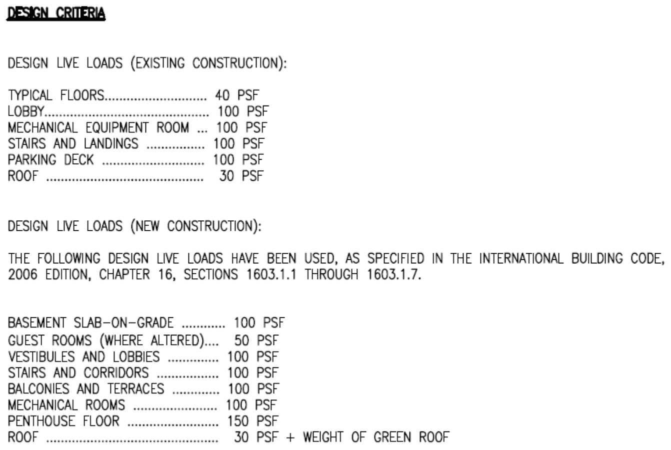


Figure 79 CFRP Plans Top (left) & Bottom (right) Reinforcing

4.8 Structural Breadth Analysis

The following analysis will propose an alternative roofing system to replace the green roof system and therefore reduce the extensive requirement of reinforcing to the slab. A careful consideration will be made to reduce the project cost while still maintaining a LEED Gold rating to the structure. In order to save time and money to the renovation of the Concordia a consideration of the current systems will be made to consider their structural integrity and capability of supporting a cool roof system over a green roof system. The structural analysis will be outlined below:

The first step in this process of analyzing whether the currently designed structure can support the application of a cool roof system to replace the green roof system currently applied. In this analysis of the structure's capability we must first determine the dead and live loads which the structural members will support some of these loading design requirements are shown in figure 80. Table 31 displays dead and live loads used for the design of the roof structural system.



DESIGN CRITERIA

DESIGN LIVE LOADS (EXISTING CONSTRUCTION):

TYPICAL FLOORS	40 PSF
LOBBY	100 PSF
MECHANICAL EQUIPMENT ROOM	100 PSF
STAIRS AND LANDINGS	100 PSF
PARKING DECK	100 PSF
ROOF	30 PSF

DESIGN LIVE LOADS (NEW CONSTRUCTION):

THE FOLLOWING DESIGN LIVE LOADS HAVE BEEN USED, AS SPECIFIED IN THE INTERNATIONAL BUILDING CODE, 2006 EDITION, CHAPTER 16, SECTIONS 1603.1.1 THROUGH 1603.1.7.

BASEMENT SLAB-ON-GRADE	100 PSF
GUEST ROOMS (WHERE ALTERED)	50 PSF
VESTIBULES AND LOBBIES	100 PSF
STAIRS AND CORRIDORS	100 PSF
BALCONIES AND TERRACES	100 PSF
MECHANICAL ROOMS	100 PSF
PENTHOUSE FLOOR	150 PSF
ROOF	30 PSF + WEIGHT OF GREEN ROOF

Figure 80 Design Load Requirements

Table 33: Live & Dead Loads on Roof	
Item	Load (PSF)
8” Normal Weight Concrete (150 PCF)	100
Built-Up-Roof	20
Total Dead Load	120
Roof Live Load (non-roof garden)	30
Total Live Load	30

Table 33 Live & Dead Loads

The column and the bay which it supports which was chosen for further analysis to determine whether the existing structure is capable of supporting the cool roof system is shown below in figure 81.

The structural members responsible for supporting the cool roof system include and 8” slab and a 21” x 24” column which supports a maximum span of 20’.

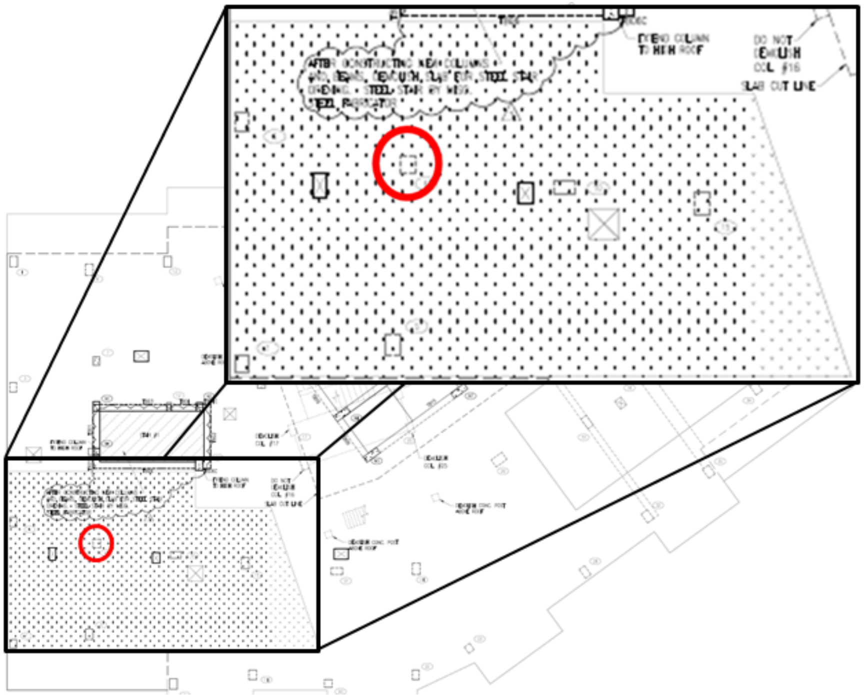
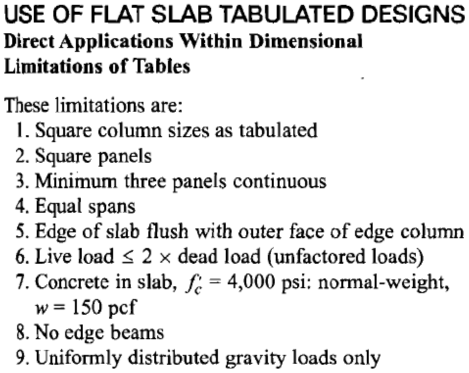


Figure 81 Structural Bay for Analysis

After gathering the detailed loading on the roof of the structure a calculation of the distributed load was conducted and the CRSI tables were referred to prior to a detailed structural analysis of the structural members.

- Factored Distributed Load: $W = (1.2)(D_L) + (1.6)(L_R)$
  - $W = (1.2)(120\ PSF) + (1.6)(30\ PSF) = 192\ PSF$

The CRSI tables were referenced in order to gain a baseline of whether or not these existing structural members were capable of supporting the cool roof system. In order to apply the CRSI Flat Plate Slab Tabulated Designs several limitations were overcome. The requirements of the systems to be analyzed in order for the values to be applicable are outlined in figure 82. While these requirements must be met the tables can still provide a general idea of the size of the structural systems required to support the present loading. The area analyzed does not employ square columns, square panels, and it does not have a minimum of three panels continuous. The way in which these complications were overcome was by using the shortest side of the column (in this case 21"), treating the bay as a square panel and one of three continuous panels. After a careful analysis of these tables, shown in figure 83, it was discovered that a 21" interior column is capable of supporting an interior 20' span with a loading of 200 PSF. Unfortunately, this analysis is not completely accurate because the column in the structure is a 21" x 24" supporting 192 psf over a 20' span. The concrete strength is f'_c=5000 psi and while it is interior panel it is not a square panel & it does not have a minimum of 3 panels continuous or equal spans. Based on this analysis it is clear that the existing structural members are capable of supporting the cool roof system, however, further analysis will be conducted to assure that the existing structural members are more than sufficient in handling this responsibility.



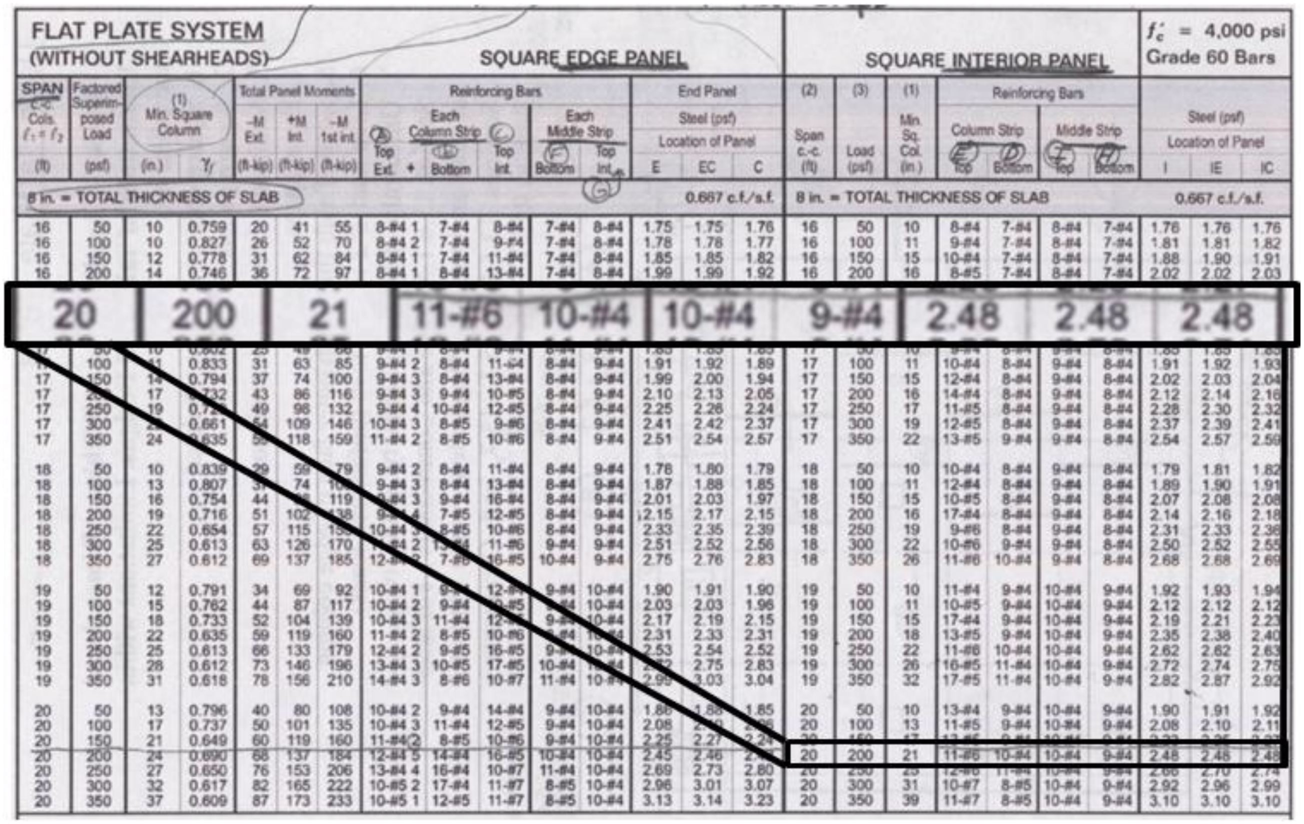
USE OF FLAT SLAB TABULATED DESIGNS

Direct Applications Within Dimensional Limitations of Tables

These limitations are:

1. Square column sizes as tabulated
2. Square panels
3. Minimum three panels continuous
4. Equal spans
5. Edge of slab flush with outer face of edge column
6. Live load ≤ 2 × dead load (unfactored loads)
7. Concrete in slab, f'_c = 4,000 psi: normal-weight, w = 150 pcf
8. No edge beams
9. Uniformly distributed gravity loads only

Figure 82 CRSI Tables Applicabilitiy Requirements



FLAT PLATE SYSTEM (WITHOUT SHEARHEADS)

SQUARE EDGE PANEL

8 in. = TOTAL THICKNESS OF SLAB — 0.667 c.f./s.f.

20	200	21	11-#6	10-#4	10-#4	9-#4	2.48	2.48	2.48

SPAN c.-c. Cols. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	(1) Min. Square Column (in.)	γ_f	−M Ext. (ft-kip)	+M Int. (ft-kip)	−M 1st int. (ft-kip)	Each Column Strip Ⓐ Top Ext.	*	Ⓑ Bottom	Ⓒ Top Int.	Each Middle Strip Ⓕ Bottom	Ⓖ Top Int.	End Panel Steel (psf) Location of Panel E	EC	C
16	50	10	0.759	20	41	55	8-#4	1	7-#4	8-#4	7-#4	8-#4	1.75	1.75	1.76
16	100	10	0.827	26	52	70	8-#4	2	7-#4	9-#4	7-#4	8-#4	1.78	1.78	1.77
16	150	12	0.778	31	62	84	8-#4	1	7-#4	11-#4	7-#4	8-#4	1.85	1.85	1.82
16	200	14	0.746	36	72	97	8-#4	1	8-#4	13-#4	7-#4	8-#4	1.99	1.99	1.92
[illegible]	50	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	100	11	0.833	31	63	85	9-#4	2	8-#4	11-#4	8-#4	9-#4	1.91	1.92	1.89
17	150	14	0.794	37	74	100	9-#4	3	8-#4	13-#4	8-#4	9-#4	1.99	2.00	1.94
17	[illegible]	17	0.732	43	86	116	9-#4	3	9-#4	10-#5	8-#4	9-#4	2.10	2.13	2.05
17	250	19	[illegible]	49	98	132	9-#4	4	10-#4	12-#5	8-#4	9-#4	2.25	2.26	2.24
17	300	[illegible]	0.661	54	109	146	10-#4	3	8-#5	9-#6	8-#4	9-#4	2.41	2.42	2.37
17	350	24	0.635	[illegible]	118	159	11-#4	2	8-#5	10-#6	8-#4	9-#4	2.51	2.54	2.57
18	50	10	0.839	29	59	79	9-#4	2	8-#4	11-#4	8-#4	9-#4	1.78	1.80	1.79
18	100	13	0.807	[illegible]	74	[illegible]	9-#4	3	8-#4	13-#4	8-#4	9-#4	1.87	1.88	1.85
18	150	16	0.754	44	[illegible]	119	[illegible]	3	9-#4	16-#4	8-#4	9-#4	2.01	2.03	1.97
18	200	19	0.716	51	102	138	[illegible]	4	7-#5	12-#5	8-#4	9-#4	2.15	2.17	2.15
18	250	22	0.654	57	115	[illegible]	10-#4	[illegible]	8-#5	10-#6	8-#4	9-#4	2.33	2.35	2.39
18	300	25	0.613	63	126	170	[illegible]	2	[illegible]	11-#6	9-#4	9-#4	2.51	2.52	2.56
18	350	27	0.612	69	137	185	[illegible]	[illegible]	[illegible]	16-#5	10-#4	9-#4	2.75	2.76	2.83
19	50	12	0.791	34	69	92	10-#4	1	[illegible]	[illegible]	9-#4	10-#4	1.90	1.91	1.90
19	100	15	0.762	44	87	117	10-#4	2	9-#4	[illegible]	[illegible]	10-#4	2.03	2.03	1.96
19	150	18	0.733	52	104	139	10-#4	3	11-#4	[illegible]	[illegible]	10-#4	2.17	2.19	2.15
19	200	22	0.635	59	119	160	11-#4	2	8-#5	10-#6	[illegible]	[illegible]	2.31	2.33	2.31
19	250	25	0.613	66	133	179	12-#4	2	9-#5	16-#5	[illegible]	[illegible]	2.53	2.54	2.52
19	300	28	0.612	73	146	196	13-#4	3	10-#5	17-#5	10-#4	[illegible]	[illegible]	2.75	2.83
19	350	31	0.618	78	156	210	14-#4	3	8-#6	10-#7	11-#4	[illegible]	[illegible]	3.03	3.04
20	50	13	0.796	40	80	108	10-#4	2	9-#4	14-#4	9-#4	10-#4	1.86	1.88	1.85
20	100	17	0.737	50	101	135	10-#4	3	11-#4	12-#5	9-#4	10-#4	2.08	[illegible]	[illegible]
20	150	21	0.649	60	119	160	11-#4	②	8-#5	10-#6	9-#4	10-#4	2.25	2.27	2.24
20	200	24	0.690	68	137	184	12-#4	5	14-#4	16-#5	10-#4	10-#4	2.45	2.46	[illegible]
20	250	27	0.650	76	153	206	13-#4	4	16-#4	10-#7	11-#4	10-#4	2.69	2.73	2.80
20	300	32	0.617	82	165	222	10-#5	2	17-#4	11-#7	8-#5	10-#4	2.96	3.01	3.07
20	350	37	0.609	87	173	233	10-#5	1	12-#5	11-#7	8-#5	10-#4	3.13	3.14	3.23

SQUARE INTERIOR PANEL

f'_c = 4,000 psi Grade 60 Bars

8 in. = TOTAL THICKNESS OF SLAB — 0.667 c.f./s.f.

(2) Span c.-c. (ft)	(3) Load (psf)	(1) Min. Sq. Col. (in.)	Column Strip Ⓔ Top	Ⓓ Bottom	Middle Strip Ⓕ Top	Ⓗ Bottom	Steel (psf) Location of Panel I	IE	IC
16	50	10	8-#4	7-#4	8-#4	7-#4	1.76	1.76	1.76
16	100	11	9-#4	7-#4	8-#4	7-#4	1.81	1.81	1.82
16	150	15	10-#4	7-#4	8-#4	7-#4	1.88	1.90	1.91
16	200	16	8-#5	7-#4	8-#4	7-#4	2.02	2.02	2.03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	100	11	10-#4	8-#4	9-#4	8-#4	1.91	1.92	1.93
17	150	15	12-#4	8-#4	9-#4	8-#4	2.02	2.03	2.04
17	200	16	14-#4	8-#4	9-#4	8-#4	2.12	2.14	2.16
17	250	17	11-#5	8-#4	9-#4	8-#4	2.28	2.30	2.32
17	300	19	12-#5	8-#4	9-#4	8-#4	2.37	2.39	2.41
17	350	22	13-#5	9-#4	9-#4	8-#4	2.54	2.57	2.59
18	50	10	10-#4	8-#4	9-#4	8-#4	1.79	1.81	1.82
18	100	11	12-#4	8-#4	9-#4	8-#4	1.89	1.90	1.91
18	150	15	10-#5	8-#4	9-#4	8-#4	2.07	2.08	2.08
18	200	16	17-#4	8-#4	9-#4	8-#4	2.14	2.16	2.18
18	250	19	9-#6	8-#4	9-#4	8-#4	2.31	2.33	2.36
18	300	22	10-#6	9-#4	9-#4	8-#4	2.50	2.52	2.55
18	350	26	11-#6	10-#4	9-#4	8-#4	2.68	2.68	2.69
19	50	10	11-#4	9-#4	10-#4	9-#4	1.92	1.93	1.94
19	100	11	10-#5	9-#4	10-#4	9-#4	2.12	2.12	2.12
19	150	15	17-#4	9-#4	10-#4	9-#4	2.19	2.21	2.23
19	200	18	13-#5	9-#4	10-#4	9-#4	2.35	2.38	2.40
19	250	22	11-#6	10-#4	10-#4	9-#4	2.62	2.62	2.63
19	300	26	16-#5	11-#4	10-#4	9-#4	2.72	2.74	2.75
19	350	32	17-#5	11-#4	10-#4	9-#4	2.82	2.87	2.92
20	50	10	13-#4	9-#4	10-#4	9-#4	1.90	1.91	1.92
20	100	13	11-#5	9-#4	10-#4	9-#4	2.08	2.10	2.11
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	200	21	11-#6	10-#4	10-#4	9-#4	2.48	2.48	2.48
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.70	2.74
20	300	31	10-#7	8-#5	10-#4	9-#4	2.92	2.96	2.99
20	350	39	11-#7	8-#5	10-#4	9-#4	3.10	3.10	3.10

Figure 83 Flat Plate System Table for 8" Slab

Detailed Structural analysis

- Factored Distributed Load: W = (1.2)(D_L) + (1.6)(L_R)
  - Wu = (1.2)(120 PSF) + (1.6)(30 PSF) = 192 PSF
- Deflection (ACI 318-11, Table 9.5, Interior Panels): L_n/33<Thickness of slab
  - 20'(12"/1')/33<8" = 7.2727"<8"
- Ultimate Shear
  - V_u = (192 PSF)(18.60' x 18.09') = 64,603 lbs.
- Critical Shear Vc = $4\lambda\sqrt{f'c}\, b_o d$
  - b_o = 2 (24" + 8") + 2 (21" + 8") = 122"
  - d= (8 – 0.75)
  - Vc = $4(1)\sqrt{5000\,psi}$ (122")(8-0.75) = 250,174.3792 lbs.
- Punching Shear
  - $V_u < \phi\ V_c$
  - 64,603 lbs. < (0.75) x (250,174.3792 lbs.)
  - 64,603 lbs. < 187,630.7844 lbs

Upon completion of the previous structural calculations it has been determined that the the existing structural system can meet the loading requirements for implementing a cool roof system. The existing slab and columns are capable of preventing punching shear in a two-way slab. Note, that all calculations and sizing methods used in this breadth study were learned in Architectural Engineering 404: Building Structural Systems in Steel and Concrete.

4.9 Mechanical Breadth Analysis

The current designed roof system for the Concordia Hotel consists of a green roof system, patio area and pool. Replacing the currently designed green roof with a cool roof will likely affect the thermal efficiency of the roofing system due to the thermal properties associated with each system. This analysis will satisfy a mechanical breadth requirement by illustrating skills to perform a mechanical analysis of the current roof system compared to the cool roof system. Only the limited area of roofing which applied a green roof will be applied considering that the patio will remain while only the green roof will be adjusted/replaced. The impact of the system will be analyzed in terms of thermal resistance between the two roofs and their impact on the mechanical load for the floor below.

The first step in the process of determining the heating and cooling load reduction through the application of the cool roof system is to compare the overall R-Value and U-Value for the original green roof versus the cool roof system. Table 32 shows the R-Values and U-Values of the roofing materials applied to the Concordia Hotel renovation project.

Table 34: Roof System R-Value & U-Value Calculation

Material	R-Value (ft^2*F*hr/BTU)		U-Value (BTU/ft^2*F*hr)	
	Cool Roof	Green Roof	Cool Roof	Green Roof
8" Concrete Slab	0.5	0.5	2	2
Hot Fluid Applied, Rubberized Asphalt Waterproofing Membrane	-	0.15	-	6.67
Densdeck Prime Roof Guard	0.56	0.56	1.79	1.79
(2) 2" Thick DOW RM Insulation @ r value of 5.0 ft^2*F*hr/BTU/in.	20	20	0.05	0.05
6.5" LiveRoof System	-	8.45	-	0.12
Single-Ply Membrane White (High Reflectance Cool-Roof)	0.15	-	0.15	-
Total	21.21	29.66	0.05	0.03

Table 34 Roof System R-Value & U-Value Calculation

With the known R-Value and U-Value, the monthly heating and cooling loads can be used to determine the annual heating and cooling loads. The degree heating and cooling degree days are based on recent temperature data provided by National Oceanic & Atmosphere Administartion (NOAA) for each state for a base temperature of 65 degrees Fahrenheit. Calculations will be performed through the use of the following equations:

- $Q_{monthly} = (UA)_h \times DD \times 24$ hours/day
    - Where $Q_{monthly}$ is monthly heating or cooling load, U is the heat transfer coefficient. A is the total area, and DD is the degree days for heating or cooling
- $E_T = L_{monthly} / \eta$ or COP
    - Where E_T is the total heating or cooling energy, and η is the efficiency of the unit or COP is the coefficient of performance.

Table 33 displays the yearly heating and cooling loads, broken down by month, for the Green Roof System.

Table 35: Yearly Heating & Cooling Load Green Roof System

Month	Degree Days	U-Value (BTU/ft_2*F*hr)	Area (ft_2)	$Q_{monthly}$ (BTU)	Q_{yearly} (BTU)
Heating Load					
March	410	0.03	2000	24,600	239,460
April	352	0.03	2000	21,120	
May	48	0.03	2000	2,880	
October	295	0.03	2000	17,700	
November	490	0.03	2000	29,400	
December	776	0.03	2000	46,560	
January	912	0.03	2000	54,720	
February	708	0.03	2000	42,480	
Cooling Load					
June	278	0.03	2000	16,680	71,880
July	461	0.03	2000	27,660	
August	313	0.03	2000	18,780	
September	146	0.03	2000	8,760	

Table 35 Yearly Heating & Cooling Load Green Roof System

Table 34 displays the yearly heating and cooling loads, broken down by month, for the Cool Roof system.

Table 36: Yearly Heating & Cooling Load Cool Roof System

Month	Degree Days	U-Value (BTU/ft_2*F*hr)	Area (ft_2)	$Q_{monthly}$ (BTU)	Q_{yearly} (BTU)
Heating Load					
March	410	0.05	2000	41,000	399,100
April	352	0.05	2000	35,200	
May	48	0.05	2000	4,800	
October	295	0.05	2000	29,500	
November	490	0.05	2000	49,000	
December	776	0.05	2000	77,600	
January	912	0.05	2000	91,200	
February	708	0.05	2000	70,800	
Cooling Load					
June	278	0.05	2000	27,800	119,800
July	461	0.05	2000	46,100	
August	313	0.05	2000	31,300	
September	146	0.05	2000	14,600	

Table 36 Yearly Heating & Cooling Load Cool Roof System

After calculating the yearly heating and cooling loads associated with each of the different roofing systems it is apparent that the green roof will require less energy to heat the same area based on its thermal efficiency. The green roof will require 239,460 and 71,880 BTU's for heating and cooling while the green roof will require 399,100 and 119800 BTU's for heating and cooling. These values are outlined in tables 33 &34. A difference of 159,640 and 47920 BTU's for heating and cooling.

Table 37: Heating & Cooling Energy Comparison					
Heating Energy			Cooling Energy		
Q_{Total} (KWH)	η	E_{Total} (KW)	Q_{Total} (KWH)	COP	E_{Total} (KW)
Green Roof					
70.18	0.71	98.85	21.07	3.2	6.58
Cool Roof					
116.96	0.71	164.73	35.11	3.2	10.97
Energy Difference		65.89	Energy Difference		4.39

Table 37 Heating & Cooling Energy Comparison

Implementing a green roof over a cool roof system will result in an energy difference of 65.89 & 4.39 KW for heating and cooling. This energy difference is outlined in greater detail in table 35.

Table 38: Annual Cost Savings For Heating & Cooling						
Heating energy Savings			Cooling Energy Savings			Total Savings
Energy Difference (KWH)	$/KWH	Savings	Energy Difference (KWH)	$/KWH	Savings	
65.89	0.122	$ 8.04	4.39	0.122	$ 0.54	$ 8.57

Figure 38 Annual Cost Savings For Heating & Cooling

The green roof will save only $8.57 in heating and cooling costs a year as outlined in table 36. A further analysis of the LEED, cost and schedule impacts will be assessed below.

4.10 Green Roof & Cool Roof LEED Impacts

Through the implementation of a green roof on the roof of the Concordia Hotel a LEED Gold rating was achieved. This was made possible via the points awarded in some of the critical sections like sustainable sites, water efficiency, energy & atmosphere and materials and resources. For this analysis only the credits that pertained specifically to the roofing system were analyzed since the full LEED credit analysis would require a consideration of the entire project. The green roof system may have contributed to the structure attaining a LEED Gold rating, however, it did not gain any credits in the areas specific to the roof. Since it was only applied to 28% of the roof it had a minute affect on the structure reaching a LEED Gold rating. Since the green roof was only applied to a fraction of the roof it did not receive this credit because it requires a vegetated roof to be installed for at least 50% of the roof area. The cool roof system did not meet this credit either, since it is proposed to replace the area of green roof which is applied to 28% of the roof, because in order to receive the credit a highly reflective roofing membrane needs to be applied to 75% of the roof. Therefore in consideration of the LEED credits it was essentially a wash since neither achieved any credits related to the roof.

4.11 Green Roof & Cool Roof Cost Impact

Installing the cool roof system in order to replace the green roof system will result in cost savings reducing the need for greater structural reinforcement and increased materials. 30 40' panels were installed to the bottom of the roof level slab, there were also 38 12' panels and 36 8' panels installed to the top of the roof level slab in order to increase the structural capability of the roof level concrete slab. This extensive amount of reinforcement was only installed for the green roof system. We will consider the total length of carbon fiber to be installed in 1944' which is also 48.6-40' panels. Since a crew of 4 laborers can install 1-40' panel/hour we know that there is exactly 48.6 hours of labor to be completed. Each qualified laborer is paid 80/hr, therefore 4 laborers will be paid $320/hr or $2560/8-hr day. As analyzed previously in the structural analysis it is apparent that the existing structural components are capable of supporting the cool roof which would result in significant savings. The only difference in materials between a green and cool roof is that the green roof utilizes a protection mat, drainage layer, filter layer, green roof substrate and plants and the cool roof uses a highly reflective waterproof membrane. Essentially the only cost difference between the two systems is the green roof substrate and the cool roof's highly reflective waterproof membrane. Assuming that the green roof requires a total average cost of $14.00/S.F. and the cool roof is an average $7.36/S.F. the cool roof system will be approximately half the cost to install. Several assumptions will be made concerning material costs and labor for CFRP installation since these details are not located in R.S. Means Online Costworks or any of the R.S. Means literature located in the Engineering Library.

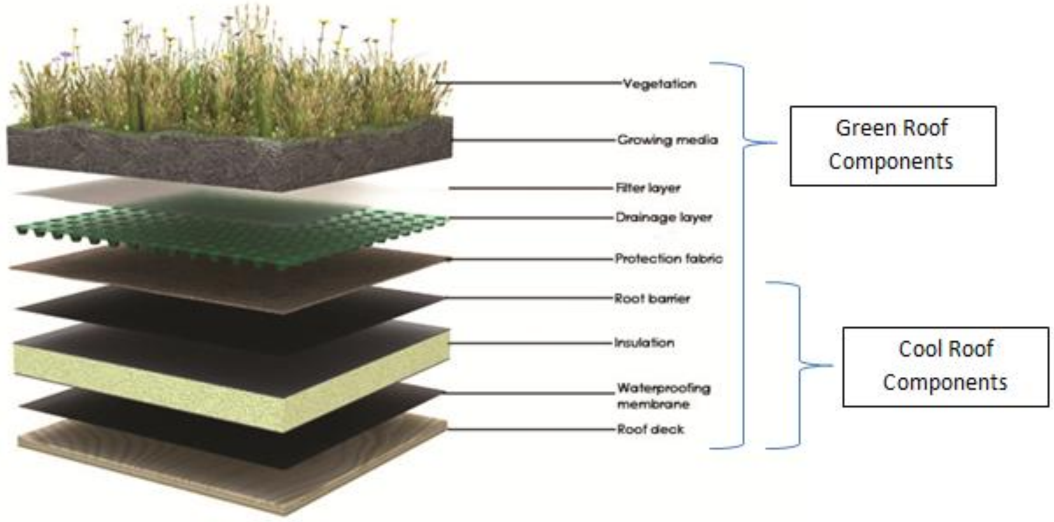


Figure 84 Cool/Green Roof Components

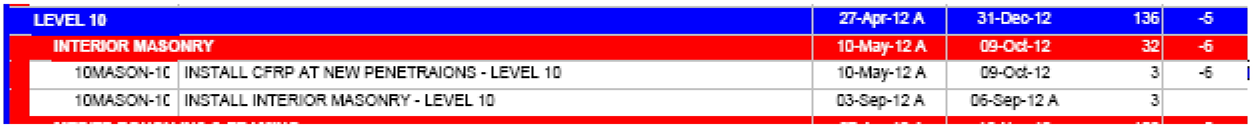
Green Roof Costs:

Structural Costs (CFRP):

- Labor Costs
  - 4 laborers qualified CFRP installers at $80/hr is $320/hr or $2560/8-hour day
  - This will result in an additional cost of $31,104.00 for labor
- Material Costs
  - Considering that a 50 ft roll of carbon fiber is $700, it will cost $27,216.00 for 1944' of carbon fiber
  - Materials, tools and adhesives for installation $2/1 ft CFRP, which will result in $3,888 for 1944' worth of carbon fiber
- Productivity
  - 30-40' panels, 38-12' panels and 36-8' panels=1944 ft total of carbon fiber to be installed
  - 4 laborers can install 1-20'panel/hr (1944'/20'= panels) 97.2-20' panels are to be installed
  - 4 laborers can therefore install 8-20' panels/8 hour day

- This means that the crew will be able to install 97.2 panels to the bottom and tops of the roof level concrete slabs in just over 12 days.

The durations that were determined are a rough estimate based on assumptions. These durations were determined since the schedule does not acurrately breakdown the durations for the CFRP installation. The schedule shown in figure 85 shows that the CFRP installation for the tenth floor will only take 3 days except that this is only considering the CFRP installation for the new penetrations. While there was an extensive amount of CFRP applied at the new penetrations there was also CFRP applied to other areas which would likely result in a much greater duration. Based on the assumptions of productivity it was determined that the entire CFRP installation would consist of a duration of 12.15 days.



LEVEL 10		27-Apr-12 A	31-Dec-12	136	-5
INTERIOR MASONRY		10-May-12 A	09-Oct-12	32	-6
10MASON-10	INSTALL CFRP AT NEW PENETRAIONS - LEVEL 10	10-May-12 A	09-Oct-12	3	-6
10MASON-10	INSTALL INTERIOR MASONRY - LEVEL 10	03-Sep-12 A	06-Sep-12 A	3	

Figure 85 CFRP Durations

Green Roof Material Costs:

- Based on the fact that a green roof will cost $14.00/S.F and it was applied to only 2000 S.F. of the roof this will result in a cost of $28,000

<u>Cool Roof Costs:</u>

Cool Roof Material Costs:

- A cool roof system is significantly cheaper since it does not require the same amount of materials or structural reinforcement. The cool roof system is approximately $7.36/S.F.and it would replace the 2000 S.F. green roof thereby resulting in a cost of $14,720.00.

Installing the green roof system will result in a cost of $90,208.00 while the installation of a cool roof system will result in a cost of $14,720.00

4.12 Cool Roof Schedule Impacts

Utilizing the cool roof system over the green roof will also result in a limited amount of schedule savings because it requires less materials to be installed. Unfortunately the schedule provided by the The Turner Construction Company did not include any durations for the roof installation other than that the construction of the roofing will take a total 32 days. It is likely that installing the green roof installation will not even take a whole day to install on the roof of The Concordia Renovation Project so this duration will be negligible. The primary schedule impact will be caused by the CFRP installation on the top and bottom of the

4.13 Analysis Summary

- After conducting a structural analysis of the existing structural members it was evident that the members are capable of supporting a cool roof system and there is no need for the CFRP reinforcement.
- Reducing the structural requirements will result in a labor savings of $31,104.00, a carbon fiber material savings of $27,216.00, and additional tools and materials savings of $3,888.00 related to the CFRP installation.

- Applying a cool roof will result in increased heating and cooling requirements due to the reduced thermal efficiency of a cool roof compared to a green roof. The green roof will only result in a cost savings of just under ten dollars a year. This is likely attributed to the fact that the green roof was only applied to 2000 S.F. of the roof which is a very insignificant amount.
- With the application of a cool roof system instead of a green roof system to the project there was an overall schedule reduction of 12 days due to the fact that the CFRP to structurally support the cool roof was not required.
- The cost of implementing the cool roof sytem would be $14,720.00 while the green roof system will cost $28,000.00 in roofing materials. The application of a cool roof to the Concordia Hotel Renovation will result in an overall cost savings of $13,280.00 for implementing the cool roof system in place of the green roof system.
- Overall, it is feasible and highly beneficial to replace the green roof system on this project based on the cost, schedule savings and benefits associated with it.

Summary & Conclusions

Over the course of the academic year, a thorough analysis has been conducted of the Concordia Renovation project. A complete assessment of the building and its systems was as well as the means and methods for renovating the structure was made. This allowed for a greater understanding of the existing conditions and building systems as well as areas where improvements might have been made in the means for renovating the Concordia Hotel. After investigating the structure extensively for the last semester four areas were considered for further investigation. The following report discusses the opportunities for improvements, areas where these suggestions can be applied and the likely results of implementing the four main research topics: BIM, re-sequencing of the demolition efforts, the prefabrication of the MEP systems and lastly the proposal of an alternate roofing systems. While considering these areas for improvement, these analyses are not to be perceived as criticisms, but rather areas of study for educational reasons. I am in no way fit to judge the way in which the renovation was performed due to the fact that I was not present for owner meetings or on-site to experience the concerns or issues associated with each technique. My goal is to shape myself as a more critical thinking project engineer for my future career in construction management.

Analysis # 1: Building Information Modeling (BIM)

BIM has been making considerable advancements in the the construction industry. While it was not widely accepted at first it has been gaining greater recognition and support. This growing recognition is likely due to the many benefits that are associated with its application to many different projects in multiple sectors in industry. While BIM is very likely to be applied to new construction it is becoming more and more favorable to apply BIM to renovation projects. With advancements in modeling equipment and software this method of updating outdated 2D drawings is becoming used more and more often. The concern with applying BIM to renovation of older structures is the inaccuracy of 2D drawings and their inability to accurately define as-built conditions. With laser scanning methods and other verification techniques the existing conditions of a structure are becoming easier to model resulting in greater applications of BIM to renovation projects. When considering some of the issues on the renovation of the Concordia project as well as some of the primary and secondary BIM uses it was determined that phase planning is very applicable to the project and has the potential to imprve several activities. It is believed that the application of phase planning to several areas of the project would be highly beneficial to the consideration of alternate methods for renovating the hotel. This BIM application will be utilized in order to analyze alternate demolition initiatives.

Analysis # 2: Re-Sequencing of Demolition Efforts

There were extensive delays in the completion of the Concordia Hotel which were partially attributed to the extensive demolition performed on the Concordia Renovation. The demolition of the Concordia project consisted of the removal of MEP systems, drywall partitions, CMU walls, concrete columns, interior finishes and several interior slabs. The entire façade of the structure was also removed except for the southern side. The demolition initiatives which took place throughout the structure were extensive and repetitious on several of the floors. Even though demolition of the interior slabs and structural columns were repetitious, this activity still delayed concurrent and succeeding activities from being started and completed. These delays resulted in the project being completed behind schedule. In this analysis several alternate demolition methods were considered in reference to feasibility and potential benefits in schedule & cost reductions. After conducting an analysis of each of the alternate sequences to demolish the structural slabs and columns it was decided that implementing a staggered demolition technique would result in schedule and general conditions savings. The staggered demolition technique would reduce the schedule of the demolition of the interior slabs by 34 days reducing the original duration of 56 days to 22 days. The implementation of a staggered demolition sequence will also reduce general conditions costs from $286,675.94 to $102,770.62 which is a savings of $183,905.32 to the project's overall cost. The new demolition sequence proposes the addition of a second crew and demolition equipment which is an additional cost of $83,906.67. This is an increased cost of $36,386.67 from the original $47,520.00 associated with the original demolition technique. The implementation of staggered demolition will result in an overall savings of $1,176,358.65 after the additional cost of laborers and equipment. It is based on these details that my recommendation is to implement this method on the project in order to capitalize on these many benefits.

Analysis # 3: Implementation of MEP Prefabrication

The site logistics of this project served as a major challenge for the project team due to the restrictive site and its limited space and potential for material laydown. The extensive construction and installation of the MEP systems caused expensive delays to the project. Duct banks, electrical bus ways, conduit, telecommunications, and various other components were constructed using an on-site, stick-built method which failed to capitalize schedule and cost savings potential. In order to stay on schedule, The Turner Construction Company has decided to bring in more tradesmen and employ extra crews during the week and weekends. These overtime crews include mechanical piping installers and plumbing trim-out crews which resulted in an additional cost of approximately $40,000. These delays and added costs could have been avoided if the MEP systems were fabricated at an off-site facility and then transported to the construction site rather than applying the typical stick-built on-site methods. This application will result in several benefits which include cost savings from reduced labor and prevention of overtime, greater productivity, safety, quality and efficiency of materials which will result in greater material savings. After conducting a thorough analysis it is clear that the original duration for MEP installations of 602 days could be reduced 113 days to 451.5 days. Reducing these durations would result in a savings in general conditions costs by reducing it from $3,256,205.96 to $2,442,154.47 which is a savings of $814,051.49. implementing prefabrication to the MEP systems would also result in labor savings due to the off-site prefabrication. It went from $17,213.44/8-hour day to $10,336.00/8-hour day which resulted in a labor wage savings of $6,877.44/8-hour day. It is based on the opportunity for capitalizing on these benefits that I recommend this initiative be applied to the Concordia project.

Analysis # 4: Alternate Roof System

The Concordia Hotel employed two different roofing systems, a green roof and a series of highly reflective pavers in different areas. While installing a green roof to 2000 S.F. of the 8597.97 S.F. roof has its benefits it resulted in exorbitant structural reinforcements to the top and bottom of the roof slab. In consideration of the implementation of the cool roof system to the roof level a structural consideration of the existing structural members was made and it was determined that they are capable of supporting the much lighter cool roof system. Therefore, the cool roof's application would reduce the required CFRP installation, which resulted in a total cost of $62,208.00 for the labor and materials associated with its application. This analysis also considered the mechanical influences that a green roof would have over a cool roof system. The green roof was much more thermally efficient, however, it only resulted in an annual energy savings of approximately ten dollars. The cost of the green roof at $14.00/S.F. resulted in a cost of $28,000.00, this could have been drastically reduced since a cool roof costs significantly less around $7.36/S.F. which would cost $14,720.00. It is based on these details that my recommendation is to apply this roof type to the Concordia Renovation project since it will result in an overall savings of the implementation of the cool roof system would result in a savivngs of $75,488.00.

The analysis areas researched within this report were all determined to be incredibly advantageous to the Concordia Renovation project team, specifically in addressing the schedule concerns. While this report provides results that serve as a benchmark for typical construction practices they provide an even greater foundation for providing insight into the industry of the challenges and corrective practices which are gaining greater prevelance in the construction industry. It is hoped that this report will help me in my future career as a project engineer with my employer.

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