Emory University
Psychology Building

Atlanta, Georgia

Final Report

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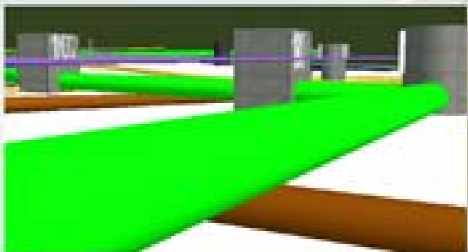
EMORY UNIVERSITY PSYCHOLOGY BUILDING
ATLANTA, GA

PROJECT OVERVIEW
-Higher education building
-Guaranteed maximum price of $35,029,000
-Construction Schedule: October, 2007 – February, 2009
-Seeking LEED Silver certification upon completion
-Use of Building Information Modeling for site coordination and MEP clash detection

PROJECT TEAM
Owner – Emory University
Construction Manager – Holder Construction
Architect – HOK Inc.
Civil Engineer – Travis Pruitt & Associates
MEP Engineer – Nottingham Brook and Pennington
Structural Engineer – KSI Structural Engineers
Lighting Design - CD+M Lighting Design Group



ARCHITECTURAL FEATURES
-Granite and stucco exterior backed by CMU
-Glazed curtain wall on east facade overlooking outdoor plaza
-5 Stories above grade plus a mechanical penthouse
-Red clay tile roof covering mechanical penthouse, modified bituminous membrane roof system over flat roof
-Contains labs, classrooms, and offices of Emory's Psychology Department

MEP SYSTEMS
-4 Rooftop AHUs ranging from 4,900 CFM to 55,280 CFM
-Variable air volume terminal units for individual room temperature control
-Steam and chill water utilities tapped into from campus
-19.8 kV electrical utility feed from campus stepped down to 480/277 V
-Some systems stepped down again to 208/120 V 3PH
-300 kW 3 PH 480/277 V diesel generator in electrical service yard
-Typically fluorescent lights with occupant sensors for power savings
-Sprinklered with wet pipe system

STRUCTURE
-Foundation of drilled piers up to 63' deep and 3' to 4' in diameter plus 4' thick grade beams
-5" concrete slab on grade plus 4, 5" concrete slabs and 6" concrete roof slab
-5 Stories cast-in-place concrete beams and columns w/ post-tensioned girders
-Structural steel to support clay tile roof ranging in size from W12x16 to W18x55
-Retaining wall along east facade under curtain wall

EMORY UNIVERSITY

Christopher Renshaw Construction Management

Executive Summary

The Emory Psychology Building is a 119,000 square foot academic building for Emory University in Atlanta Georgia. It has a total of five stories as well as a mechanical penthouse. The project started in late October, 2007 and completed major construction in March of 2009. Emory selected HOK as the architect for the project and Holder Construction as their construction manager. Emory and Holder agreed on a $35,029,000 guaranteed maximum price for Holder to deliver the project. Emory is pursuing LEED Silver certification for this building and is currently the leader among universities for buildings with LEED certification.

Building Information Modeling (BIM) was implemented on this project by HOK and Holder Construction. It was not planned to be a BIM project by Emory and was not a requirement of the architect or construction manager. BIM was used to aid in design and visualization by HOK. Holder used BIM for planning, estimating, scheduling, visualization, and MEP clash detection. Emory was pleased with the use of BIM on this project and will further promote BIM usage on their projects in the future.

This report will assess unique aspects of BIM on this project. It will also provide a study of other construction managers BIM applications throughout the construction industry to determine the state of BIM use around the country. The construction managers involved in the study are considered to be well ahead of the curve in terms of BIM implementation and share their experiences of how they go about using BIM on their projects. Recommendations will be given to conclude the BIM study based on the industry member's responses.

A study on how or if a green roof would have been beneficial for the Psychology Building is also included. The overall green roof benefits are first identified to determine how a green roof could make the building friendlier to the environment and if the green roof has the potential to save the owner money. A green roof system was then selected and applied to the building to determine the direct affects of the change in roofing system.

The first study on the direct affect of the green roof will be on the existing structural system. The green roof is a very heavy system which will add a significant load to the building's structure. The structure will have to be modified to support the additional weight. The affects of the changed structure on the budget and schedule will be analyzed to determine indirect affects of the green roof.

The next study will be on mechanical system load reductions achieved by the green roof. The green roof is expected to help cool the building in the summer which will reduce the amount of air conditioning required in the building. The extent to which the green roof reduces the load and accompanying energy costs will be analyzed on an annual basis. The energy costs will be incorporated into a study of the life cycle costs of the both the proposed green roof and the designed white roof. Both roof's costs will be projected over 50 years to include installation, maintenance, energy, and re-roofing costs.

The last analysis will be the affect that the green roof has on the current LEED rating. The addition of a green roof has the potential to add LEED credits to the building's current score and push the building from silver to gold certification. Finally, the green roof's ability to benefit the Psychology Building will be analyzed and a recommendation will be made to either add a green roof or keep the current roofing system.

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1.0 Project Overview

The new Emory Psychology Building is a 119,000 square foot facility which will house labs, classrooms, and offices of Emory University's Psychology Department. There are five stories above grade plus a mechanical penthouse covering half of a sixth story. The building follows the traditional stucco and clay tile roof style of Emory's campus but adds a hint of modern design with a glazed curtain wall along the east façade.

Figure 1.1 Psychology Building on Emory Campus.

1.1 Client Information

The owner of this project is Emory University. Emory is a private liberal arts school located in Dekalb County, Georgia, a part of Atlanta. They have an excellent academic reputation and strive to provide the best learning environment possible for their students. Emory understands the need for environmental awareness and currently they have more LEED-certified buildings than any other university in the United States.

The new building is being built to house the psychology department. Currently the department is spread all over campus and this new building will bring them all under one roof. The building is strategically located in the newly planned science commons along with a chemistry building. The chemistry and psychology departments are both strengths of Emory and the close proximity allows for free flow of ideas from department to department.

The construction manager on this project, Holder Construction, has worked with Emory many times in the past. During those projects Holder gained the trust of Emory and that trust has helped make the Psychology Building a very successful project. Since they have a good relationship, cost and schedule are monitored heavily, but quality is the main focus of this project. Emory expects the same quality and efficiency that they received on previous projects for their new building. In addition to Holder's internal quality assurance actions, they must follow the Emory College Standards and Emory Campus Services Standards in their efforts to provide an exceptional product.

Emory does not plan to move into the building until after substantial completion. Most of the psychology department will not even move in until a couple of months after that in May. The building will not be fully occupied and used until the Fall Semester of 2009.

1.2 Local Conditions

Like many universities, Emory's buildings look very much alike and all have basically the same look of limestone or granite dimensional stone, stucco, and a clay tile roof. They usually have a structure of concrete with steel to support the roof, like the new Psychology Building. The curtain wall on this building will set it apart from the traditional style and showcase Emory's dedication to innovation and the future.

1.2.1 Soil Conditions

The new building's foundation will vary because of the inconsistent depths of bedrock underneath the footprint. The drilled piers of the foundation extend to the depths of the rock and are located mostly under the central and western areas of the building. They are as deep as 63'-0" in some places, but luckily there were no issues with the water table, even at that depth. Under the east façade of the building, the shallow rock depth allowed for grade beams as a foundation.

1.2.2 Site Restrictions

Emory's campus is urban and due to area restrictions on the site, workers have to park off site in a remote lot about one mile away. The on-site subcontractors are each allowed one parking spot on the site and hire a shuttle to get the rest of the workers to the job. The parking fees were about $65/month/spot, so most subs accounted for parking in their pricing.

1.2.3 Regional Factors

Atlanta is located in the southeastern United States and is subject to very warm temperatures and humidity. Temperatures are uncomfortable in the summer, but the climate is mild and easy to work in during the spring and fall. The winters are not as warm and snow is rarely an issue. The south is also associated with lower costs, and construction is no exception. Based on RS Means Data[1], Atlanta's costs are about 90% of what the average for the rest of the country would pay. Based on data collected from local businesses, a typical 30 yard, six ton dumpster will cost between $350-$375 per removal, which is consistent with the RS Means Data location adjustment. For the psychology building Holder has implemented onsite recycling and does not pay any additional fees associated with recycled material.

1.3 Site Plan of Existing Conditions

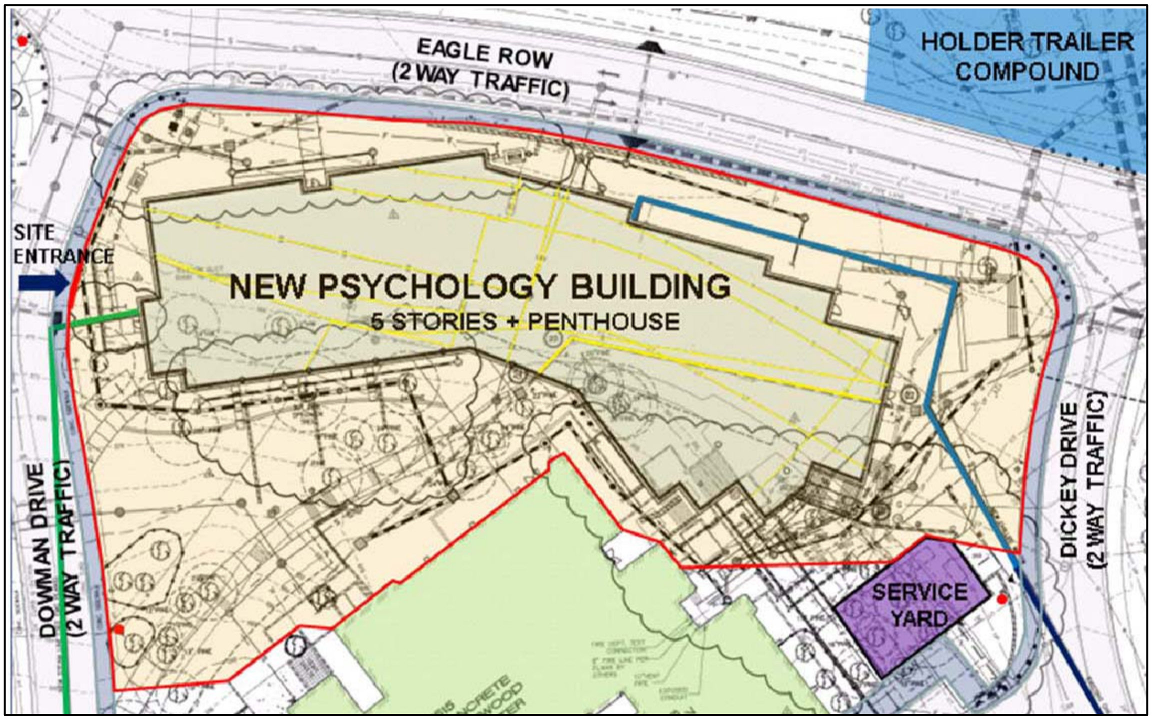


Figure 1.2 Site plan of existing conditions.

The site of the Emory Psychology Building is very tight. It is constricted by three roads, Dickey Drive to the north, Dowman Drive to the south, and Eagle Row to the west, and the Atwood Chemistry Building to the east. The building footprint takes up a large portion of that space. Also, since there is a building making up one border, Holder must be careful not to damage or disturb the occupants of the neighboring building. There are several underground utilities on the existing site which will have to be relocated. Due to site limitations, the trailer compound will be located across from Eagle Row Rd. There is two-way traffic on Eagle Row as well as the other roads which may make deliveries problematic. Please see Appendix A for the full site plan of existing conditions.

1.4 Construction Site Layout Planning

The limited space forced Holder to set up the field offices west of the site, across Eagle Row. That space occupies field office trailers, some storage, and a limited amount of parking. Each subcontractor is allowed one spot in that area for a worker shuttle van. The van transports the building workers from the site to a remote parking area, about one mile away. Holder's staff and limited subcontractors are allowed to park near the field offices. A superstructure site plan is provided to show more detail of the site during that phase of construction.

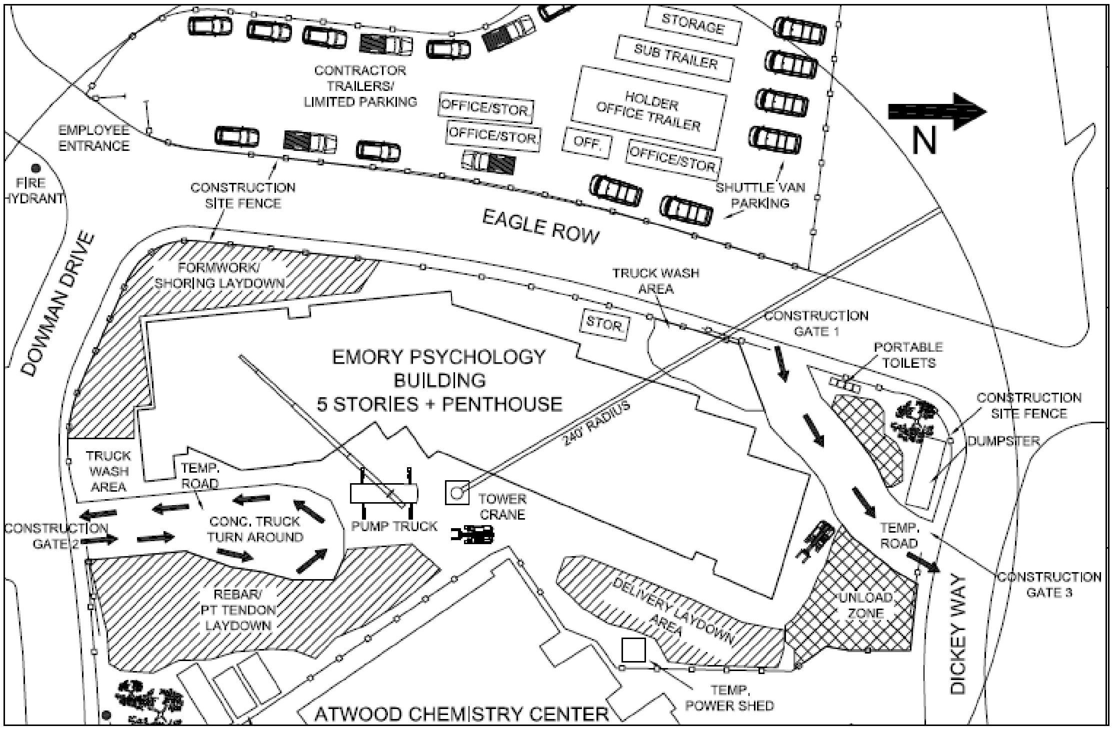


Figure 1.3 Superstructure Site Plan.

While the structure is going up, the site is very congested. Concrete trucks need to have constant access during the pours, but deliveries also have to come in. For that reason it is very beneficial that this site has three entrances. The temporary road on the Northwest corner has been modified since excavation to fit around the building footprint and the other road is extended and widened to allow concrete trucks to turn around. There are wash down areas next to the exits for the concrete trucks to get cleaned off before returning to the roadways. The pump truck is mobile and stations itself outside the temporary roads for easy access. Also, the formwork and shoring for the slabs takes up a lot of room on site. By this time the tower crane with a 240' operating radius has been brought on site and erected. The large radius allows the crane to pick anything on the site. Temporary power is pulled from the Atwood Chemistry Center. Large forklifts help move material from delivery areas to lay down areas. Please refer to the full site plan located in Appendix B for more information.

1.5 Building Systems Summary

The following table provides a brief overview of the scope of work contained on this project.

YES	NO	Work Scope
X		Demolition Required?
X		Structural Steel Frame
X		Cast-in-Place Concrete
	X	Pre-cast Concrete
X		Mechanical System
X		Electrical System
X		Masonry
X		Curtain Wall
X		Support of Excavation

Table 1.1 Building system scope.

1.5.1 Demolition

Although there were no buildings on the existing building site, some demolition still had to be completed along with the excavation. Most of the demolition included removal and relocation of underground utilities. These included gas, storm, water, and sanitary sewer lines as well as man holes and duct banks. The only structures that needed to be removed were a site wall, slab, stair, and pavement connected to the adjacent Chemistry Building. Tree removal and relocation was coordinated with Emory.

1.5.2 Structural Steel Frame

The structural steel on this building is used only as support for the penthouse roof. A braced frame is used as well as wide flange beams ranging in size from W12x16 to W18x35. Channels along the outside perimeter of the roof make up the last part of the structural steel. The steel was partially set by the tower crane already in place for the concrete, and partially by a mobile crane. The steel erector used both to expedite the installation process.

1.5.3 Cast-in-Place Concrete

This building's primary structural system is cast-in-place concrete. The foundation consists of drilled piers for deep foundations, and grade beams for shallow foundations. The drilled piers average about 40 ft. deep and range in diameter from 3 ft. to 4 ft. The grade beams are 4 ft. thick and support the east façade of the building. The columns, beams, and slabs of the superstructure are all cast-in-place concrete with steel reinforcing. Slabs are typically 5 in. thick. Post-tensioning was used for the girders that support the beams for added support. A crane was used to place the concrete.

1.5.4 Mechanical System

There are 4 penthouse air handling units (AHUs) for this building. Each unit is a different size ranging from 4,900 cubic feet per minute (CFM) to 55,280 CFM for a total of 104,380 CFM. There is also an outdoor air energy recovery unit (ERU) that helps to cool/heat the outside air using stale indoor air, depending on the season, to save energy in the AHUs. Outdoor air is supplied through perforated panels from the plenum under the large roof overhang. The units are fed from 6" chilled water pipes from the campus, which decrease in size as they enter the building. The campus pipes enter on the west side of the building and run up a chase on the west side to the mechanical penthouse. The steam is also fed from the campus. The steam enters on the south end of the building and runs up a chase in the south stairwell to the mechanical penthouse. The penthouse also contains two unit heaters for heating water.

Each room in the building contains a variable air volume (VAV) unit to allow for individual room temperature control. There is a thermostat in every room that works with the VAV to control the temperature of that room. The VAV controls how mch air it will supply from the return air and supply air since they each enter the VAV at different temperatures. They are mixed based on a percentage determined by the VAV to provide the room with the desired temperature. A large air conditioner, separate from the rest of the building, will serve the functional magnetic resonance imaging (fMRI) room.

1.5.5 Electrical System

The Psychology building is fed by a 19.8 kV utility from Emory's Campus. There is a service yard located just outside of the NE corner of the building that takes in the 19.8 kV from campus and steps it down to 480/277V before entering the building. From there the power is distributed to 2 electrical rooms on each floor. Once the power gets to the electrical rooms, it is either sent to various panel boards on that floor, or stepped down again to 208/120 V and sent out to panel boards on that floor. The service yard also houses a 300 kW 480/277 V generator to account for any utility power outages. In the future, the Psychology Building and Chemistry Building will share the service yard for incoming electric service.

1.5.6 Masonry

The north, south, and west exterior walls of the building are all backed by 8" CMU. The first floor and half of the second floor of these walls are each clad with limestone dimensional stone. The rest of the façade of each of those walls is clad with stucco. There is also a small amount of limestone with CMU backing on the east façade.

1.5.7 Curtain Wall

Almost the entire east façade of the Psychology Building is a glazed curtain wall. The curtain wall is comprised of aluminum infill panels and solarban 60 glass. Solarban 60 glass reduces heat gain while allowing visible light to pass through which is perfect for the hot climate of Atlanta. There are also similar curtain wall constructions on the north and west facades, but are on a much smaller scale.

1.5.8 Support of Excavation

There was very little support necessary for this project; however, there is a retaining wall on the east side of the building that required shoring. Soldier beams and lagging were used for this part of construction to hold back the soil.

1.6 Project Cost Evaluation

The following table displays the total building cost, project cost and major systems costs for Emory's Psychology Building.

Item	Cost	Cost/SF
Sitework/Site Utilities	$ 3,026,243.00	$ 25.42
Foundations/Structure	$ 5,202,505.00	$ 43.70
Building Skin	$ 5,958,134.00	$ 50.05
Interior Construction	$ 4,606,691.00	$ 38.70
HVAC/Plumbing	$ 5,329,653.00	$ 44.77
Electrical	$ 4,263,367.00	$ 35.82
General Conditions/Fee	$ 2,409,406.00	$ 20.24
Building	$ 32,002,757.00	$ 280.05
Total Project	$ 35,029,000.00	$ 294.27

Table 1.2 Costs and Costs/SF by system.

The building cost is the total project cost minus landscaping, excavation, and site utilities, etc. costs. Basically it starts with the foundations and includes everything from there on. As you can see, the building estimate came in at just over $35 million.

1.7 Project Schedule

This project schedule breaks down the Emory Psychology Building by phase of construction and activity. The major phases for the building are the substructure, superstructure, exterior skin, first through fifth floor interiors, and MEP installation and start up. The schedule can be found in Appendix C.

1.7.1 Structure

Since the building footprint is basically divided into two wings, the schedule is divided into two sequences per floor. There is a north and south sequence starting with the foundation and continuing through to the penthouse steel. The work flow starts with the south sequence, and then moves to the north sequence, then to the south sequence of the floor above. The building tops out on June 12, 2008.

1.7.2 Exterior Skin

The first and second floor masonry are each done as one sequence. Next the masonry gets completed on the third through penthouse floors starting with the south and moving to the west, and then north. The stucco finish and windows follow a similar path on those facades. Meanwhile, the curtain wall is installed on the south, then the north of the east façade. The roofing is also installed while the facades are being completed. Since the west façade is so large, it takes the longest to complete and the building is not dried in until it is complete on August 8, 2008.

1.7.3 Interiors

The interior flow of work is pretty standard for the Psychology Building. Each floor is treated as one sequence, unlike the structure. The sequence starts with MEP rough-in, and then moves to framing, distribution, and finishes. Most of the interior work moves up through the building, first floor through the penthouse. The finishes do not. The second floor of this building is the main floor and contains a lot of higher end finishes. The owner, Emory, was making last minute changes on the design of the second floor interior. To prevent any schedule delays, Holder decided to change the schedule of the finishes so that the sequence was first floor, third through fifth floors, and then second floor. This way, Emory has the longest amount of time possible to make their decisions.

1.7.4 Schedule Summary

The total duration for the Psychology building is 352 working days. That equates to 70 weeks of construction, or just over 16 months. The schedule milestones of the Emory Psychology Building are:

- October 19, 2007 – Building Permit Received
- October 23, 2007 – Site Work Begins
- June 12, 2008 – Top Out Structure
- August 1, 2008 – Permanent Power
- August 8, 2008 – Building Dry in
- August 15, 2008 – Conditioned Air
- March 3, 2009 – Substantial Completion

1.8 Project Delivery System

Holder Construction is an at risk construction manager for this project. They assume some risk because they are performing the concrete work for the project. Emory holds a Guaranteed Maximum Price (GMP) Contract with Holder, and they hold similar contracts with the mechanical and electrical contractors. The rest of the contracts are lump sum. The architect has a separate contract with Emory. Holder communicates with the architect only for RFIs and things of that nature; they do not have a contract. The figure on the following page displays the project team hierarchy and the contracts held between parties.

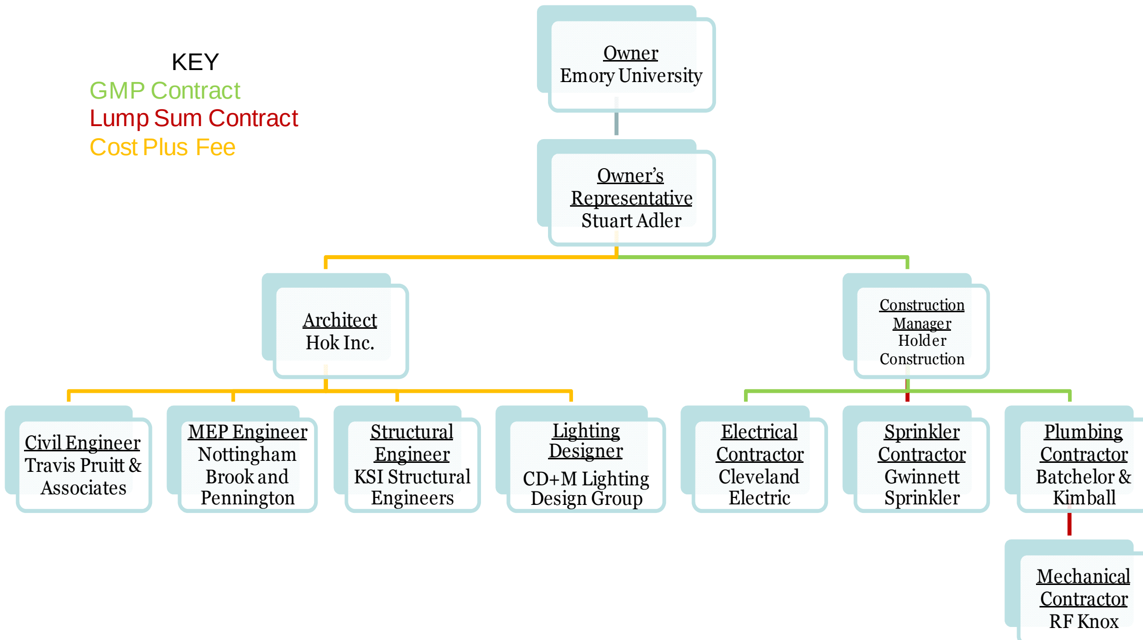


Figure 1.4 Project team hierarchy.

Holder was selected by Emory over other contractors after responding to Emory's Request for Proposal. Subcontractors were selected based on price, reputation and past performance when working with Holder. The owner mandates that the subs participate in an Owner Controlled Insurance Program (OCIP) that is held by Marsh Inc. Each sub submits their forms and information to be reviewed for safety performance. After they are approved, they receive a certificate of insurance issued by Marsh Inc. The contracts, insurance, and selection methods were all fairly standard for a University building of this size and scope.

1.9 Staffing Plan

Holder Construction assigns separate responsibilities to the field supervision, pre-construction services, and management staff with a project executive and a project director to oversee the whole project. All of the pre-construction services are performed by a team at the Holder home office. The construction services have their own operations team. For this project as well as most Holder projects there is a project manager and superintendent at the site at all times.

1.9.1 Project Management Staff

The project management staff primarily deals with cost, procurement, and material delivery status. They settle most issues that arise from the offices of the subcontractors. The project engineers typically are given trades as their own to manage and report their work to the project manager. They also are responsible for most of the paperwork including RFIs, submittals, change orders, etc. The smallest scope trades are assigned to the project engineer, larger scope trades to the senior project engineers, and the largest scope trades may be run by the project manager. The project manager brings all of their information together to assure that the project will run smoothly.

1.9.2 Field Supervision

The superintendent is responsible for maintaining the schedule, quality assurance, and safety. His job is to oversee work and help subcontractors with large scope planning between other subcontractors. He also collects daily reports from subcontractor's foremen and deals with day to day issues that may arise in the field. The Sr. Field Engineer assists the Superintendent and also is responsible for layout work on the site. The Safety Coordinator is walks the job and makes sure that all of the workers will be safe; he also runs weekly safety meetings. The hierarchy of the entire construction management team can be seen in the figure below.

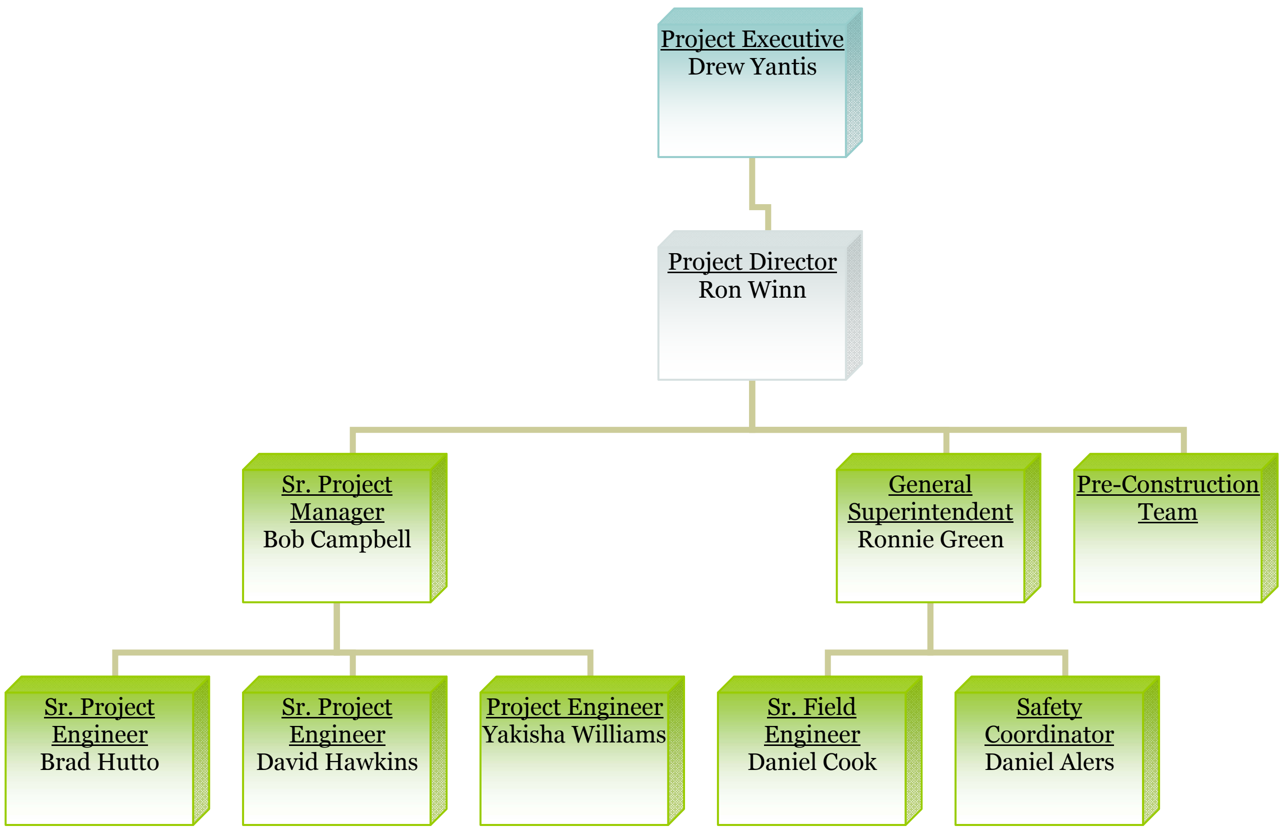


Figure 1.5 Holder Construction project staff hierarchy.

1.10 General Conditions Estimate

General conditions costs are costs that are not actually caused by work done on the project. The main portion of the general conditions is staffing costs for the construction management or general construction team. The team members bill how much time they work on the project to the owner. Most people are on site full time but some upper management people divide their time between a number of projects and do not bill their full salary. Items like telephone bills, internet service, and temporary utilities also need to be planned for and paid for during construction. In order to estimate the general conditions costs of the Emory Psychology Building, time and local rates were considered. Then each item was given a dollar amount based on previous knowledge and general estimates from Holder Construction.

1.10.1 Cost Evaluation

The general conditions cost of this building is estimated to be $1,374,100.00, which accounts for approximately 3.93% of the total building cost. The percentage shows that it is a pretty accurate estimate of typical general conditions on a project like this. Of the total general conditions, about 77% of the costs are from staffing, which is also pretty standard in terms of percentage. As a way to manage the general conditions, they were broken down into 4 categories, staffing, temporary utilities, safety, and any other items that fall under general conditions.

1.10.2 Staffing Costs

Almost everyone included in the staffing costs are on-site at all times at Emory. The only two people who are not are the project executive and the project director. In the following table, they are identified with asterisks. It was determined that the project director will most likely be splitting his time between Emory and another similarly sized project. Therefore, his total price per unit cost is halved to represent half of his time spent at Emory for the duration of the project. The project executive has his time split between two other similarly sized projects and is represented in the general conditions similar to the project director. The rest of the people bill their full weekly amount to Emory for their time on site, which varies. Some people do not join the project until the structure goes up, and others leave during the close out phase. The number of weeks next to their title represents their time on site in the table below.

Staffing	*Qty.*	*Unit*	*Price/Unit*	*Price*
Project Executive*	72	Wks	$ 1,200.00	$ 86,400.00
Project Director*	72	Wks	$ 1,550.00	$ 111,600.00
Sr. Project Manager	70	Wks	$ 2,800.00	$ 196,000.00
General Superintendent	68	Wks	$ 2,800.00	$ 190,400.00
Sr. Project Engineer	65	Wks	$ 1,700.00	$ 110,500.00
Sr. Project Engineer	72	Wks	$ 1,700.00	$ 122,400.00
Project Engineer	64	Wks	$ 1,200.00	$ 76,800.00
Sr. Field Engineer	70	Wks	$ 1,500.00	$ 105,000.00
Field Office Processor	72	Wks	$ 800.00	$ 57,600.00
			Total	**$1,056,700.00**

Table 1.3 Staffing costs.

1.10.3 Temporary Utilities Costs

During construction different utilities are necessary for various tasks. It is Holder Construction's responsibility to pay for these utilities while under construction. All of the utility bills come on a monthly basis, but Holder will not have to pay for all the utilities for the duration of the project. The internet and trailer temporary power are the only two items that need to be paid for during the entire construction process of November, 2007 to March, 2009. The cost per month is averaged over the entire 17 months. Most of the rest of the items can start into December, 2007 and can be billed for one less month. The temporary power duration is 12 months since the building will have access to permanent power in August, 2008, but there will be some overlap in the use of temporary and permanent power. The table below details the temporary utility costs.

Utilities	Qty.	Unit	Price/Unit	Price
Temporary Water	15	MO	$ 350.00	$ 5,250.00
Temporary Power	12	MO	$ 1,000.00	$ 12,000.00
Phone Service	16	MO	$ 1,200.00	$ 19,200.00
Trailer Sewer Service	16	MO	$ 300.00	$ 4,800.00
Temporary Toilets	15	MO	$ 1,250.00	$ 18,750.00
Trailer Internet Service	17	MO	$ 350.00	$ 5,950.00
Trailer Temporary Power	17	MO	$ 250.00	$ 4,250.00
			Total	**$ 70,200.00**

Table 1.4 Temporary utility costs.

1.10.4 Safety Costs

Safety is paramount to any contractor and Holder is no exception. Holder's safety program, or Zero Accident Culture (ZAC), is incorporated on every project, no matter how large or small. Holder employs a full time safety coordinator to make sure all employees are safe on-site and follow all of the site safety rules. The coordinator is billed in this section since he is an hourly worker and not included with the salaried Holder employees. His time is averaged as 50 hours per week and includes any overtime. General safety measures include meetings, safety equipment for Holder employees and visitors, and some visits and meetings with Holder's corporate safety director. Incentives are prices given to employees or companies who are doing an exceptional job staying accident free and working safe. The following table summarizes the safety general conditions.

Safety	Qty.	Unit	Price/Unit	Price
General	15	MO	$ 500.00	$ 7,500.00
Coordinator	70	Wks	$ 1,200.00	$ 84,000.00
Incentives	16	MO	$ 150.00	$ 2,400.00
			Total	**$ 93,900.00**

Table 1.5 Safety costs.

1.10.5 Other General Conditions Costs

The rest of the general conditions costs sum up anything else that Holder will have to pay for during construction. All Holder project managers and superintendents are given trucks and Holder pays for gas, insurance, and maintenance. Traditionally, construction sites will have parties for groundbreaking, topping out, and other major milestones. Holder plans to have these and also has barbeques and other functions for major holidays as a thank you to the workers. Office supplies and maintenance is another large cost. The table on the following page summarizes the rest of the general conditions costs.

Other	***Qty.***	***Unit***	***Price/Unit***	***Price***
Superintendent Truck	16	MO	$ 1,000.00	$ 16,000.00
Project Manager Car	17	MO	$ 1,000.00	$ 17,000.00
Tools/Other	17	MO	$ 300.00	$ 5,100.00
Job Parties/Meetings	6	LS	$ 1,000.00	$ 6,000.00
Signage	1	LS	$ 2,500.00	$ 2,500.00
Moving/Travel Expenses	17	MO	$ 800.00	$ 13,600.00
Computers/Tech.	16	MO	$ 2,100.00	$ 33,600.00
Office Costs	17	MO	$ 3,500.00	$ 59,500.00
			Total	**$ 153,300.00**

Table 1.6 Other general conditions costs.

1.10.6 General Conditions Conclusions

The final general conditions estimate came out to $1,374,100.00. A summary of the costs can be found in the table below.

General Conditions	***Price***
Staffing	$1,056,700.00
Temporary Utilities	$ 70,200.00
Safety	$ 93,900.00
Other	$ 153,300.00
Total	**$1,374,100.00**

Table 1.7 General conditions estimate.

Obviously, the staff's salaries make up most of the general conditions. This is fairly typical on a construction project. The rest of the general conditions are also typical for a project of this size and scope.

2.0 BIM Implementation (Depth Study and Critical Industry Issue)

2.1 Problem Identification

Recently, there has been a push in the construction industry toward Building Information Modeling. Unfortunately, it seems that building modeling has taken off while the "information" part has been left behind. Some designers have started to use 3D modeling in their designs while others have created 3D computer models from traditional 2D drawings. Construction managers are trying to implement the 3D models into their practices, but some are struggling with finding ways to use the model to its full potential. As a result, many construction managers are failing to see the benefits of the models that they had hoped for. Many managers understand that the potential is in the model but may see it as intangible.

2.2 Proposal

By talking to some of the more successful BIM users throughout the construction industry, there will be a clearer understanding of how BIM can be used. An analysis of how BIM was used on the Psychology Building will also be performed to see how the application of BIM measures up against other projects. The interviewees will be asked what sets them apart from other BIM users, how they determine when to use BIM, innovative BIM applications, and what they would or would not do again on future projects.

2.3 Goal

The goal of this analysis is to determine what methods construction managers are using to implement BIM on their projects. Also, the goal is to find out how different companies are using BIM, and how it has worked for them. The research could be shared by construction managers and influence how they use BIM in the future. The assessment will also be used to see how Holder's use of BIM for the Psychology Building compares with their peers.

2.4 Methodology

Interviews with the people using BIM will help determine:

- How and when to use BIM
- Successful applications of BIM
- Ways in which BIM can be used more effectively
- Problems with current BIM practices
- Lessons Learned
- BIM for the future

Four construction managers were included in this research, including Holder Construction, who used BIM on the Psychology Building. Each company was known to have used BIM and is considered to be ahead of the curve in terms of total usage and innovative applications of BIM on their projects. The Psychology Building's BIM use was thought to be innovative itself, so an analysis of the usage will be completed first.

2.5 Psychology Building BIM Process and Applications

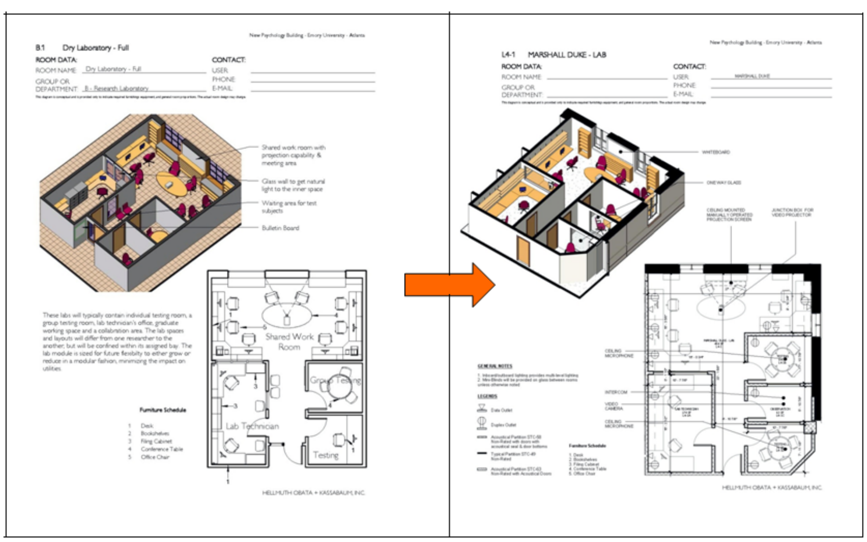
Although Emory knew about BIM and had used in on projects for their campus before, it was not selected as a BIM building and was not required in the architect request for Proposal (RFP). HOK, the architect was selected based on other factors for the project, and their intention to use BIM was a bonus. The RFP for the construction manager did not include a BIM requirement either, but like HOK, Holder decided to use BIM on the project.

2.5.1 Architect Implementation

HOK used BIM from the very beginning in the programming phase[2]. The programming phase is intended to gain an idea of what the owner expects from the building. HOK used BIM to help the end users visualize the space that they would be occupying. This process was previously done using 2D drawings, which was difficult for someone without a background in design drawings to understand. Emory expects a decline in post-construction changes because of the clearer design review between the architects and the building users.

2.5.2 Design Review

For the lab spaces, each individual Emory faculty member was allowed to pick the space that best suited them. The faculty members were able to see their space in 3D from HOK's Revit model and could determine what they needed and where they needed it. HOK was able to link the 3D room data sheets, created from Revit, to the model so that each room had the characteristics desired by the faculty member. The faculty members were then asked to sign off on the data sheet to make sure they understood what they would be getting. This process is usually done with 2D AutoCAD drawings and Excel spreadsheets and is much more complicated. Also, the information cannot be retained anywhere except on paper when using AutoCAD and Excel. The Revit data sheets retain the information throughout the entire design process. The figure below shows the original data sheets which the occupants saw, and the finalized construction document of the room.



Programming **Construction Documents**

Figure 2.1 Progression of design review sheet to actual construction document.

HOK also used the Revit model for "block and stack" review with the owner. They identified the needs of the building by square footage requirements and tried to arrange them into a footprint and onto separate floors. Each department or space is given a color and represented on a model to represent relationships between spaces and layout. The figure below shows the block and stack model created by HOK from Revit.

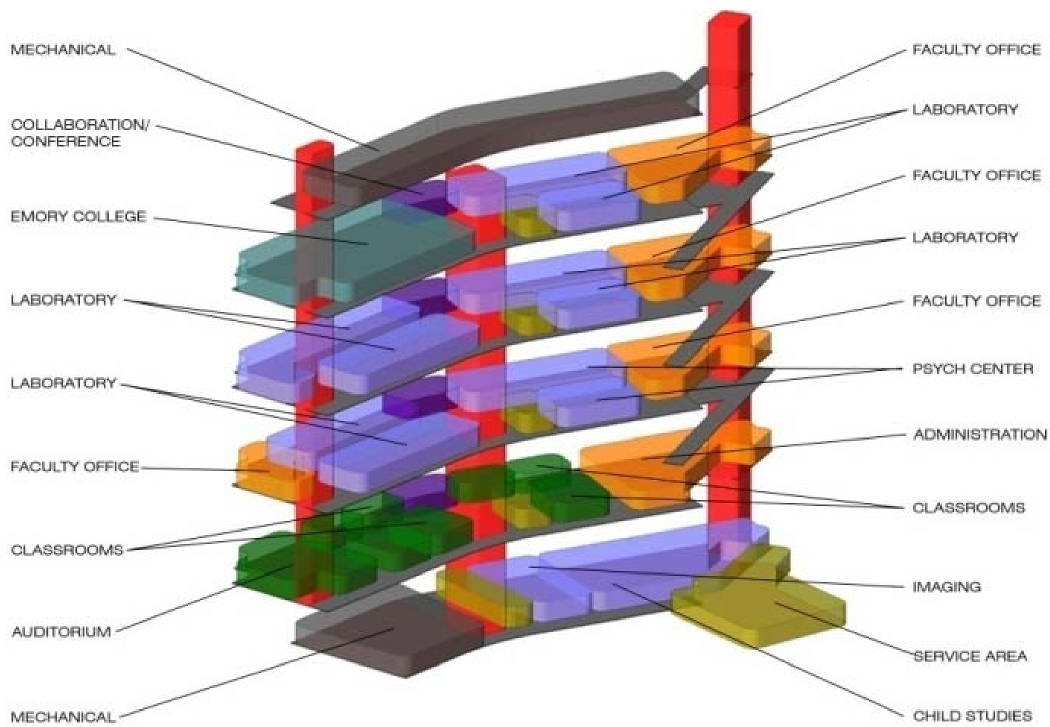


Figure 2.2 Block and stack model.

The block and stack also helped the MEP engineers. The engineers could see where the lab spaces, which needed more intensive mechanical systems, were located and could incorporate that into their preliminary design. The engineers could also specify more lighting or whatever was need for given spaces.

HOK linked data sheets to all the rooms in building. By doing this they were able to keep track of inventory for the building such as casework, equipment, owner provided materials, or anything else in the building. Revit was able to generate reports for all of these items based on what was in the model.

The 3D model also helped the architect decide what materials to use for the façade. The renderings that they could create much earlier in the design process gave an accurate representation of what the building was to look like. The figure on the following page shows the architect's studies of façade options on the Psychology Building.

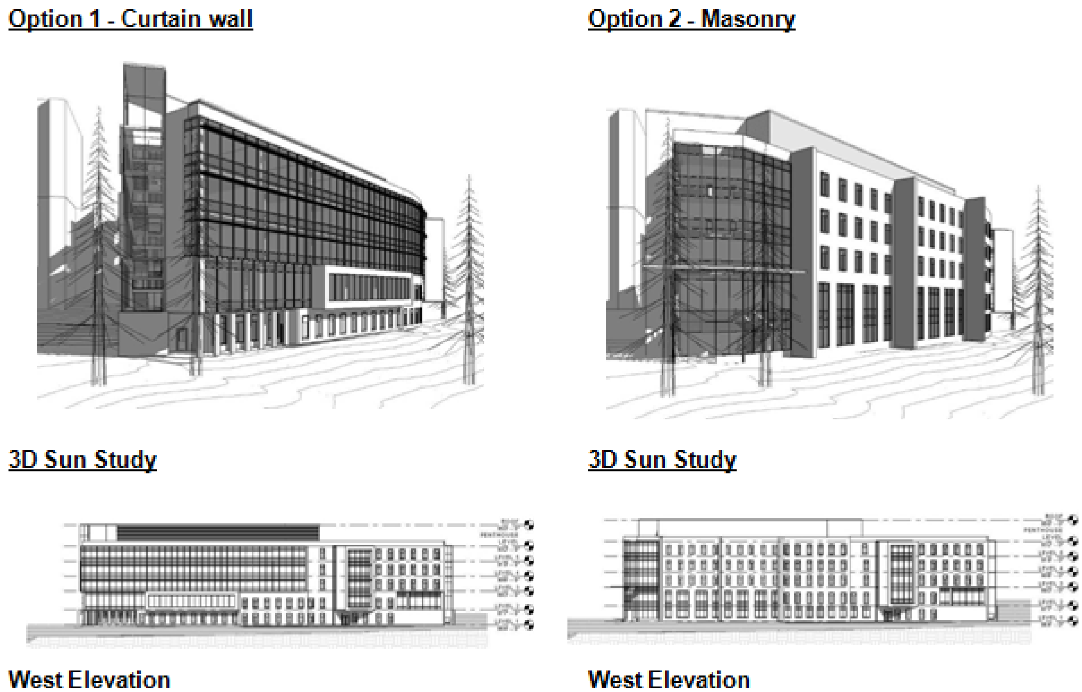


Figure 2.3 HOK façade determination study.

A daylight study directly impacted the building design. To use sunlight more effectively, HOK reduced the building height, reduced the amount of glazing on the west elevation of the building, and changed the mechanical penthouse. Images of the study can be seen below. In addition to studies like this, HOK used Revit to do preliminary clash detection, print renderings, and allowed Holder to use the model for preliminary estimates.

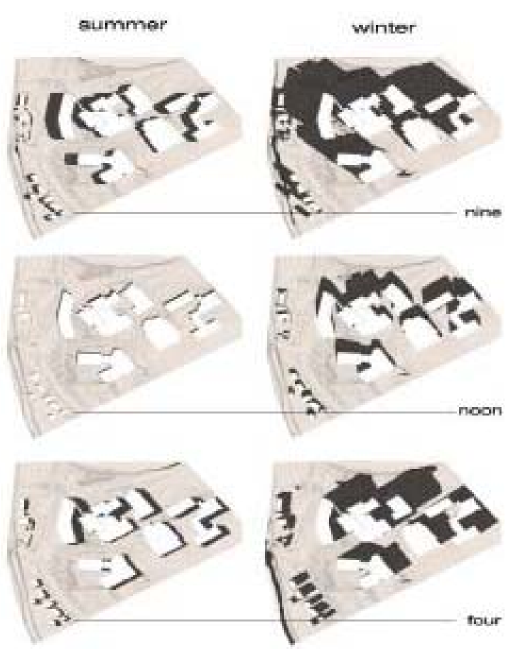


Figure 2.4 HOK sun shading investigation.

2.5.3 Integrated Project Delivery

MEP subcontractors were brought in during the design development phase of the project, which is much earlier than usual. The RFP to the subcontractors required them to have or purchase Navisworks and provide 3D coordination. This was crucial because the MEP engineers did not design in 3D, but the subcontractors were able to create the model early from their drawings. Also, the subcontractors were able to get used to the coordination software during the design phase and not during the construction phase, which may have caused schedule delays. The structural model was created by Holder from the structural engineer's 2D drawings.

2.5.4 Coordination

Holder also provided an FTP site on their website to ensure that each contractor or designer was working with the latest drawings. After updating their models, the files were uploaded to the FTP site. On Friday mornings, Holder held coordination meetings that combined the files in Navisworks and ran clash detection. The contractors also coordinated their models among themselves to reduce the amount of clashes during the weekly meetings.

2.5.5 Cost Estimation

HOK kept inventory of the equipment and other quantities in the model and allowed Holder to use that do estimate the cost of the Psychology Building. Holder used performed the estimate using the software program Quest, which has been customized to their needs. Holder claimed that they benefited from the accuracy of the model and the speed at which quantities could be developed. They also estimated the quantities using Oncenter estimation software. There was only a 1% variance between the two estimates, proving that the BIM take offs are just as accurate but much faster than traditional methods. The accuracy especially helped to eliminate waste by providing exact quantities instead of mark ups and other time saving methods. Holder also used the quantity take offs to validate subcontractor estimates. The figure below is an example of how quantities can be taken of from a computer model

Figure 2.5 Quantity take off from building model (Note: This is not the Psychology Building).

2.5.6 Prefabrication

The only prefabrication that used the BIM model was by the mechanical contractor for the mechanical penthouse steel piping. They used the detail of the model to create spool sheets to send to their shop. They can then cut the pipe at the shop and reduce the amount of labor done on site.

2.5.7 Construction

Holder created a BIM field coordinator position on their project team to work with the BIM model and trade contractors. The weekly coordination meetings continued onsite during the construction phase. The 2D drawings were still used as the contract documents and on-site review was done with all 2D drawings. The model was still available for visualization and used in the weekly coordination meetings. The BIM model was also used for sequence planning. It was linked to the project schedule through Navisworks Timeliner.

Having the coordination done early allowed for more efficiency during construction. For instance, the ceiling overheard MEP coordination was more accurate since the model was precise to the inch. This allowed MEP contractors to install hangers for their equipment while the structure was still being built without the fear of having to move something. Also, the areas around equipment that would need service were shown on the model and could be coordinated around. On a 2D drawing it would be difficult to see the blockage since it is not a direct collision. The problem would most likely have to be solved in the field after installation.

RFIs also were completed faster during construction. There were fewer RFIs since the model eliminated much of the confusion about design intent. If there was an RFI, an image of the problem on the model was attached with it so that it would be easier to visualize. The architect noted that it made the RFIs much easier to answer.

2.5.8 Post-Construction

HOK and Holder have verbally agreed to give Emory an As-Built model after construction although they were not contractually obligated to do so. These will come in addition to the standard 2D drawings. Emory hopes to be able to use the BIM for facility management after construction. There are still some problems they need to work out, like exactly what they need on the model and who will update the BIM once they have it. They see the Psychology Building as a pilot project, which they will use as a guide for the future. Emory predicts that in the near future they will require BIM post-documentation as they are moving toward BIM use campus wide.

2.5.9 Emory's Perspective

The Psychology Building project taught two main things to Emory for them to use on future projects. One is that BIM is the future, and that the innovations in technology have made them a major asset to the construction industry. The other is that Integrated Project Delivery (IPD) has the ability to streamline the design and construction process making coordination easier and the finished product better. The two main ideas go hand in hand. Both can help a project, but when used in conjunction they provide many benefits.

Emory sees BIM as something that can be used a lot in the future. Their view of BIM is: "Shoot for the stars but be flexible. Look at the various issues and determine if it is easier to do it the traditional way or use the technology. Don't use the newest way just because you want to be on the cutting edge of technology, do it because it is going to improve the process."

2.6 Other Construction Manager BIM Practices

Each construction manager was asked a variety of questions about BIM with the main points being:

- When they decide to implement BIM on a project
- How the model is created
- Uses of BIM
- If the uses have been successful
- Problems that they have faced with BIM
- Owner reactions

Their responses are summarized and can be found in Appendix D.

2.7 Similarities among Construction Managers

While interviewing the construction managers it became evident that there were many similarities among them. There were also some areas where they differed, or simply have had different experiences. A summary table of how the construction managers responded to 19 different criteria is located in Appendix E. The table also includes how the use of BIM on the Psychology Building relates to uses of other construction managers.

There were seven categories in which all of the construction managers generally had the same thoughts:

- BIM assessment has to be done as early as possible, usually while reviewing the RFP.
- When analyzing the payoffs of using BIM on a project, the other members of the project team and MEP complexity are typically looked at the hardest.
- Subcontractors are expected to create the model, or have the model created for their discipline.
- MEP clash detection is the primary use of BIM.
- Subcontractors may be hesitant at first toward BIM, but they eventually realize the same benefits as the CM and are happy with it.
- If the model is being used for estimation, it is not completely trusted and backed up by the tradition method of the manager.
- RFI's are decreased because of improved clarity, if there are RFI's, the model helps to display the problem and facilitates a quicker response

Two of the construction managers create the model within their own company and two do not. All of them have been successful with their BIM use. Architects rarely create a 3D model for their design. If the architect does provide them with the model, it is a benefit and a head start but otherwise the CM assumes that they will be creating the model.

2.7.1 Owner Reactions

Owner reactions are generally positive but the owners still do not know what to expect from the model. More and more owners are seeing BIM as something important for the construction industry, but they may not understand how it can help them. Even if they do know what they want, they still don't know how to ask for it. Increased awareness would help them get more out of the model. If not already trying facilities management programs and uses for the model, each CM had plans to. This seems to be the next big wave for BIM because it is something that can be a direct advantage for the owner.

2.7.2 Integrated Project Delivery

Thoughts in integrated project delivery and starting as early on the project varied. One CM was adamant about getting on the project early and believes that IPD is the best way to deliver a BIM project. Others said that it would help, but it is not crucial to the project's success. However, all of the construction managers agreed that getting on the project would help BIM because it would allow more time to add information to the model. Also, if early enough, being brought on early opens up the opportunity to use the model for estimation and 4D schedule visualization.

2.7.3 Material Tracking

Material tracking is being done by half of the construction managers. One has been using it a lot and sees it as one of the biggest assets of BIM for them. They have brought in technology from other industries and used it to their advantage for great success. The others either have no interest, or haven't had the type of project where they think material tracking will be worth the extra effort yet.

2.7.4 Individual Experiences

Each construction manager seems to be at different levels for implementing BIM. The levels do not necessarily mean that one is farther ahead than another, but each CM has definitely found their niche and taken off with it. They are also searching for other ways to use BIM, but there is some technology that they feel more comfortable with for their buildings. They are becoming comfortable with their software and are really starting to see the benefits of the BIM applications that they've implemented. The benefits that they see vary because of the different ways they use BIM. Each CM is in agreement that it is very beneficial and they only plan to use BIM more and more.

2.8 Schedule Impacts of BIM Implementation

Unfortunately there is no concrete way to quantify schedule savings on a project that has implemented BIM. This is one reason why BIM implementation is met with such hesitation; to convince the owners that BIM will work, the owner has to take the CM at their word that it will result in a better project. None of the CMs interviewed felt that the extra time spent developing the model caused any delays in the schedule. The time saved in the field due to the reduction in clashes more than makes up for time lost (if any) in the beginning of the project.

There is also a time reduction from the decrease in RFIs submitted on a project. If there is an RFI, there is something unclear, which means that activity must wait until the RFI is answered to be completed. With less RFIs, there is less time spent waiting. Also, RFIs can be sent with an image of the problem in the model to give the architect or engineer a better idea of what the problem actually is. This allows them to respond faster.

2.9 Cost Impacts of BIM Implementation

The initial costs of BIM remain high, but the construction manager's interviewed have felt that the initial costs pay off significantly, especially on large projects. The large projects have a higher initial cost, but the scale of the problems that they fix is so large that they payoffs can be enormous. One CM noted that even on smaller projects, the costs of modeling systems and running clash detection are less, so they can be just as beneficial, even on a smaller scale.

Owner's hesitation can limit the use of BIM on projects, but it doesn't have to. The constructions managers seemed willing to absorb the costs of BIM if they really think that it will have a positive affect on a project. The idea that new uses of BIM will eventually pay off, even if not on the first project that it is used must be the mindset. The company must be stable enough to be able to invest their money into a project when the payoffs may not come until the next project that they are able to use a particular application. Since the practices of MEP coordination and are becoming more common with these companies, it is likely that the money spent learning new uses will be offset by the savings realized from their typical BIM use. Basically, he companies have to have an open mind and be willing to try new things with the model. Based on current trends, it is highly likely that a new idea for the model will pay off.

2.10 Psychology Building BIM use vs. Industry

The use of BIM on the Psychology building was a huge success. One advantage that the Psychology Building had was that the architect designed in 3D and was more than willing to share and help out with the model. The IPD pushed the learning curve earlier in the project and the BIM use was at full speed by the time construction started. It also allowed the CM to use more with the model like estimating, sequence planning, and 4D modeling. MEP clash detection was used, as is becoming standard in the industry, and proved to be successful.

This project ranks among one of the more advanced for the industry right now with the amount that BIM was used effectively. This is also one of few where the architect used 3D modeling. There are other projects doing similar things, but not many that are using all the uses of BIM in one project like the Psychology Building. Also, the building ranks high among CMs interviewed for this study, which themselves are among the top BIM users in the country. The Psychology Building BIM uses are therefore very advanced for the industry as a whole and can be used as an example of how to implement BIM to success.

2.11 BIM Conclusions

Based on the interviews with industry members it is safe to say that BIM is the future of construction. While there are some small issues that are still being worked out, as a whole the industry members using BIM having nothing but positive things to say about it. The construction management companies all basically use the same BIM process although the individual applications may differ. The basic processes are:

1. Analyze the risks on a project by project basis while reviewing the RFP. Develop an idea of how BIM use may be beneficial early.
2. Create the model, or have it created. Load as much information on it as possible.
3. Use the model for MEP clash detection and determine if other areas would benefit that are currently struggling.
4. Provide an as-built model for the owner.

The third step is where there is the most disparity among the CMs. Each of them finds a use for the model which suits their individual project or company. The more uses that they can find for the model, the more pay back there will be on the initial investment. The success of the Psychology Building can be attributed to following these steps and developing a role of BIM which was appropriate for the project.

2.12 BIM Recommendations

From the interviews with different construction managers it was easy to see that the issues that they are currently having are common among the whole group. The following are recommendations based on their responses:

1. Keep an open mind for new uses of BIM, do not be afraid to try new things. Be willing to spend a little extra initially because it will likely pay off.
2. Trust the technology more. Estimating is a prime example where the managers are using the model but also traditional methods. The model has proven to work, still estimating with other methods adds costs.
3. Move to more integrated project delivery methods now while the technology is still new and still a learning curve, this takes care of problems before construction starts, not during.
4. Find a way to quantify cost and schedule savings. This is broad, but it is a major selling point and finding a way could lead to much more BIM consideration by owners.
5. Find a way to educate potential owners about how your company is using BIM even before they send out an RFP. Pre-education will limit their hesitations and they will be more likely to pay for BIM costs, which will in turn save both the CM and the owner money.

The last recommendation is a summation of all of these; invest in new uses now while the market is down. Invest in new technology and education of your company and who they will be working with. Educating subcontractors now will help you succeed in the future. After the market picks back up there will be more owners and more projects ready to go that may have been delayed. Using BIM on these projects will lead to faster, more economical construction.

3.0 Green Roof Analysis

3.1 Problem

Emory is seeking LEED Silver Certification for the Psychology Building and the credits have been achieved very efficiently. The only part of the building that may have not maximized its potential for LEED credits is the roof. Currently the roof is composed of a white modified bituminous membrane system. There is approximately 14,600 square feet of flat roof space. This analysis will determine whether leaving the space open was the best option, or if the space could have been used for a rooftop garden and been more effective in terms of sustainability and financially.

3.2 Proposal

If a green roof were a cost effective and sustainable option for the owner, they may have changed their decision on the roofing type. The green roof is expected to cost more initially, but over time, may prove to save money. This proposal will study the upfront costs, installation time, LEED credit attainability, structural impact, environmental impact, energy usage, and life cycle costs of both roofs to determine which has the most benefits.

3.3 Goal

The goal of this analysis is to determine which roofing system will be a better selection for the owner. Emory has a strong interest in sustainability and being a good environmental steward, but they also have to worry about costs. A green roof is known to lower energy costs and help the environment, but it also has a high initial cost. A life cycle analysis will determine which roof has the cost advantage. A LEED analysis will determine how well the roof serves the environment. If it performs well enough, the green roof may add enough LEED Credits to make the building Gold Certified.

3.4 Methodology

Several steps will be taken to determine if the green roof will outperform the current roof over time. These steps will be:

1. Study the benefits of a green roof.
2. Determine what type of green roof system will work best for the Psychology Building.
3. Calculate the structural impact of a heavier green roof on the structural system and determine what extra costs this will cause.
4. Determine the energy usage of air handlers due to the cooling load reduction of the green roof and develop an annual energy savings.
5. Analyze the sustainability of the green roof and what LEED credits it would be awarded.
6. Calculate the cost of the green roof as compared to the existing roof, including structural impacts.
7. Perform a life-cycle cost analysis which will take account of initial cost, energy costs, maintenance costs, and roof replacement costs to determine which roof will be more cost effective over the building's lifetime.

3.5 Benefits of Green Roofs

Green roofs for buildings have many benefits. The basic idea of a green roof is that it reduces the impact of the building's footprint by placing a natural surface on the roof. The natural surface can reduce runoff into stormwater sewers, naturally put back water into the atmosphere, reduce the heat on top of the roof, and provide extra insulation to help insulate the building. These basic measures provide several more benefits of the green roof such as:

- Reduction in the heat island effect
- Water quality improvements
- Energy conservation
- Increase in roof service life
- Reduction in sound reflection
- Improvement of roof aesthetics
- Creation of an outdoor public space

3.5.1 Heat Island Mitigation

The heat island effect is a phenomenon that occurs in cities due to the lack of vegetation and the increase in impermeable, dark surfaces like roads and parking lots[3]. As shown in the figure below, the heat island effect causes the temperature in urban areas to be significantly higher than the surrounding rural areas.

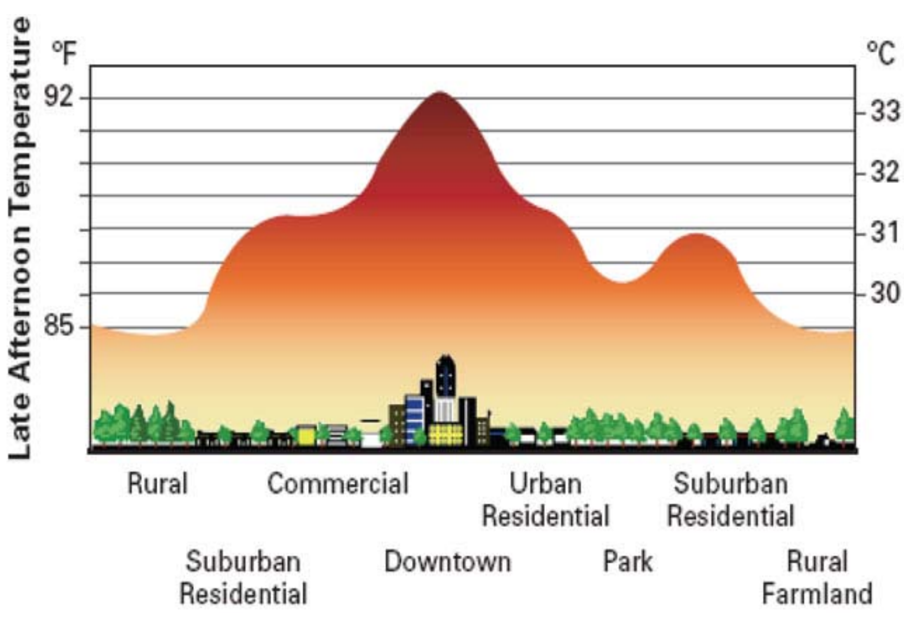


Figure 3.1 Heat island effect temperature concerns.

The higher temperatures cause poorer human and animal health, increased greenhouse gas emissions, and a higher cooling demand in the summer which increases energy demands. Green roofs lower the heat on the surface of the roof and absorb water. Each of these actions helps to mitigate the heat island effect.

3.5.2 Water Quality Improvements

The green roofs absorb water instead of sending the water from the roof into a storm sewer, or having the water runoff on the ground into a drain or creek. On the way to the drain or creek the water can pick up pesticides and other litter which pollutes water that would otherwise be clean.

3.5.3 Reduction in Energy Consumption

Not only do green roofs help to reduce energy consumption of the surrounding buildings by mitigating the heat island effect, they reduce their own as well. In the summer, the green roofs use latent heat loss to help cool the surface of the roof and prevent heat from entering the building. In the winter, the plants and growing media provide additional insulation which will help to keep heat from exiting the building.

3.5.4 Increase in Roof Service Life

Green roofs in Germany have proven to have a service life of 50 or more years. The plants and growing media protect the membranes underneath them and save them from having to be replaced. The sun's UV rays hit most roofs and cause the plasticizers in the membrane to deteriorate and fail. Since the membranes are under the growing media, green roofs do not have this problem. Also, the membranes go through less temperature fluctuations and are preserved on a green roof.

3.5.5 Reduction in Sound Reflection

Green roofs naturally absorb sound as they would water. The surface is soft and does not reflect sound back as it would on a regular roof or harder surface. A three inch deep green roof can be expected to reduce sound transmission by a minimum of five decibels.

3.5.6 Improvement of Roof Aesthetics

Generally, roofs are ugly. They are usually not seen by the public but in urban areas there are taller buildings around that have a view of other building's roofs. Instead of being an eyesore for the neighboring buildings, the green roof is something pleasant to look at. This may not be a factor for some owners, but Emory is a university and will most likely build more buildings around the Psychology Building. There is already one building that has a view of the Psychology Building. A comparison of the current aesthetics, and how the roof would look with the addition of a green roof is shown on the following page.

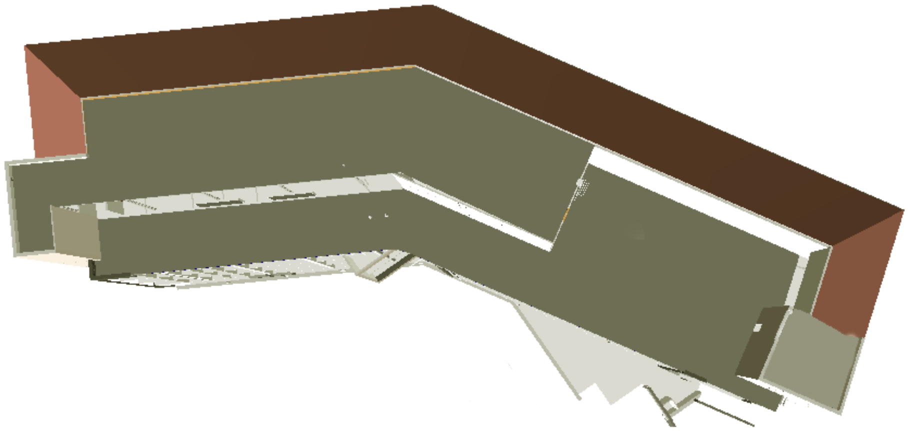


Figure 3.2 View of current Psychology Building roof design.

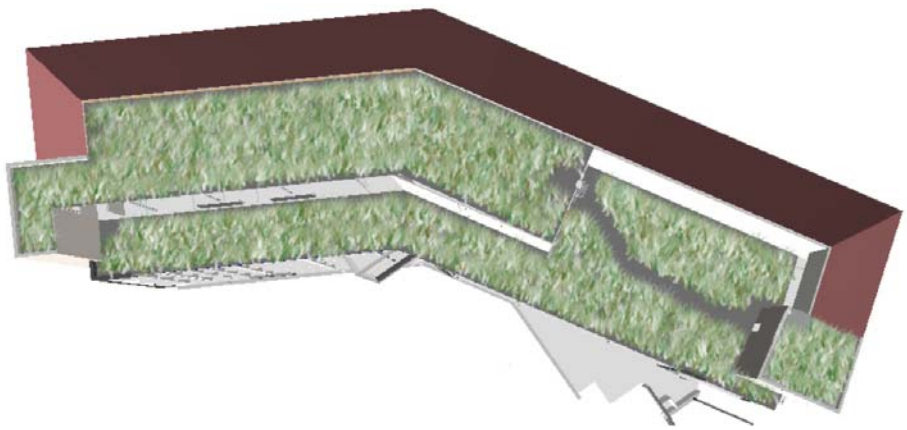


Figure 3.3 Simulated view of Psychology Building roof with the addition of a green roof.

3.5.7 Creation of an Outdoor Public Space

Although not relevant for Emory's situation, green roofs can provide an outdoor room for people to use. Developers may see this as a way to sell there buildings and realtors would most likely be able to market a building with an accessible green roof better than one with a traditional roof. Especially in urban areas, the green roof can be a garden which may be highly sought after in areas with little vegetation.

3.6 Selected Green Roof System

The green roof system selected for the Psychology Building is an extensive system with four inches of growing media and a variety of plants. Extensive green roofs generally have two to six inches of growing media and low lying plants and grasses. Conversely, intensive green roofs have six inches to three feet of growing media and can support full trees in some cases. An extensive roof was chosen for the Psychology Building because it will be lighter and have less impact on the structure. Also, the roof is expected to be a non-public space because of the difficulties in accessing the roof. The low lying grasses and flowers will have the same environmental effects as an intensive roof, but will not be as public friendly.

The plant area of the roof extends to within one foot of the parapet walls. At that point there will be pavers on the growing media to allow access to different parts of the roof. Also, at the ladders and doors to the roof, there will be pavers to allow access to all areas. There will be a small path leading from the north stairwell door to the mechanical penthouse door also of created by pavers.

3.6.1 Green Roof Plants

The plants for the roof were selected based on their ability to survive in the mild climate of Atlanta. Several species were chosen because local conditions on the roof may prevent some of the species from thriving. Some local conditions on the roof include wind, shading, and proximity to roof penetrations. The majority of the plants are sedums, with a few varieties of delospermas. These species are hearty and have the ability to withstand the harsh conditions of the Atlanta summer as well as the winters. A full plant list can be found in Appendix F.

3.6.2 Waterproofing System

Other than the plants, the green roof system was developed by NationsRoof, a national roofing contractor with experience in green roof construction. Their system was selected because it will work well with the selected plants and the climate of Atlanta. This system allows for "flood irrigation" on the roof. The drainage and root barrier layer under the growing media is allowed to "flood" up to one inch of its total three inch depth. This allows the plants to draw from the pooled water. After the one inch depth, the water is drained down off of the roof. A section view of the green roof system is pictured below.

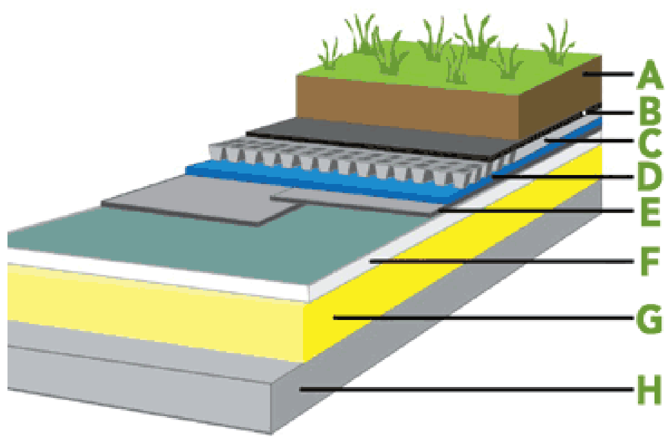


Figure 3.4 NationsRoof green roof section: A -Growing Medium & Plants, B - Moisture Retention Mat, C - Drainage Layer, D - Protection Fabric/Root Barrier, E - Waterproofing Membrane, F - 1/2" DensDeck Prime® , G – Insulation, H - Structural Deck

The flood irrigation will allow the plants to be properly watered without an additional irrigation system, which would be costly. This system is also beneficial because it can be applied to both concrete deck and metal deck. Some systems require a certain deck, but this one will work for both of the types of deck that the green roof will be used on.

This system is also easily replaced. The layers are secured with an adhesive instead of being mechanically fastened. When the roof needs to be replaced, another layer of adhesive can be applied directly over the old system, and new layers can be added. In most cases, at least some of the layers will be removed, but in general, this makes replacing the roof easier and less invasive.

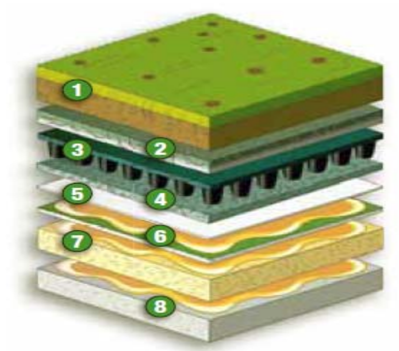


Figure 3.5 Section of green roof showing adhesive layers.

3.6.3 Existing Roof Cost

Cost data for the existing roof was provided by Holder Construction. The 14,600 square feet of modified bituminous white roof cost $382,000. This comes out to approximately $26.16 per square foot. Usually, modified bituminous roofs tend to cost less than this; however, the Psychology Building roof has additional insulation and a special solar reflective topping cap that is usually not part of the mod bit system. The extra costs are thought to derive from the special needs of this roof.

3.6.4 Green Roof Cost

The green roof is expected to cost more than the originally designed roofing system. It contains many of the same membranes and parts that the white roof has, but it also contains the growing media and plants. These things will add to the total cost of the roof.

The green roof system by Nationsroof was estimated at $27-$31 per square foot by a Nationsroof representative. The prices given were for the Washington DC area, which is more expensive than the Atlanta area. The Psychology Building green roof cost should be slightly lower than that estimate. An additional estimate of the green roof cost was performed using RS Means cost data. The system components and their costs per unit are shown in the table on the following page.

Component	Cost/Unit	Unit	Qty.	Cost
Plants	$ 7.60	SF	14600	$ 110,960.00
Media	$ 1.74	SF	14600	$ 25,404.00
EPDM	$ 2.88	SF	14600	$ 42,048.00
Insulation	$ 3.45	SF	14600	$ 50,370.00
Prime Board	$ 1.87	SF	14600	$ 27,302.00
Adhesive	$ 0.68	SF	43800	$ 29,784.00
Asphalt Felt	$ 1.03	SF	14600	$ 15,038.00
Pavers	$ 3.69	SF	2607	$ 9,619.83
Edging	$ 12.80	LF	1614	$ 20,659.20
Drainage Layer	$ 4.14	SF	14600	$ 60,444.00
			Total	**$ 391,629.03**
			SF Cost	**$ 26.82**

Table 3.1 Green roof assembly cost estimate.

The estimated cost is accurate and will be used to determine the life cycle costs of the green roof. It is an increase of $0.66 per square foot of roof and an overall increase of $9,626.03 for roofing installation.

3.6.5 Schedule Considerations

The green roof system is expected to take five and a half weeks to install. The vegetation will not be planted at the time of installation since it will be too hot to do so at that time. The vegetation will instead be planted in the fall to ensure successful growth. The total installation will have no affect on the critical path. The original roof took just over three weeks to install and finished seven and a half weeks before the building was dried in. The green roof will be waterproofed after four weeks of the installation and will still be completely finished five and a half weeks before dry in. The image below depicts how the green roof will affect the schedule.

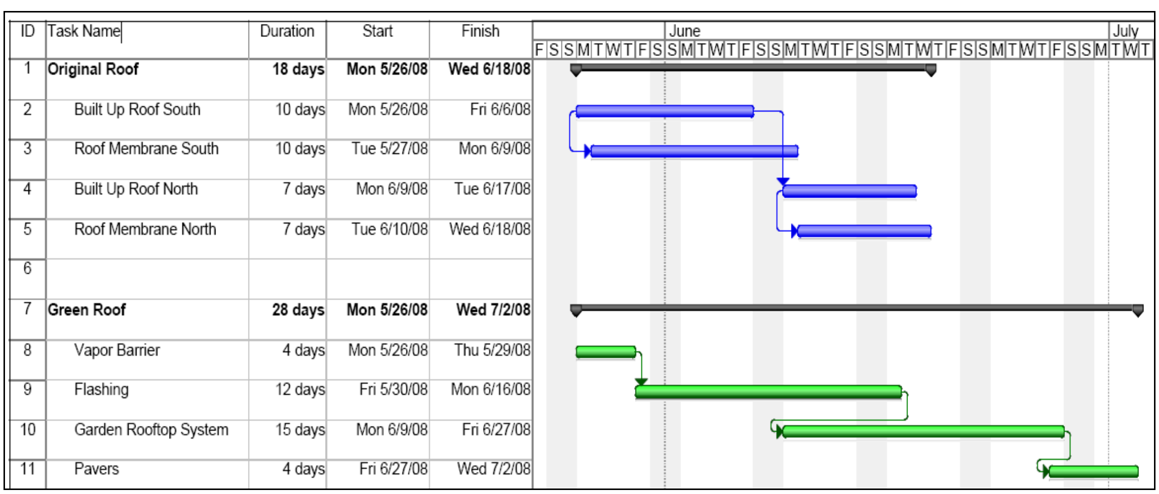


Figure 3.6 Green roof vs. original roof schedule.

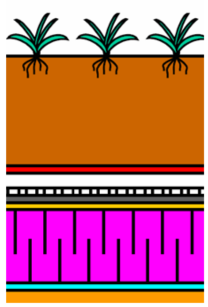
For a full version of the schedule please see Appendix G.

4.0 Green Roof Structural Analysis (Structural Breadth)

The addition of a green roof will add a large amount of weight to the existing structure. The structure must be analyzed to determine if it can support the excess weight. The green roof system is uniform on both levels of the roof, but the roof structure is not. The mechanical penthouse roof is supported by structural steel while the 5th floor roof is concrete, like the rest of the building. Each system will have to be examined separately since the weight will affect each in different ways. However, since the green roof system is the same, the additional weight can be totaled first and the extra load can be applied to both parts of the structure.

4.1 Additional Weight Determination

The weight of each of the layers of the green roof system was summed to achieve a total weight for the system. The roof superimposed dead load was given as 15 psf. The growing media has a saturated weight of 88 pounds per cubic foot. The saturated weight was used for the design since it is the heaviest that they media can be. There is four inches of growing media, so the media will be one third of the 88 pounds per cubic foot which is approximately 30 psf. The figure below shows the calculation of the green roof system total dead load.



Superimposed Load:	15 psf
Plants:	5 psf
Growing Media:	30 psf
Membranes:	5 psf
Insulation:	5 psf
Miscellaneous:	5 psf
Total:	65 psf

Figure 4.1 Calculation of green roof loads.

The dead load of the system will be 65 psf. The live load for the roof will be 20 psf, which is the same for the original roof design. If the green roof were open to the public and expect more foot traffic, the live load would be increased.

4.2 Structural Steel Analysis

The original structural steel on the roof consists mostly of 26' long W14x22 beams and 32' long W18x40 girders. The columns are 23.5' tall W8x35 members. The current roofing sits on 20 gauge metal deck which is supported by the beams. A section of the current roof at the parapet wall is shown in the figure on the following page.

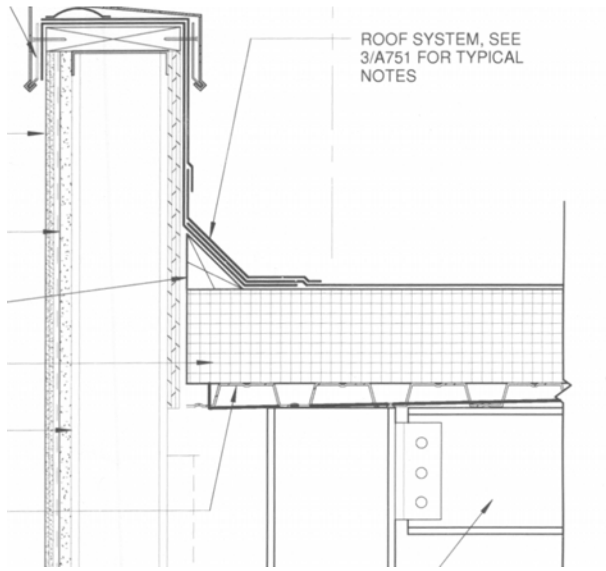


Figure 4.2 Current roof section at parapet wall.

4.2.1 Load Calculation

The deck will add 2 pounds per square foot of dead load to the calculation above which will bring the total dead load to 67 psf. The dead and live loads must be factored for safety for the redesign by the equation:

$$1.2*(\text{Dead load}) + 1.6*(\text{Live load}) = \text{Factored Load}$$

$$1.2*(67\text{ psf}) + 1.6*(20\text{ psf}) = 112.4\text{ psf}$$

The beams are spaced eight feet apart. Multiplying the load by the spacing will give the line load on one beam:

$$112.4\text{ psf} * 8' = 900\text{ plf}$$

There is a load of 900 pounds per linear foot on the mechanical penthouse roof beams. The shear and moment forces on the beam are then:

$$\text{Shear: } V = (900\text{ plf} * 26') / 2 = 11.7\text{ kips}$$

$$\text{Moment: } M = (900\text{ plf} * (26')^2) / 8 = 76.05\text{ ft.-kips}$$

4.2.2 Beam Analysis

By the AISC Steel Construction Manual,[4] it appears that the W14x22 beams can support these loads. However, in addition to the above roofing, the steel beams help to the support the structure of the clay tile roofing, which has a large overhang. Since it is difficult to determine the loads generated laterally on these beams, and what affect additional green roof load will have on them, the beams were sized up by the factor of additional load that the green roof causes. The original load on the roof was 660 pounds per linear foot, which means the green roof adds 36.4% of the original load to the structure. Therefore, the maximum loads reported in the steel manual for W14x22 members will be multiplied by this factor to find the new beam requirements.

Member	Max Shear (kips)	Max Moment (ft.-kips)
W14x22	94.8	125
x(1.364)	**129.3**	**170.5**

Table 4.1 Steel beam maximum shear and moment calculations.

The new beam must able to withstand a shear load of 129.3 kips and a moment of 170.5 ft.-kips. The two best candidates to replace the W14x22 beam are shown in the table below:

Member	Max Shear (kips)	Max Moment (ft.-kips)
W14x38	131	231
W16x31	131	203

Table 4.2 Possible re-sized steel beams.

Each of these beams is capable of supporting the increased loads. The W14x38 beam is shallower and slightly heavier than the W16x31; however, the W16x31 beam is cheaper to manufacture since it is a more common shape. The W16x31 will be selected. The new beam will add 2" of depth to the original beam. This will not affect the ceiling height below since it is an open ceiling. Also, the girders are 18" deep, so the depth of the girders will not have to change. All of the mechanical equipment in the penthouse had a 4" clearance from the girders, so the additional 2" will not affect the room layout.

4.2.3 Girder Analysis

The shear loads on the beams determine how much weight will be supported by the girders. The girders were found to support 17.55 kips of shear force and 210.6 ft.-kips of moment force. Like the beams, it appears that the current design would be able to support the additional load. Since the other loads cannot be determined, the same increases in size will be applied to the girders.

Member	Max Shear (kips)	Max Moment (ft.-kips)
W18x40	169	294
x(1.364)	**230.5**	**401**

Table 4.3 Steel girder maximum shear and moment calculations.

The girder chosen to replace the W18x40 member is a W18x65 member. This shape is fairly irregular and it will be expensive to make; however, it will not add any height to the structure. A W21x55 girder also would have been able to support the required loads, but it would have either added three inches to the structure or taken away three inches of clearance from the mechanical equipment. Both of these situations are undesirable. Also, since there are relatively few girders on the building, the cost will not be a huge deterrent. The maximum allowable stresses on the new W18x65 girder are shown in the table on the following page.

Member	Max Shear (kips)	Max Moment (ft.-kips)
W18x65	248	499

Table 4.4 Re-sized girder allowable stresses.

4.2.4 Steel Column Analysis

The original columns for the Psychology Building's mechanical penthouse are W8x24 steel members. Like the beams and girders, they will need to be increased to support the added loads. The columns support an axial load calculated to be 41 kips with the additional weight of the green roof. Most of the columns support this load but some of the others support part of the clay tile roof with a total estimated load of 60 kips. Since the clay tile roof will remain unchanged, the resizing of those columns due to the green roof weight is expected to be sufficient. The following table shows the current maximum stresses on the column, the factored stresses due to the green roof weight, and the new column selected to support the loads.

Member	Max Axial (kips)
W8x24	76
x(1.364)	103.7
W8x35	115

Table 4.5 Re-sized column allowable stresses.

4.2.5 Redesigned Steel Cost Analysis

The redesigned steel is larger and will cost more than the original steel. The steel was taken off and priced using RS Means. The RS Means book gives a price per linear foot for the steel. A table showing the additional steel cost is shown below.

	Member	**LF**	**Cost/LF**	**Cost**
Original	W14x22	797	$ 40.40	$ 32,198.80
Redesign	W16x31	797	$ 55.64	$ 44,345.08
			Difference=	**$ 12,146.28**
Original	W18x40	268	$ 71.62	$ 19,194.16
Redesign	W16x31	268	$ 113.00	$ 30,284.00
			Difference=	**$ 11,089.84**
Original	W8x24	494	$ 47.10	$ 23,267.40
Redesign	W8x35	494	$ 65.60	$ 32,406.40
			Difference=	**$ 9,139.00**
		Additional Cost		**$ 32,375.12**

Table 4.6 Structural steel redesign cost.

Placing a green roof on the existing roof of the Psychology Building would result in a $32,375.12 increase in steel costs. Since there are no additional members and the redesigned members are approximately the same size, there is no anticipated delay to the schedule by changing the steel members.

4.3 Concrete Analysis

Like the steel, the concrete on the 5th floor will have to be redesigned to support the additional loads caused by the green roof. As stated previously, the green roof will have a dead load of 65 psf and a live load of 20 psf. The concrete deck on the 5th floor roof is a 6" slab, and will add 75 psf of dead load to the structure for a total of 140 psf dead load. The factored loads are calculated below:

$$1.2*(140 \text{ psf}) + 1.6*(20 \text{ psf}) = 200 \text{ psf}$$

4.3.1 Interior Beam Analysis

The 12"wide interior beams are spaced at 9.5' on center typically and are 28' long. The line load on the beams will then be 1900 plf. The beam self-weight also must be factored into the load on the beam. The beam is 12"x28" but only 22" inches of the depth are factored in because the 6" slab has already been calculated. The weight of the beam is:

$$1' *(22"/12")*150 \text{ pcf} * 1.2 \text{ (dead load factor)} = 330 \text{ plf}$$

The beam and its load are then added to get 2230 plf. Next, shear and moment forces must be determined for the beam:

$$\text{Shear: } V = (2230 \text{ plf} * 28') / 2 = 31.22 \text{ kips}$$

$$\text{Moment: } M = (2230 \text{ plf} * (28')^2) / 8 = 218.54 \text{ ft.-kips}$$

General concrete structure design guides can help to determine if the beam can support these forces before going any further. The two equations that can help this are:

$$20M_u \leq bd^2 \quad \text{and} \quad A_s \geq M_u / 4d$$

Where M_u is the designed moment, b is the width of the beam, d is the distance from the top of the beam to the center of the reinforcement, and A_s is the area of the steel in the beam. The calculation of these variables is shown in Appendix H. A section of a typical 12" interior beam is shown in the figure on the following page.

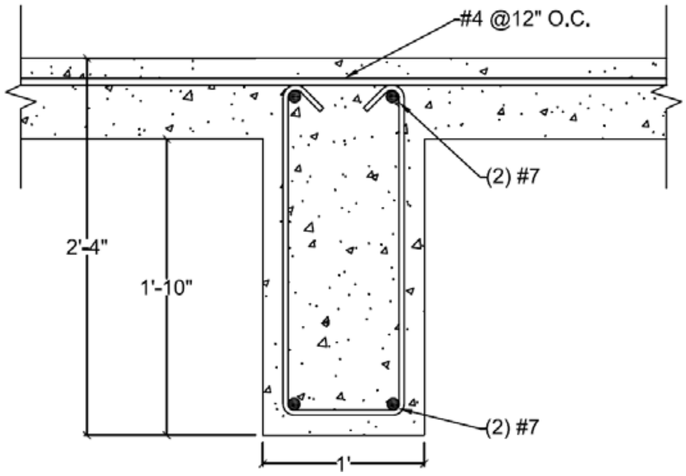


Figure 4.3 Typical interior beam.

The design guide calculations for this beam are:

20*218.54 ft.-kips ≤ 12”*(25.7”)^2 (Satisfactory)

1.2 ≥ 218.54 ft.-kips / 4*25.7” **(Unacceptable)**

The second equation indicates that there is not enough reinforcing steel in the beam to support the additional loads. The solution to this problem is simple: add more reinforcement. Since the beam already has 2 #7 bars, and #7 bars are very common throughout the building, the additional reinforcing will be 2 more #7 bars. The beam will also be widened from 12” to 16” to accommodate the additional reinforcement. A section of the new beam design is shown below:

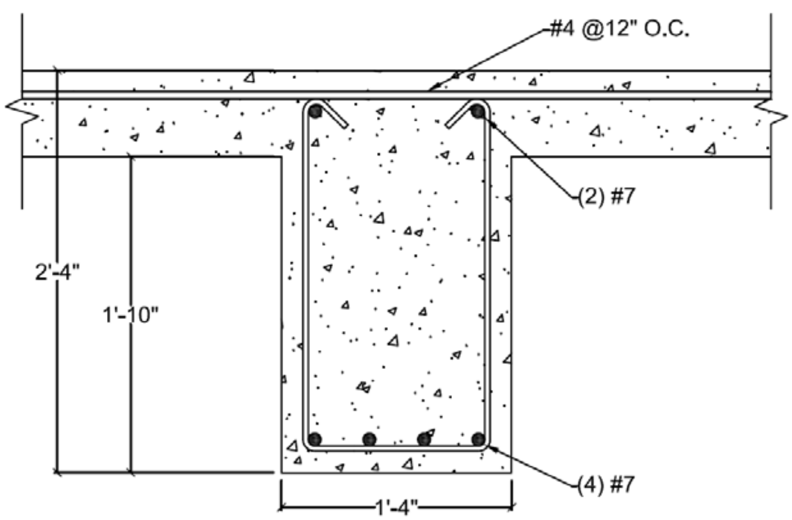


Figure 4.4 Redesigned interior beam.

Although the addition of 2 #7 bars will have little affect on the weight of the structure, the extra 4” of concrete will. The extra 4” must be added into the line load on the beam which will produce new shear and moment forces.

(16”/12”)*(22”/12”)*150 pcf * 1.2 (dead load factor) = 440 plf

This adds 110 pounds per linear foot to the beam. The new line load will be 2340 plf. The new shear and moment forces will be 32.76 kips and 229.32 ft.-kips, respectively. The new design guide calculations are:

$20*229.32$ ft.-kips $\leq 16”*(25.7”)^2$ (Satisfactory)

$2.4 \geq 229.32$ ft.-kips / 4*25.7” (Satisfactory)

The actual allowable moment of the beam is 266.1 ft.-kips and is determined in Appendix H. The allowable shear stress of the beam is 53.15 kips. The 16” wide beam with 4 #7 bars fits within the allowable limits and will be used for the redesign. Other factors that need to be accounted for with the new beam are also shown in Appendix H.

The end beams were resized by the same factor as the interior beams. The interior beams added 33% of the concrete that they originally had and the reinforcing was doubled. The interior beams more than adequately met the load requirements and it is assumed that the end beams will be more than sufficient since they are increased by the same amount.

4.3.2 Post-Tensioned Beam Analysis

The concrete beams will be used as a basis for the analysis of the post-tensioned beams. The post-tensioned beams act as girders and support the slab above as well as the concrete beams. They are a very complicated system and would be very difficult to examine thoroughly. For that reason, the post-tensioned beams will be increased in the same manner as the concrete beams. The concrete will be increased by 33% and the tendons will be doubled. Tables showing the full calculation of the post-tensioned beam formwork and concrete increases are located in Appendix I.

It was determined that 47.8% of the fifth floor roof post-tensioned beams were affected by the green roof loads. Since there are five floors, the affected beams make up 9.56% of the total building post tensioning. The percentage was multiplied by the total building post-tensioning tendon cost to find the cost of affected tendons.

$ 55,940.00 * 0.0956 = $ 5347.86

Since the cost will be doubled, this will be the additional cost of PT Tendons

4.3.3 Fifth Floor Roof Additional Structure Cost Analysis

The additions to the structure will have cost implications. The calculations of the additional concrete, reinforcement, and formwork can be found in a table located in Appendix I. Using those calculations, RS Means cost information was used to determine the additional costs of the redesigned structure. The cost of the additions is shown in the table on the following page.

	Increase	Unit	$/Unit	Cost
Concrete	98.8	CY	$ 132.15	$ 13,056.42
Formwork	1540	SF	$ 5.96	$ 9,178.40
Rebar	5.006	Ton	$ 2,170.00	$ 10,863.02
PT Tendons	5347.86	$	N/A	$ 5,347.86
				$ 38,445.70

Table 4.7 Fifth floor roof additional concrete costs.

4.3.4 Concrete Column Analysis

The columns were resized based on the percentage of load that was added to the structure. The additional load percentage was calculated to be 36% including the weight of the structural members:

Original: 1.2*(95 psf) + 1.6*(20 psf) + 330 plf / 9.5' = 181 psf

Redesign: 1.2*(140 psf) + 1.6*(20 psf) + 440 / 9.5' = 246 psf

246/181 = 36% increase

That increase is applied floor by floor in the table below. Each column supports its own floor and the floors above, so the additional roof load is only a small increase to the columns several floors below. Since each column level represents 20% of the total columns, the total was divided by 5.

Columns	Load Increase
5th Floor	0.3600
4th Floor	0.1800
3rd Floor	0.0900
2nd Floor	0.0450
1st Floor	0.0225
Total	0.6975
Total / 5	**0.1395**

Table 4.8 Concrete column increase.

The percentage increase was then multiplied by the total estimated cost of the columns, $197,509.81. The total cost was used from a previous estimate which is located in Appendix J.

0.1395*($ 197,509.81) = $ 27,552.62

The estimated additional cost for columns is $ 27, 552.62. This includes formwork, reinforcement, and concrete.

4.4 Total Structural Cost Impact

The total structural cost impact of the green roof is the sum of the costs from the steel penthouse framing, fifth floor roof, and columns. The summation of these items is shown in the table below.

Additional Structural Cost	
Penthouse Steel	$ 32,375.12
5th Floor Roof	$ 38,445.70
Columns	$ 27,552.62
Total	**$ 98,373.44**

Table 4.9 Redesigned structure total cost.

The total increase in cost of the structural system due to the green roof is $ 98,373.44. This equates to an increase of $0.83/SF of the total building cost or a $6.74 increase of the roofing cost.

4.5 Additional Structure Schedule Impact

The increase in concrete will cause somewhat of a schedule impact. Some time will be added to some of the activities, but it will not interrupt the critical path. For the structure, the building is divided in half into north and south sections. Each north or south floor section is one activity in the schedule. Each section of the columns takes four days to form, pour, and remove forms. Although the structure is on the critical path, the columns are not. The slabs take longer and hold up the columns for each floor. The extra weight from the green roof will add 6.31 CY of concrete per section, or activity, in the schedule. Originally, the columns were being poured in one day, which was 45.22 CY of concrete. The additional concrete should not require any more days to be added to the schedule. Even if it did, it wouldn't take more than one day, which would still cause the columns to be waiting for the slab to finish. The rest of the structure will not be affected by the column increase.

The 5th floor roof will have much more concrete added to it. For the entire slab, there will be a 16.2% increase in concrete from 611.2 CY to 710 CY for the slabs and beams. As with the columns, the slab is divided into north and south sections. There is an increase of 49.4 CY per section, which is about five to six truckloads of concrete. Since the slab must be poured all in one day, the 49.4 extra CY of concrete will make for a longer day, but it will not add any time to the schedule.

5.0 Green Roof Energy Analysis (Mechanical Breadth)

One of the well known benefits of a green roof is the reduction in energy costs due to the additional thermal mass of the growing media and plants on the roof. The greatest reductions are typically realized in the summer, when latent heat loss off of the roof becomes a large factor.

5.1 Goal

The goal of this analysis is to determine the energy savings of a green roof as compared to the designed white roof. The energy savings over the building's lifecycle could be a factor in determining if a green roof will be a good investment or not.

5.2 Methodology

Green roofs are still fairly new technology and as such have not been researched extensively. There are many factors that can change the way a green roof will perform such as location, temperature, growth media moisture content and depth, and plant coverage. The methodology of attempting to define the energy savings of a green roof is explained below.

5.2.1 Latent Heat Loss Effects

Latent heat transfer occurs on a green roof when the sun and warm outdoor air cause the water absorbed by the growing media to evaporate.[5] Essentially, instead of heating the roof and having that heat enter the building, the heat is used to evaporate the water. Therefore, the more moisture that is present in the growing media, the greater potential the green roof has to prevent heat transfer through the roof. Since there is more rainfall in the summer and the temperatures are the mildest, green roofs save the most energy during the summer months.

5.2.2 Green Roof R-Value

Besides latent heat loss, green roofs help to prevent heat transfer through their mass as any other material would. The R-value is a measure of a material's resistance to thermal conductivity, or heat flow through it. To calculate the R-value of a typical roof system, the R-values are added to find the total system R-value. The R-value of a green roof however is complicated to quantify. The thermal resistive properties of a green roof's growing media change with the water content it possesses; high water content relates to a lower R-value and vice versa. The total system value is very difficult to calculate since the water content of the media is constantly changing. Also, since latent heat loss also prevents heat from entering the building, it is impossible to determine the actual R-value of the growing media on a green roof.

5.2.3 Performance Evaluation

For a typical roofing assembly, the R-value would be determined by its ability to prevent heat loss through the assembly. An easy comparison can then be made between two systems since the higher R-value assembly will provide a higher thermal resistance. Unfortunately, a green roof does not have an accurate method of quantifying an R-value.

For this reason, the best way to accurately compare a green roof system to a typical roofing assembly is to use information gathered from the research of similar projects.

5.3 Canadian Study

A study done by the National Research Council of Canada directly compares a green roof to a typically constructed roof.[6] Thermocouples were used to determine the heat flux through both of the roofs to the ceiling on the interior of the building. This comparison was the best model because it directly compares the two roof assemblies as seen in the figure below. The data from this study provided the information necessary to compare the energy efficiencies of the Psychology Building's white roof to those of the proposed green roof.

Figure 5.1 Canadian study photo showing the data collection surfaces of each roof.

The Canadian Study reported that the green roof would have the most impact during the summer, as previously assumed. In fact, the study found that the green roof outperformed the typical roof by as much as 95% for the hottest months of the year. In the spring and fall the performance was not as differentiated, but the green roof still proved to be much more resistive to heat transfer. During the winter months, the green roof still outperformed the traditional roof, but only by 10%.

The reference roof in the Canadian Study was a dark two-ply modified bituminous membrane with three inches of fiber board insulation supported by a plywood deck. The Psychology Building has a two-ply modified bituminous membrane but the cap or surface membrane is white and solar reflective. The solar reflective index (SRI) of the Psychology Building roof is 95. According to other studies and research, the white exterior layer will keep the surface of the roof cooler and provide a 15% decrease in air conditioning energy consumption.

5.4 Heat Gain Calculation

To find the amount of heat that enters the Psychology Building with the original white roof, the following equation was used:

$$Q = U*A*(\Delta T)$$

Where Q is the heat entering the building, A is the area of the roof, and ΔT is the difference between the interior and exterior temperature. The designed indoor temperature for the building is 74 °F, and the exterior summer outdoor temperature is 94 °F. The U-value is determined by the roof assembly and shown in the table below.

Current Roof Assembly	
Material	R-Value
Exterior Air Film	0.17
Roofing Membranes	0.33
Insulation	30
Concrete Deck	0.48
Interior Air Film	0.61
Total Assembly R-value	31.59
Coefficient of Transmission U=(1/R)	**0.0317**

Table 5.1 U-value of white roof.

The total heat to be removed is then:

$$Q = (0.0317\ ^{Btu}/_{hr\text{-}ft2\text{-}°F})*(14{,}600\ ft^2)*(20\ °F)$$

$$Q = 9256.4\ ^{Btu}/_{hr}$$

Since this is thought to be a 15% reduction from the dark roof in the study, the quantity must be adjusted to show the heat gain of a dark roof:

$$9256.4\ (^{Btu}/_{hr}) / (1\text{-}0.15) = 10890\ ^{Btu}/_{hr}$$

Now the heat gain may be compared to the green roof. The report indicated that the green roof could reduce heat gain by as much as 95%. For the summer months it typically outperformed the traditional roof by 75% - 90%. Those results would have been on a very hot sunny day, probably closely following a rainy day. 95% would be the maximum potential savings from the green roof. Another factor that must be considered however is that the study was done in Ottawa, Canada, and the Psychology Building is located in Atlanta, Ga, which would experience warmer weather and more direct sunlight. Taking both of these things into account, the Psychology Building green roof would expect to see 90% decreases in heat gain during the summer. Also, the green roof in the study has six inches of growing media, and the proposed roof only has four. All of these things are factored into the equation on the following page to find the heat gain of the proposed green roof:

$$10890\ (^{Btu}/_{hr})*(1 - (0.9*(4''/6''))) = 4356\ ^{Btu}/_{hr}$$

Next, the green roof can be re-entered into the Q = U*A*(ΔT) equation to find an equivalent U-value:

$$4356\ ^{Btu}/_{hr} = U*(14{,}600\ ft^2)*(20\ °F)$$

$$U = 0.01492\ ^{Btu}/_{hr\text{-}ft2\text{-}°F}$$

This U-value can be used to evaluate the green roof assembly for the hottest months of the year. For the rest of the year, the green roof will not be as efficient because it will not be as hot outside and there will not be as much direct sunlight on the roof to evaporate the moisture in the growing media. For this reason, the U-value for the other months that require cooling will be assumed as half as efficient as the summer months for a U-value of $0.02985\ ^{Btu}/_{hr\text{-}ft2\text{-}°F}$.

5.5 Mechanical System Load

The U-value will help determine the burden of the heat gain on the mechanical system. Since the temperature varies by month, degree days are used to find the amount of cooling necessary for a given month. A degree day measures the amount of cooling or heating necessary per month using the following equation:

$$\text{Degree Day} = (T_{outside} - T_{inside})*(\text{Days cooling / Month})$$

The degree days for a month can then be multiplied by 24 to get the degree hours per month. A positive degree day represents a cooling need and a negative value represents a need to heat the building. The degree day information used in this report came from American Technical Publishers, who publishes a variety of weather data for engineers.[7] To check the accuracy of the degree day information, one month, July, was singled out and reviewed to see how long heat would need to be removed for a single day in July. The published amount of degree days for July in Atlanta was 238.

$$238 = (94\ °F - 74\ °F)*\text{Days cooling}$$

$$(11.9\ \text{days})*(24\ \text{hours/day}) / 31\ (\text{days in July}) = 9.21\ \text{hours / day (cooling)}$$

For July in Atlanta, 9.21 hours of cooling per day is definitely feasible and the degree day information is accurate.

Next, the U-values from the designed roof assembly and the green roof assembly are multiplied by the degree hours and square footage of the roof to determine the amount of Btu's have to be removed from the building per month. The monthly totals are then summed to find the amount of cooling Btu's required annually. The calculation of this is shown in the chart on the following page.

Cooling					
Month	Degree Days	U value White	U value Green	BTU White	BTU Green
January	0	0.0317	0.02985	0	0
February	0	0.0317	0.02985	0	0
March	4	0.0317	0.02985	44,431	41,838
April	18	0.0317	0.02985	199,938	188,270
May	87	0.0317	0.01492	966,368	454,833
June	183	0.0317	0.01492	2,032,705	956,718
July	238	0.0317	0.01492	2,643,628	1,244,256
August	226	0.0317	0.01492	2,510,336	1,181,521
September	134	0.0317	0.02985	1,488,429	1,401,565
October	30	0.0317	0.02985	333,230	313,783
November	6	0.0317	0.02985	66,646	62,757
December	0	0.0317	0.02985	0	0
			Total Btu/yr	10,285,711	5,845,541
				Saved Btu	**4,440,170**

Table 5.2 Annual cooling load calculation.

5.6 Annual Energy Savings

From the table, the green roof will save 4,440,170 Btu's of cooling load per year. That means that the air handling units will have their load reduced by that amount each year. Since the units will not have to be on, they will save energy. The energy savings can be calculated by converting the amount of Btu's saved per year into kilowatt hours of electricity per year. Since there are 3412 Btu's per kWh, there will be a savings of 1301.34 kWh per year of cooling load. That quantity must be adjusted by the efficiency of the air conditioning system. Since the system alrea[dy includes an Energy Recovery Unit (ERU) to improve efficiency, the efficiency of the system will be assumed at 90%. Finally, the electricity used can be multiplied by the price per kWh in Atlanta to find the energy savings per year of the green roof, as shown in the following table.

kWH (Load)	kWH (Electricity)	$/kWh	Energy Savings
1301.34	1445.93	0.0917	**$ 132.59**

Table 5.3 Annual energy savings from green roof.

The addition of a green roof on the Psychology Building would cause a savings of $132.59 per year at current energy prices.

5.7 Winter Heating Impact

The Canadian Study found that the green roof outperformed the traditional roof by 10% in the winter. The reason for the slightly better performance is that the roofs had identical insulation and the media and plants of the green roof provided additional insulation to warrant a 10% improvement. For the Psychology Building, the designed roof already has a very high R-value. The design of the green roof was intended to match the winter performance of the original roof. Adding insulation to the green roof design to make it out perform the original roof would have made it incredibly thick and not feasible without having to raise the height of the parapet walls. Raising the height would have added more to the structure and would have resulted in additional material and labor costs. For this reason, the green roof is assumed to have the same energy saving properties as the original roof on the Psychology building and therefore will have no advantage in energy efficiency or energy cost.

5.8 Conclusions

By changing the current white roof to a green roof, the owner would expect to save $132.59 per year at current energy prices. This savings would only be realized in the summer when it would reduce the cooling load. The fact that the designed roof has a white reflective surface and a large amount of insulation caused the green roof to have very little performance advantage during the summer months. Also, the Energy Recovery Unit aids the air handling units with efficiency. In the winter, the green roof would not have any affect since the designed roof is very well insulated and the green roof had to be increased just to match it. This is not that much of a savings and would not convince the owner that the green roof is a more economical solution than the designed roof.

6.0 Life Cycle Cost Analysis

So far, the green roof has shown to increase the initial cost of the Psychology Building. However, as stated previously, many of the benefits of green roofs are not realized until after construction. A life cycle cost analysis was performed to determine total of the initial costs, energy costs, maintenance costs, and replacement costs of the roofs after 50 years. 50 years was the time frame chosen because the green roof is expected to last 50 years without needing to be replaced. Typically, a modified bituminous roof lasts up to 20 years, and in fact the Psychology Building roof has a 20 year warranty. However, the reflective surface of this roof is expected to add some life to the roof since it will undergo less temperature fluctuations which can be damaging to the roof. The Psychology Building's current white roof is estimated to need replacement 25 years after installation.

6.1 Initial Cost

As stated previously, the Psychology Building roof cost $382,000. The total cost of the green roof and the additional structure that it caused is estimated to be $490,002.47. Initially the green roof will cost $108,002.47 more than the designed roof. The green roof's initial cost is $7.40 per square foot of roofing higher than the white roof's initial cost.

6.2 Energy Cost

From the mechanical analysis, the green roof will save $132.59 per year on the electric bill due to the cooling effects of the roof. The actual cost of the electric to power the air handling system with the green roof is $174.56. The designed roof will cost $307.15 per year. These are 2009 prices and will increase each year. The energy prices are assumed to increase by 5% each year.

6.3 Maintenance Cost

The green roof is fairly simple to maintain. Since there will not be public access, the plants do not need to be pristine since they are not there for people to see. The only maintenance that they will need is some minor trimming and weeding. When the growing season first starts, someone will have to go up on the roof and make sure that there are not too many weeds present which may harm the plants. A few weeks later, just before summer, someone must again go up and remove the weeds that have started to grow. This is the most crucial time, and care must be taken to make sure that all of the weeds are gone. After that, someone must go up once more towards the end of the growing season to make sure that weeds will not be around until the spring. This will result in a total of 12 man hours per year of total maintenance. At a labor rate of $18.00 per hour, this maintenance cost is very low. An additional $120.00 per year is added to cover the cost of cleaning and replacing the filters that provide the drainage on the roof. The total cost of maintenance will be $336.00 per year.

For the white modified bituminous roof, there is an estimated maintenance cost of $415.00 per year. These costs are taken from a study of roofs maintained at Penn State University by their Office of the Physical Plant (OPP). The three and a half year maintenance costs of a modified bituminous roof were determined by summing the total costs and dividing them by the service life of the roof. The square foot cost was taken to apply the results to the Psychology Building roof. Most of the costs were for preventative maintenance. Every few months OPP workers go up on the roof and check for any problems. Typically, there is some minor clearing and cleaning up on the roof. Occasionally there is a small leak. The cleaning that occurs does not have to occur on the green roof because the leaves, dust, or whatever else has gathered on the roof is allowed to sit on the media or plants without harm.

6.4 Inflation

The maintenance cost and re-roofing costs are subject to inflation. The inflation rate used was the average inflation over the past ten years, which was 2.89%.[8] Factoring in inflation will give a more accurate idea of how much the two roofs will cost over the 50 year examination period.

6.5 Results of Analysis

The following graph shows the 50 year life cycle costs of both the green roof and white roof. The lines represent a summation of how much each roof has cost up and until that particular date.

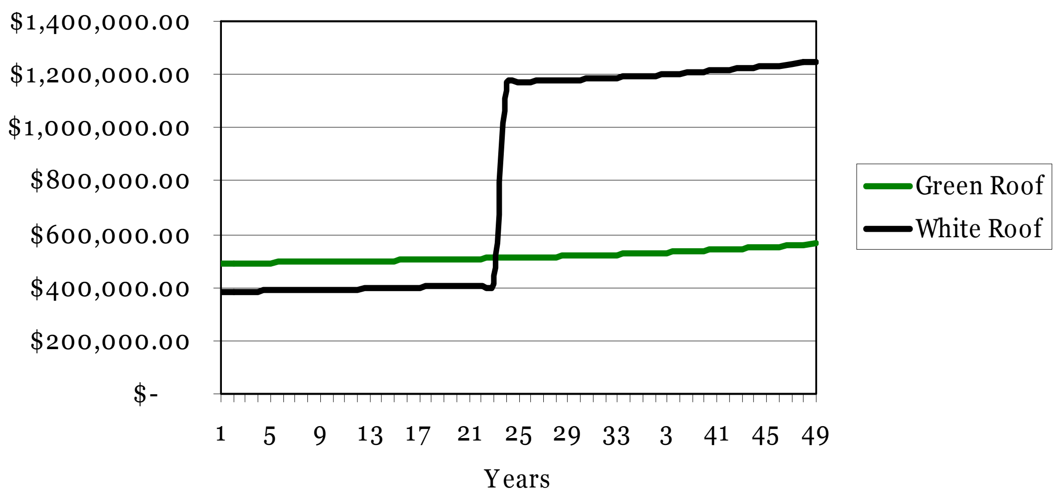


Figure 6.1 50 year life cycle cost analysis.

As assumed, the green roof will take a considerable amount of time to pay for itself, in this case, 25 years. The large additional cost at the 25th year is the re-roofing of the white roof. Due to inflation, the white roof replacement is expected to cost $756.866.66 in 25 years. The following table shows the total costs of each roof in selected years as well as the savings incurred by the green roof.

Year	Green	White	Savings
1	$ 490,513.03	$ 382,722.15	$ -(107,790.88)
10	$ 496,761.57	$ 391,648.89	$ -(105,112.68)
25	$ 510,408.63	$ 1,168,440.00	$ 658,031.37
50	$ 563,236.94	$ 1,248,485.26	$ 685,248.32

Table 6.1 Costs of each roof for selected years.

The owner cannot expect to see a return on their investment for 25 years according to this analysis. At that point the savings of the green roof will increase each year due to the lower maintenance and energy costs. The graph below shows how the costs compare for each roof over the 50 year examination period.

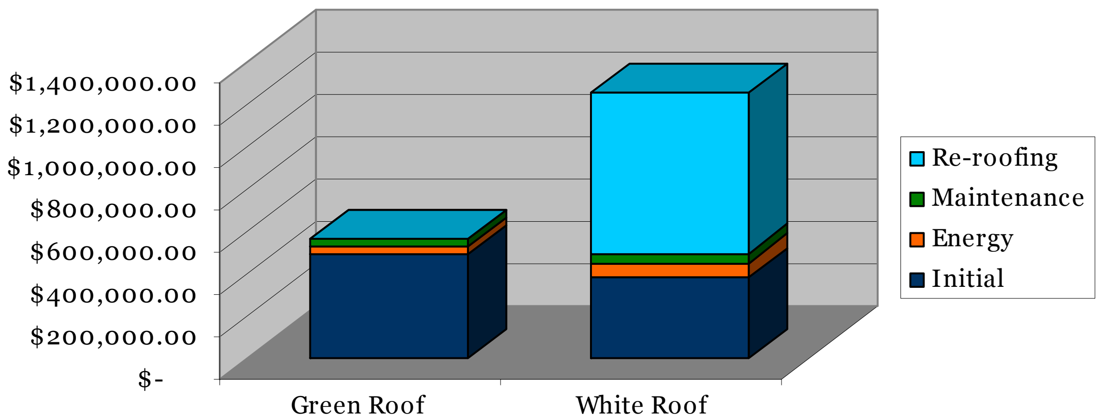


Figure 6.2 Total 50 year cost for each roof.

It is evident that the re-roofing of the white roof makes up a majority of the cost. After 50 years there will be a savings of $685,248.32. For reference, that amount would be equal to $169,653.49 in today's dollars. At the 50th year, each roof will need to be replaced. Since the majority of the cost for the green roof was an addition to the structure, the replacement costs will be similar for both roofs. The graph below shows the total cost after 51 years, to include the replacement of both roofs. Each replacement and all other costs are adjusted for inflation.

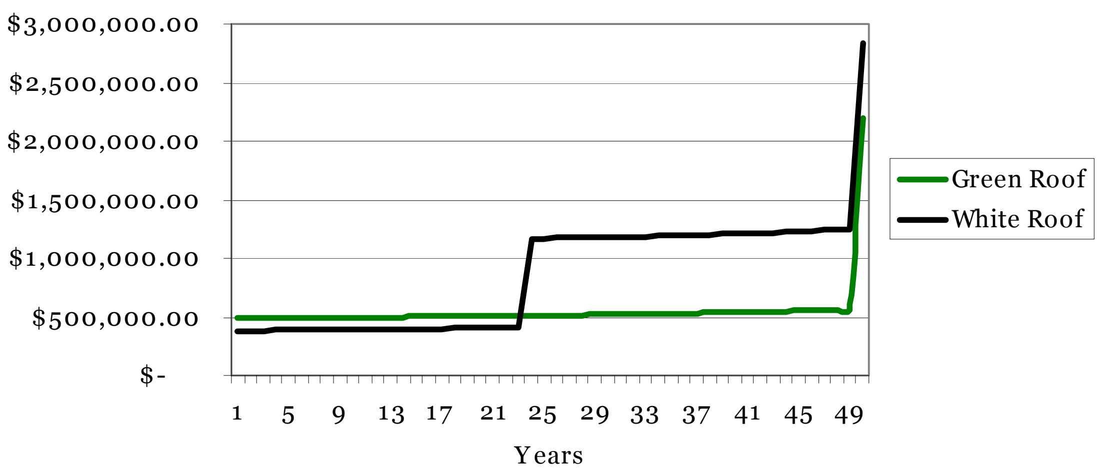


Figure 6.3 51 year life cycle cost analysis.

This graph shows that the green roof will continue to be cheaper over time than the white roof even after both roofs have been replaced.

6.6 Assumptions

This analysis relies on the following assumptions:

1. The inflation rate is constant at 2.89% per year.
2. The energy rate increases constantly at 5% per year.
3. There is no major damage to either roof.
4. If there is major damage, it will be equal in magnitude and cost for both roofs.
5. Each roof will reach its respective life expectancy of 25 and 50 years.
6. The costs of removing the old roof are not included in the re-roofing costs.

6.7 Cost Interpretation

The green roof and accompanying structure additions will initially increase the square foot cost of the roof from $26.16 per square foot to $33.56 per square foot, an increase of $7.40 per square foot. Over 50 years, the green roof will have saved $46.93 per year, or $0.94 per square foot per year. In today's dollars that would be equal to about $0.23 per square foot per year.

7.0 Green Roof LEED Analysis

The United States Green Building Council (USGBC) created LEED for New Construction Rating System is designed to guide and distinguish high-performance building projects. The Psychology Building is being assessed under Version 2.2.[9] There are 69 possible points and different certifications based on the number of points. The certifications are earned based on the following scale:

- Certified: 29-32 pts.
- Silver: 33-38 pts.
- Gold: 39-51 pts.
- Platinum: 52-69 pts.

7.1 Psychology Building Rating

Emory University is seeking a LEED Silver Certification by the USGBC. It currently has 34 credits which it is all but guaranteed to receive, and additional four which are likely. The likely credits are yet to be determined by the USGBC, but Emory will earn Silver Certification regardless of the results.

7.2 Green Roof Impact on LEED

Green roofs typically add LEED points to buildings since they are intended to reduce a buildings impact on the environment. The categories that cater to green roofs are Sustainable Sites and Water Efficiency. The following points are potentially awarded to green roof projects:

- Sustainable Sites 5.2: Site Development: Maintain Open Space
- Sustainable Sites 6.1: Stormwater Design: Quantity Control
- Sustainable Sites 6.2: Stormwater Design: Quality Control
- Sustainable Sites 7.2 Heat Island Effect: Roof
- Water Efficiency 1.1: Water Efficient Lanscaping: Reduce by 50%
- Water Efficiency 1.2: Water Efficient Landscaping: No-Potable Water Use
- Water Efficiency 3.1: Water Use Reduction: 20%
- Water Efficiency 3.2: Water Use Reduction: 30%

The Psychology Building has already been awarded all of these credits except SS 6.1 and WE 1.2. If the green roof can maintain the credits that the Psychology Building has already earned, add two of its own, and the building earns the likely points, the Building has the potential to be LEED Gold Certified.

7.2.1 Sustainable Sites 6.1 Credit Assessment

The idea of Credit 6.1 is to reduce the amount of run-off that would enter a watershed due to the building. The goal is to have the run-off equal the amount of run-off that would have occurred before the site was developed. Specifically, the description requires that the two-year 24-hour storm be used as a guide. A two year storm is a rain event that would on average happen about every two years. For Atlanta, a two-year storm means a rain event of about 4 inches in one day. The amount of run-off caused by the building is directly related to the area of its impervious footprint. The green roof would expect to absorb most of the rain in normal situations. During a two-year rain event, the green roof might not be able to absorb much of the rain water since it is falling at such a fast rate. Because of the unknown performance of the green roof during a two-year rain event, this credit would be in the “maybe” category. With the addition of a rainwater collection system and cistern for the clay tile roof, the credit would move into the “likely” category and would almost be definite.

7.2.2 Water Efficiency 1.2 Credit Assessment

This credit would only be possible with the addition of a rainwater collection system and cistern to store and disperse the water to surrounding landscaping. During the design of the green roof, it was recommended that an irrigation system be used in case of long periods without precipitation. The original irrigation system plan was to have the additional water collected off of the remaining clay tile roof. The collected rainwater would have to be stored in an underground cistern and be pumped up to the roof to provide irrigation. The original irrigation plan has been discarded, but the rainwater collection remains an option.

There would also be run-off from the green roof itself. The growing media would eventually become saturated with enough rainfall and the excess water would need to be removed from the roof surface. A drainage system under the growing media would account for the excess water and drain into an underground cistern along with the rainwater collected off of the clay tile roof.

It is estimated that even if the green roof needed some irrigation, it would not use all of the water collected off of the other part of the roof. The remaining water would be used to irrigate the building’s landscaping. The credit description requires that no potable water be used for irrigation. Since it has not been determined if there would be enough rainwater to irrigate all of the landscaping, this credit would fall into the “maybe” category.

7.2.3 Rainwater Harvesting

Unfortunately, due to existing site conditions, this proposal has been ruled out. Rainwater collection of this magnitude would require a tank of about 1 month’s supply, which would be about 25,000 gallons. Due to the height of the water table, the tank would not be able to go underground, which leaves no other practical place to put it. However, the green roof would still absorb most of the water that falls on it and the reduction of water entering the stormwater sewer can still be calculated.

Atlanta receives 50.2 inches of rain in an average year.[10] The water that falls onto the roof of the Psychology Building could potentially be collected and stored for irrigation or other uses instead of adding to the stormwater demand. The proposed green roof has an area of 14,600 ft^2. The area of clay tile is 10,033 ft^2. The total amount of rain expected to fall on this roof per year is given by the following equation:

$$\text{Gallons / yr.} = (14{,}600\ ft^2 + 10{,}033\ ft^2)*(50.2\ in / yr)*(0.6233\ gallons / in\text{-}ft^2)$$

$$\text{Gallons / yr.} = 770{,}758$$

A large portion of this water would be used up by the green roof. The rest of it would still be run off as if it were a regular roof. To determine the amount of reduced water, the roof has to be multiplied by the efficiency of its collection. The green roof would use approximately 90% of the rainwater immediately.

$$\text{Gallons reduced} = (14{,}600\ \text{ft}^2)*(50.2\ \text{in / yr})*(0.6233\ \text{gallons / in-ft}^2)*(0.9)$$

$$\text{Gallons reduced} = 411{,}146\ \text{gallons / yr}$$

The green roof would prevent 411,126 gallons of stormwater from entering the sewer each year. This equates to a 53.3% reduction from the total amount of water that falls on the Psychology Building's roof. This is a significant reduction and may have an impact on the SS 6.1 LEED credit.

7.3 Green Roof Impact on LEED Conclusions

There were only two credits that had the potential of being attainable with the addition of a green roof. The Sustainable Sites 6.1 Credit remains a maybe because the actual impact on the storm sewer is unknown even though the green roof appears to save 53.3% of the water from entering it. The Water Efficiency 1.2 credit will be ruled out without the option of a rainwater harvesting system. If the only reason the owner wanted to add the green roof was to achieve the one extra LEED credit for a Gold Certification, it would not be recommended. The green roof would have little impact if any on additional LEED credits for the Psychology Building.

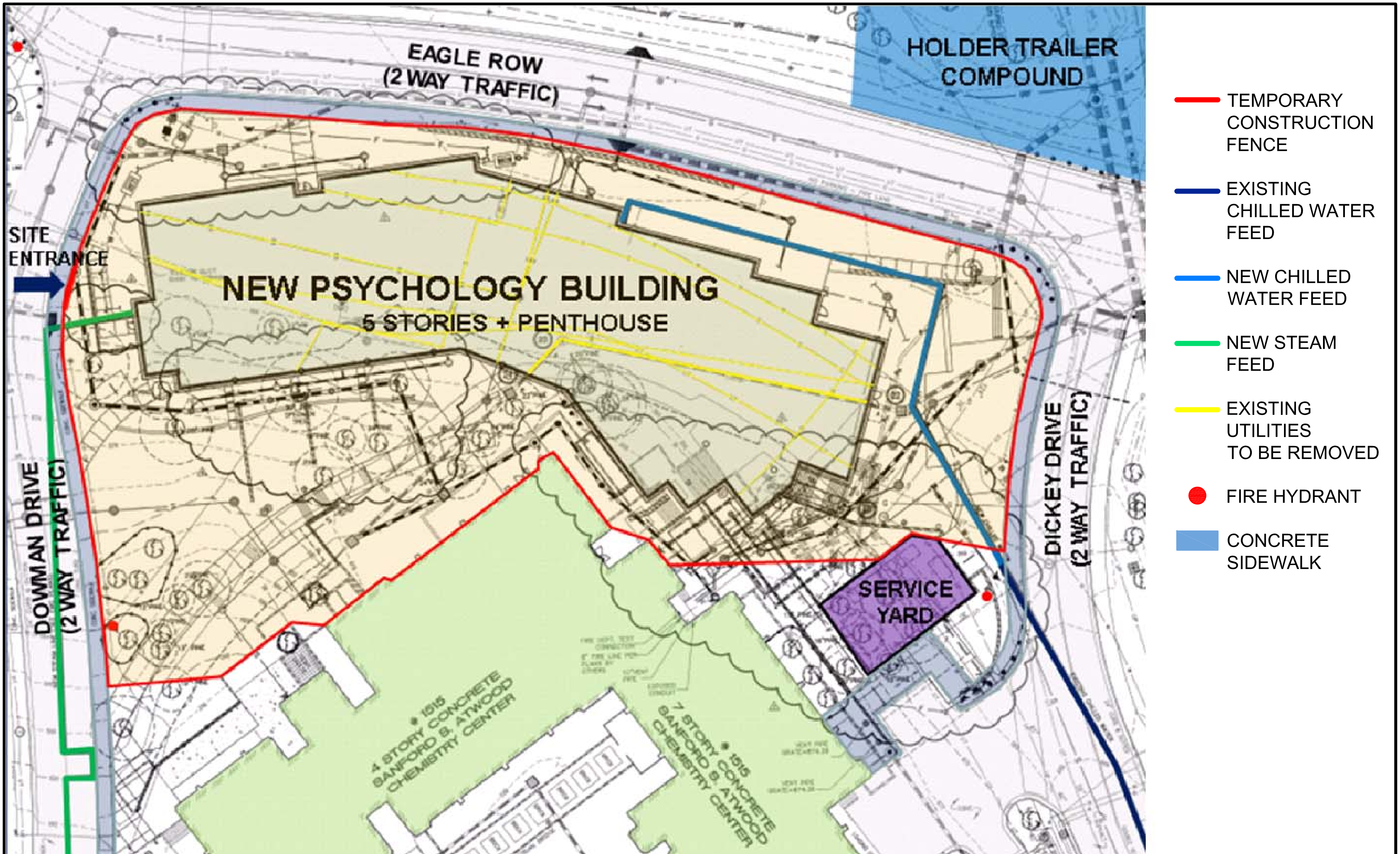
8.0 Green Roof Conclusions and Recommendations

The green roof does have a higher initial cost than the original white roof, as expected. There were some energy savings, but not nearly as much as expected. The white roof is very well insulated and saves a lot of energy already, so there is not much more to save. The maintenance costs for each roof are similar with the green roof having a slight advantage. Although adding a green roof to most buildings will help the project achieve more LEED credits, this project already earned the credits that the green roof would be eligible for. There is only one credit that would maybe be earned with a green roof.

The only true decisive victory of the green roof over the white roof was the lifespan. The green roof is expected to last twice as long as the white roof because its waterproofing membranes are protected from the sun under the growing media. For that reason, a green roof would be recommended for the Psychology Building.

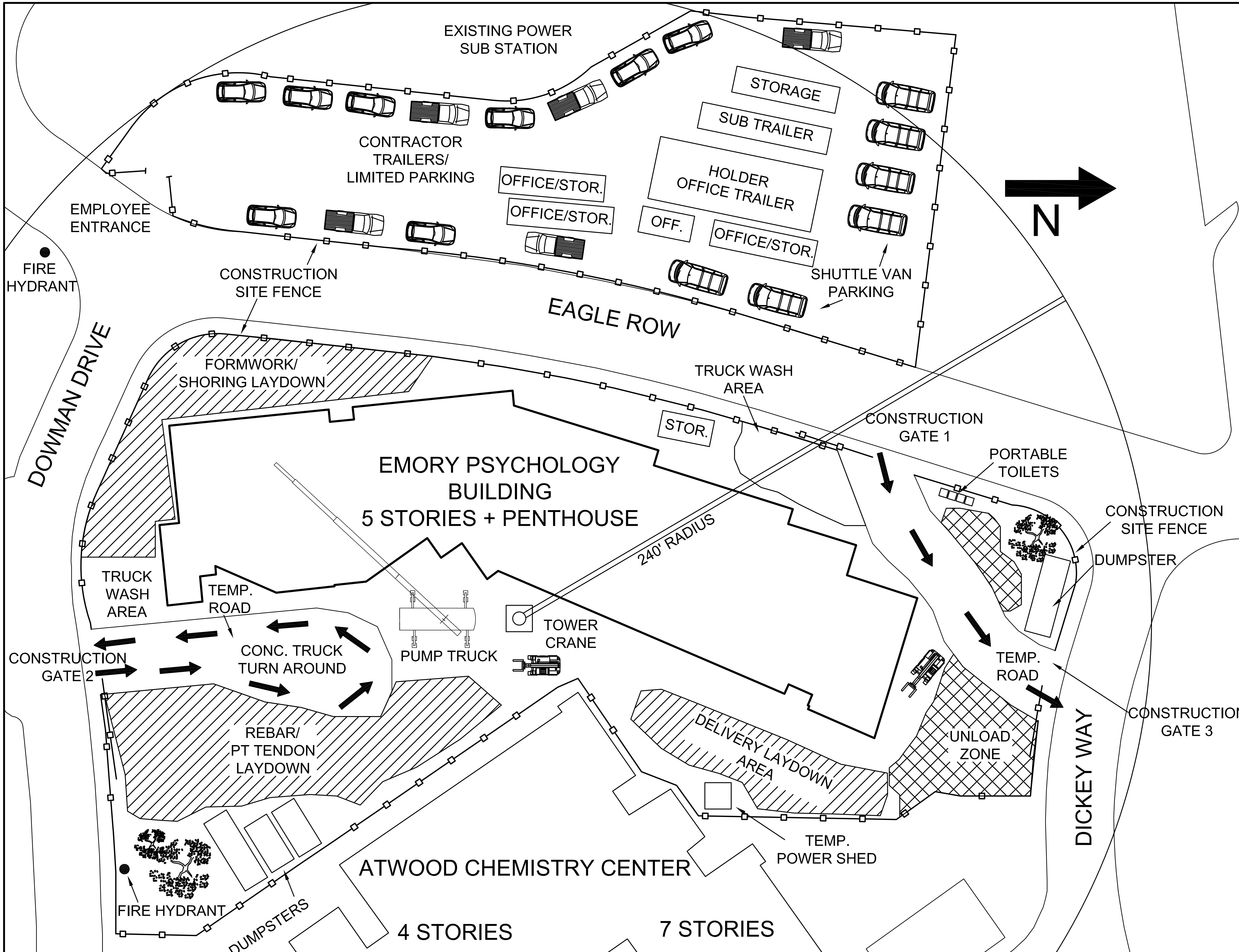
The green roof would be recommended because the owner actually has the opportunity to realize the savings of the roof. Most owners would not be guaranteed to retain ownership of their building as long as a university. Emory is almost certain to still be operating the building in 25 years when the green roof would have paid for itself. It is even likely that the building will still be around in 75 years when the savings will again be large by not having to replace the roof. The green roof was a viable option for the Psychology Building because of its lifespan and the ability of the owner to invest money now and realize the financial benefits in the future.

Appendix A: Site Plan of Existing Conditions



EMORY PSYCHOLOGY BUILDING ATLANTA, GA	**CONSTRUCTION SITE PLAN**	**CHRIS RENSHAW**	**SEPTEMBER 29, 2008**

Appendix B: Superstructure Site Plan



EMORY PSYCHOLOGY BUILDING

ATLANTA, GA

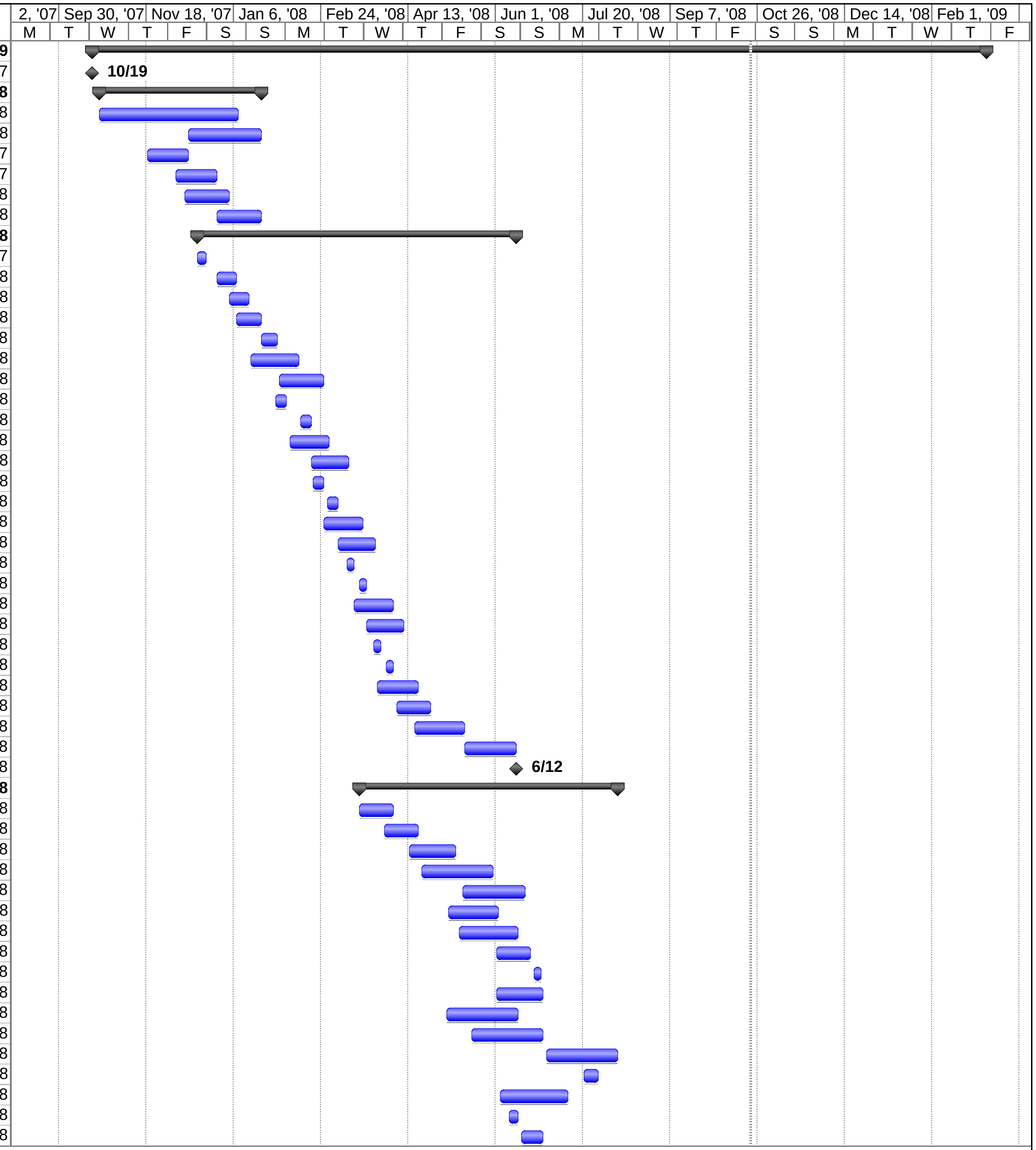
CHRIS RENSHAW

OCTOBER 24, 2008

STRUCTURE SITE PLAN

Appendix C: Overall Project Schedule

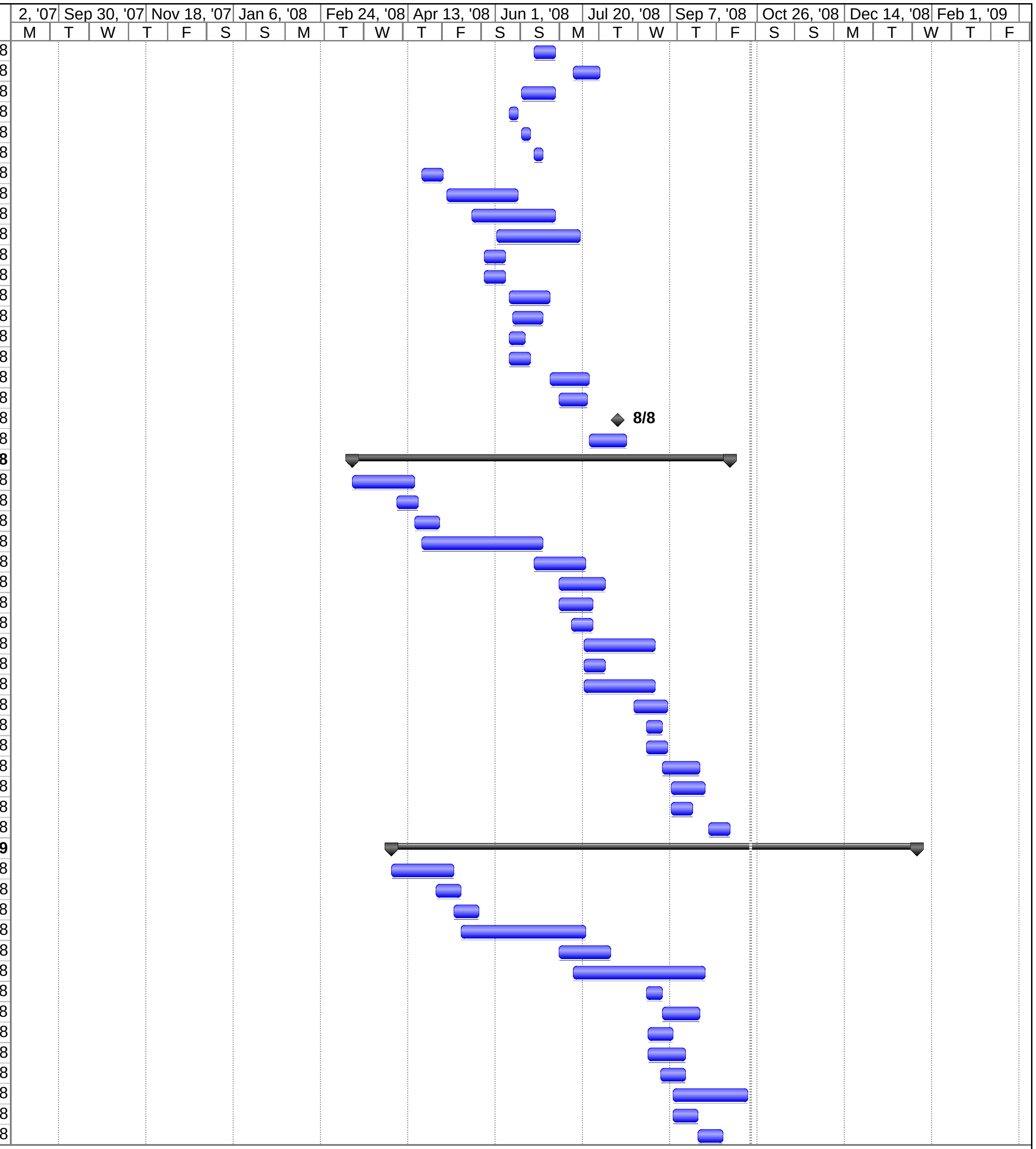
ID	Task Name	Duration	Start	Finish
1	**Emory Psychology Building**	**352 days**	**Fri 10/19/07**	**Tue 3/3/09**
2	Building Permit Obtained	0 days	Fri 10/19/07	Fri 10/19/07
3	**Substructure**	**59 days**	**Tue 10/23/07**	**Mon 1/21/08**
4	Earthwork/Site Utility Relocation	50 days	Tue 10/23/07	Tue 1/8/08
5	MEP Underground	25 days	Wed 12/12/07	Mon 1/21/08
6	Deep Foundations South	15 days	Mon 11/19/07	Tue 12/11/07
7	Deep Foundations North	15 days	Wed 12/5/07	Thu 12/27/07
8	Shallow Foundations South	15 days	Mon 12/10/07	Thu 1/3/08
9	Shallow Foundations North	15 days	Fri 12/28/07	Mon 1/21/08
10	**Superstructure**	**125 days**	**Mon 12/17/07**	**Thu 6/12/08**
11	1st Level Columns South	5 days	Mon 12/17/07	Fri 12/21/07
12	1st Level Columns North	5 days	Fri 12/28/07	Mon 1/7/08
13	SOG South	7 days	Fri 1/4/08	Mon 1/14/08
14	Electrical Underground	10 days	Tue 1/8/08	Mon 1/21/08
15	SOG North	7 days	Tue 1/22/08	Wed 1/30/08
16	2nd Level Slab South	19 days	Wed 1/16/08	Mon 2/11/08
17	2nd Level Slab North	17 days	Fri 2/1/08	Mon 2/25/08
18	2nd Level Columns South	4 days	Wed 1/30/08	Mon 2/4/08
19	2nd Level Columns North	4 days	Wed 2/13/08	Mon 2/18/08
20	3rd Level Slab South	16 days	Thu 2/7/08	Thu 2/28/08
21	3rd Level Slab North	15 days	Tue 2/19/08	Mon 3/10/08
22	3rd Level Columns South	4 days	Wed 2/20/08	Mon 2/25/08
23	3rd Level Columns North	4 days	Thu 2/28/08	Tue 3/4/08
24	4th Level Slab South	16 days	Tue 2/26/08	Tue 3/18/08
25	4th Level Slab North	15 days	Wed 3/5/08	Tue 3/25/08
26	4th Level Columns South	4 days	Mon 3/10/08	Thu 3/13/08
27	4th Level Columns North	4 days	Mon 3/17/08	Thu 3/20/08
28	5th Level Slab South	16 days	Fri 3/14/08	Fri 4/4/08
29	5th Level Slab North	15 days	Fri 3/21/08	Thu 4/10/08
30	5th Level Columns South	4 days	Tue 3/25/08	Fri 3/28/08
31	5th Level Columns North	4 days	Tue 4/1/08	Fri 4/4/08
32	Penthouse Slab South	17 days	Thu 3/27/08	Fri 4/18/08
33	Penthouse Slab North	15 days	Mon 4/7/08	Fri 4/25/08
34	Penthouse South Steel	20 days	Thu 4/17/08	Wed 5/14/08
35	Penthouse North Steel	21 days	Thu 5/15/08	Thu 6/12/08
36	Top Out Structure	0 days	Thu 6/12/08	Thu 6/12/08
37	**Exterior Skin**	**105 days**	**Mon 3/17/08**	**Fri 8/8/08**
38	1st Level Masonry	15 days	Mon 3/17/08	Fri 4/4/08
39	2nd Level Masonry	15 days	Mon 3/31/08	Fri 4/18/08
40	South Elev. Levels 3-6	20 days	Mon 4/14/08	Fri 5/9/08
41	West Elev. Levels 3-6	30 days	Mon 4/21/08	Fri 5/30/08
42	North Elev. Levels 3-6	25 days	Wed 5/14/08	Tue 6/17/08
43	South Elev. Waterproofing	20 days	Tue 5/6/08	Mon 6/2/08
44	South Elev. Stone	25 days	Mon 5/12/08	Fri 6/13/08
45	South Elev. Stucco/Glazing	15 days	Mon 6/2/08	Fri 6/20/08
46	South Elev. Curtain wall	4 days	Mon 6/23/08	Thu 6/26/08
47	South Elev. Penthouse Soffit	20 days	Mon 6/2/08	Fri 6/27/08
48	West Elev. Waterproofing	30 days	Mon 5/5/08	Fri 6/13/08
49	West Elev. Stone	30 days	Mon 5/19/08	Fri 6/27/08
50	West Elev. Stucco/Glazing	30 days	Mon 6/30/08	Fri 8/8/08
51	West Elev. Curtain wall	6 days	Mon 7/21/08	Mon 7/28/08
52	West Elev. Penthouse Soffit	28 days	Wed 6/4/08	Fri 7/11/08
53	North Elev. Waterproofing	5 days	Mon 6/9/08	Fri 6/13/08
54	North Elev. Stone	10 days	Mon 6/16/08	Fri 6/27/08



Project: Emory Detailed Schedule.mpp
Date: Wed 10/22/08

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

ID	Task Name	Duration	Start	Finish
55	North Elev. Stucco/Glazing	10 days	Mon 6/23/08	Fri 7/4/08
56	North Elev. Curtain wall	11 days	Tue 7/15/08	Tue 7/29/08
57	North Elev. Penthouse Soffit	15 days	Mon 6/16/08	Fri 7/4/08
58	East Elev. Waterproofing	5 days	Mon 6/9/08	Fri 6/13/08
59	East. Elev. Stone	5 days	Mon 6/16/08	Fri 6/20/08
60	East Elev. Stucco	5 days	Mon 6/23/08	Fri 6/27/08
61	Curtain Wall Layout	10 days	Mon 4/21/08	Fri 5/2/08
62	Curtain Wall South	30 days	Mon 5/5/08	Fri 6/13/08
63	Curtain Wall North	35 days	Mon 5/19/08	Fri 7/4/08
64	East Elev. Penthouse	35 days	Mon 6/2/08	Fri 7/18/08
65	Built Up Roof South	10 days	Mon 5/26/08	Fri 6/6/08
66	Roof Membrane South	10 days	Mon 5/26/08	Fri 6/6/08
67	Clay Tile South	17 days	Mon 6/9/08	Tue 7/1/08
68	Gutters and Downspouts South	13 days	Wed 6/11/08	Fri 6/27/08
69	Built Up Roof North	7 days	Mon 6/9/08	Tue 6/17/08
70	Roof Membrane North	10 days	Mon 6/9/08	Fri 6/20/08
71	Clay Tile North	16 days	Wed 7/2/08	Wed 7/23/08
72	Gutters and Downspouts North	12 days	Mon 7/7/08	Tue 7/22/08
73	Building Dry In	0 days	Fri 8/8/08	Fri 8/8/08
74	Penthouse Steel Spray on	15 days	Thu 7/24/08	Wed 8/13/08
75	**1st Floor Interior**	**152 days**	**Thu 3/13/08**	**Fri 10/10/08**
76	MEP/Spk. Overhead Rough Ins	25 days	Thu 3/13/08	Wed 4/16/08
77	Wall Framing/Door Frames	10 days	Mon 4/7/08	Fri 4/18/08
78	Bathroom Plumbing Rough In	10 days	Thu 4/17/08	Wed 4/30/08
79	Electrical Rough In/Pull Wire	50 days	Mon 4/21/08	Fri 6/27/08
80	Walls and Insulation	21 days	Mon 6/23/08	Mon 7/21/08
81	Duct and Plumbing Insulation	20 days	Mon 7/7/08	Fri 8/1/08
82	Install ACT Grid/Frame Gyp. Ceiling:	15 days	Mon 7/7/08	Fri 7/25/08
83	Hang Drywall/Finish	10 days	Mon 7/14/08	Fri 7/25/08
84	Set Spk. Heads/Light Fixtures/Diffus	30 days	Mon 7/21/08	Fri 8/29/08
85	Prime Paint	10 days	Mon 7/21/08	Fri 8/1/08
86	Ornamental Staircase	30 days	Mon 7/21/08	Fri 8/29/08
87	Finish Paint/Drop ACT	15 days	Mon 8/18/08	Fri 9/5/08
88	Bathroom Tile/Countertops	7 days	Mon 8/25/08	Tue 9/2/08
89	Terrazzo Flooring	10 days	Mon 8/25/08	Fri 9/5/08
90	Bathroom Partitions/Fixtures/Finishe	15 days	Wed 9/3/08	Tue 9/23/08
91	Carpet/Linoleum	15 days	Mon 9/8/08	Fri 9/26/08
92	Millwork	10 days	Mon 9/8/08	Fri 9/19/08
93	Interior Glazing and Door Installatior	10 days	Mon 9/29/08	Fri 10/10/08
94	**2nd Floor Interior**	**211 days**	**Fri 4/4/08**	**Fri 1/23/09**
95	MEP/Spk. Overhead Rough Ins	25 days	Fri 4/4/08	Thu 5/8/08
96	Wall Framing/Door Frames	10 days	Tue 4/29/08	Mon 5/12/08
97	Bathroom Plumbing Rough In	10 days	Fri 5/9/08	Thu 5/22/08
98	Electrical Rough In/Pull Wire	50 days	Tue 5/13/08	Mon 7/21/08
99	Duct and Plumbing Insulation	21 days	Mon 7/7/08	Mon 8/4/08
100	Terrazzo Flooring	54 days	Tue 7/15/08	Fri 9/26/08
101	Bathroom Tile/Countertops	7 days	Mon 8/25/08	Tue 9/2/08
102	Bathroom Partitions/Fixtures/Finishe	15 days	Wed 9/3/08	Tue 9/23/08
103	Walls and Insulation	10 days	Tue 8/26/08	Mon 9/8/08
104	Install ACT Grid/Frame Gyp. Ceiling:	15 days	Tue 8/26/08	Mon 9/15/08
105	Hang Drywall/Finish	10 days	Tue 9/2/08	Mon 9/15/08
106	Set Spk. Heads/Light Fixtures/Diffus	30 days	Tue 9/9/08	Mon 10/20/08
107	Prime Paint	10 days	Tue 9/9/08	Mon 9/22/08
108	Wood/Fabric Panels	10 days	Tue 9/23/08	Mon 10/6/08



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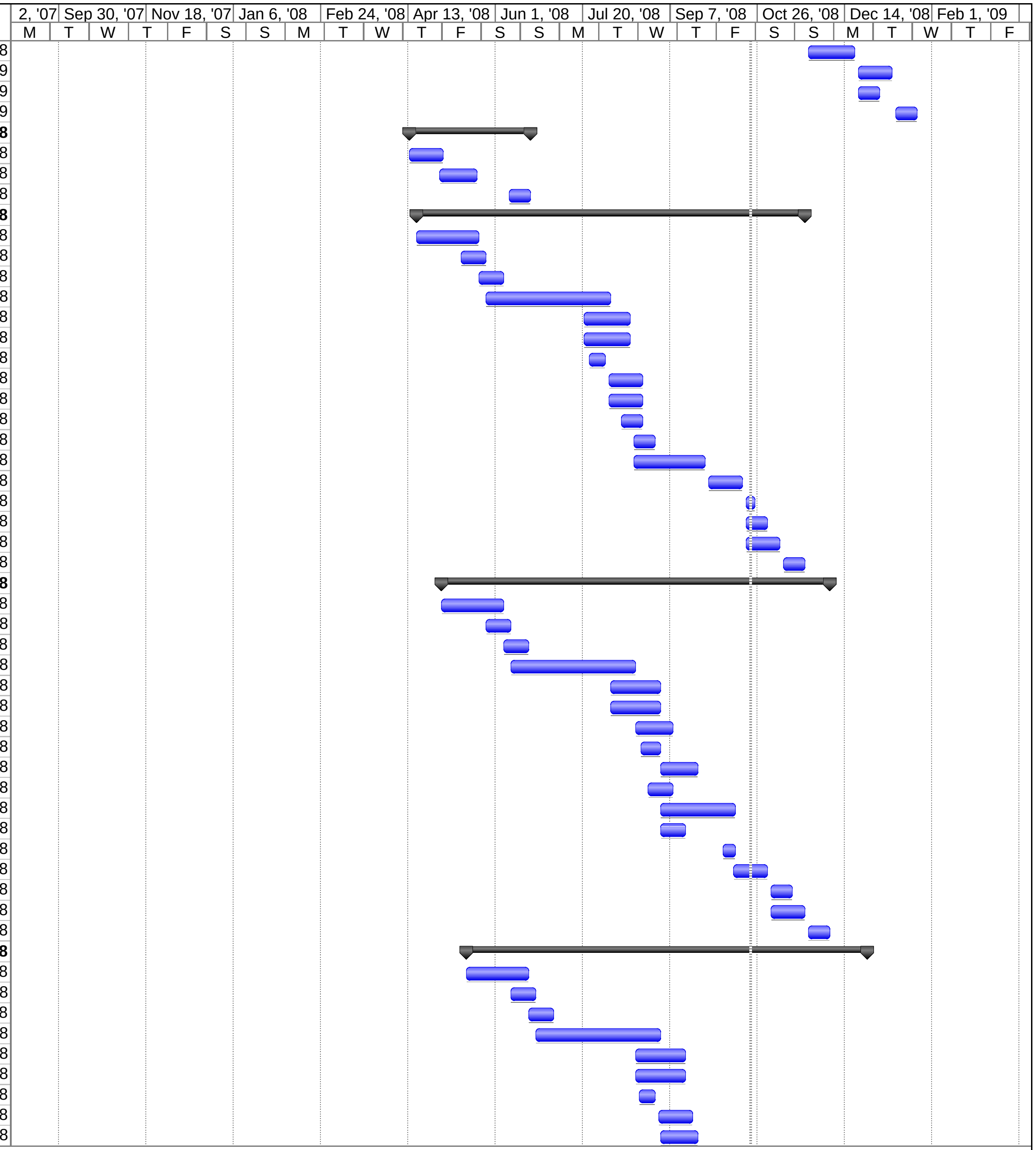
Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

ID	Task Name	Duration	Start	Finish
109	Finish Paint/Drop ACT	20 days	Mon 11/24/08	Fri 12/19/08
110	Carpet/Linoleum	15 days	Mon 12/22/08	Fri 1/9/09
111	Millwork	10 days	Mon 12/22/08	Fri 1/2/09
112	Interior Glazing and Door Installatior	10 days	Mon 1/12/09	Fri 1/23/09
113	**Stairs**	**50 days**	**Mon 4/14/08**	**Fri 6/20/08**
114	North Stairs	15 days	Mon 4/14/08	Fri 5/2/08
115	Central Stairs	15 days	Thu 5/1/08	Wed 5/21/08
116	South Stairs	10 days	Mon 6/9/08	Fri 6/20/08
117	**3rd Floor Interior**	**156 days**	**Fri 4/18/08**	**Fri 11/21/08**
118	MEP/Spk. Overhead Rough Ins	25 days	Fri 4/18/08	Thu 5/22/08
119	Wall Framing/Door Frames	10 days	Tue 5/13/08	Mon 5/26/08
120	Bathroom Plumbing Rough In	10 days	Fri 5/23/08	Thu 6/5/08
121	Electrical Rough In/Pull Wire	50 days	Tue 5/27/08	Mon 8/4/08
122	Walls and Insulation	20 days	Mon 7/21/08	Fri 8/15/08
123	Duct and Plumbing Insulation	20 days	Mon 7/21/08	Fri 8/15/08
124	Bathroom Tile/Countertops	7 days	Thu 7/24/08	Fri 8/1/08
125	Bathroom Partitions/Fixtures/Finishe	15 days	Mon 8/4/08	Fri 8/22/08
126	Install ACT Grid/Frame Gyp. Ceiling:	15 days	Mon 8/4/08	Fri 8/22/08
127	Hang Drywall/Finish	10 days	Mon 8/11/08	Fri 8/22/08
128	Prime Paint	10 days	Mon 8/18/08	Fri 8/29/08
129	Set Spk. Heads/Light Fixtures/Diffus	30 days	Mon 8/18/08	Fri 9/26/08
130	Finish Paint	15 days	Mon 9/29/08	Fri 10/17/08
131	Drop ACT	5 days	Mon 10/20/08	Fri 10/24/08
132	Millwork	10 days	Mon 10/20/08	Fri 10/31/08
133	Carpet/Linoleum	15 days	Mon 10/20/08	Fri 11/7/08
134	Interior Glazing and Door Installatior	10 days	Mon 11/10/08	Fri 11/21/08
135	**4th Floor Interior**	**156 days**	**Fri 5/2/08**	**Fri 12/5/08**
136	MEP/Spk. Overhead Rough Ins	25 days	Fri 5/2/08	Thu 6/5/08
137	Wall Framing/Door Frames	10 days	Tue 5/27/08	Mon 6/9/08
138	Bathroom Plumbing Rough In	10 days	Fri 6/6/08	Thu 6/19/08
139	Electrical Rough In/Pull Wire	50 days	Tue 6/10/08	Mon 8/18/08
140	Walls and Insulation	20 days	Tue 8/5/08	Mon 9/1/08
141	Duct and Plumbing Insulation	20 days	Tue 8/5/08	Mon 9/1/08
142	Install ACT Grid/Frame Gyp. Ceiling:	15 days	Tue 8/19/08	Mon 9/8/08
143	Bathroom Tile/Countertops	7 days	Fri 8/22/08	Mon 9/1/08
144	Bathroom Partitions/Fixtures/Finishe	15 days	Tue 9/2/08	Mon 9/22/08
145	Hang Drywall/Finish	10 days	Tue 8/26/08	Mon 9/8/08
146	Set Spk. Heads/Light Fixtures/Diffus	30 days	Tue 9/2/08	Mon 10/13/08
147	Prime Paint	10 days	Tue 9/2/08	Mon 9/15/08
148	Drop ACT	5 days	Tue 10/7/08	Mon 10/13/08
149	Finish Paint	15 days	Mon 10/13/08	Fri 10/31/08
150	Millwork	10 days	Mon 11/3/08	Fri 11/14/08
151	Carpet/Linoleum	15 days	Mon 11/3/08	Fri 11/21/08
152	Interior Glazing and Door Installatior	10 days	Mon 11/24/08	Fri 12/5/08
153	**5th Floor Interior**	**161 days**	**Fri 5/16/08**	**Fri 12/26/08**
154	MEP/Spk. Overhead Rough Ins	25 days	Fri 5/16/08	Thu 6/19/08
155	Wall Framing/Door Frames	10 days	Tue 6/10/08	Mon 6/23/08
156	Bathroom Plumbing Rough In	10 days	Fri 6/20/08	Thu 7/3/08
157	Electrical Rough In/Pull Wire	50 days	Tue 6/24/08	Mon 9/1/08
158	Walls and Insulation	20 days	Tue 8/19/08	Mon 9/15/08
159	Duct and Plumbing Insulation	20 days	Tue 8/19/08	Mon 9/15/08
160	Bathroom Tile/Countertops	7 days	Thu 8/21/08	Fri 8/29/08
161	Bathroom Partitions/Fixtures/Finishe	15 days	Mon 9/1/08	Fri 9/19/08
162	Install ACT Grid/Frame Gyp. Ceiling:	15 days	Tue 9/2/08	Mon 9/22/08



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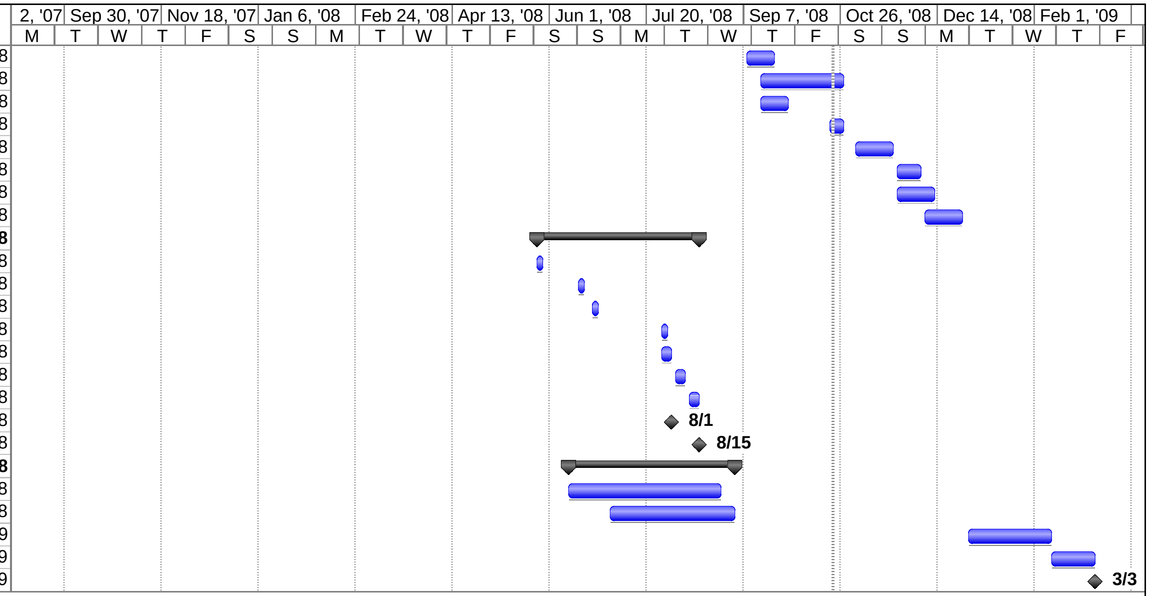
Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

ID	Task Name	Duration	Start	Finish
163	Hang Drywall/Finish	10 days	Tue 9/9/08	Mon 9/22/08
164	Set Spk. Heads/Light Fixtures/Diffus	30 days	Tue 9/16/08	Mon 10/27/08
165	Prime Paint	10 days	Tue 9/16/08	Mon 9/29/08
166	Drop ACT	5 days	Tue 10/21/08	Mon 10/27/08
167	Finish Paint	15 days	Mon 11/3/08	Fri 11/21/08
168	Millwork	10 days	Mon 11/24/08	Fri 12/5/08
169	Carpet/Linoleum	15 days	Mon 11/24/08	Fri 12/12/08
170	Interior Glazing and Door Installatior	15 days	Mon 12/8/08	Fri 12/26/08
171	**MEP Installation/Start Up**	**60 days**	**Mon 5/26/08**	**Fri 8/15/08**
172	Automatic Transfer Switch	3 days	Mon 5/26/08	Wed 5/28/08
173	Set 25 KV Loop Switch	3 days	Mon 6/16/08	Wed 6/18/08
174	Transformer	3 days	Mon 6/23/08	Wed 6/25/08
175	Generator	3 days	Mon 7/28/08	Wed 7/30/08
176	Energize 25 KV Loop Switch	5 days	Mon 7/28/08	Fri 8/1/08
177	AHU & ERU Start Up	5 days	Mon 8/4/08	Fri 8/8/08
178	Chill Water Start up	5 days	Mon 8/11/08	Fri 8/15/08
179	Permanent Power	0 days	Fri 8/1/08	Fri 8/1/08
180	Conditioned Air	0 days	Fri 8/15/08	Fri 8/15/08
181	**Elevators**	**60 days**	**Wed 6/11/08**	**Tue 9/2/08**
182	4500 lb Elevator	55 days	Wed 6/11/08	Tue 8/26/08
183	3500 lb Elevator	45 days	Wed 7/2/08	Tue 9/2/08
184	Lansdscaping	30 days	Tue 12/30/08	Mon 2/9/09
185	Occupancy	16 days	Tue 2/10/09	Tue 3/3/09
186	Substantial Completion	0 days	Tue 3/3/09	Tue 3/3/09



Project: Emory Detailed Schedule.mpp
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Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

Appendix D: BIM Practices by Construction Manager

Holder BIM Practices

Each project that Holder either bids for or is asked to build is assessed for BIM use. The first step is a BIM Assessment and Planning Meeting where they decide whether BIM services will be appropriate or not. Following this meeting there is another meeting with the preconstruction department which performs a similar assessment. The specifics that the team is looking for are:

- Staffing resources
- Cost benefit of BIM use
- Building type
- If the owner is bought in
- Other project team players
- Subcontractor ability to model in 3D

The experience of Holder has shown that even if they absorb some of the upfront costs of BIM, they acceleration in coordination and reduced field clashes will still pay off. If the owner is bought into BIM use, they may pick up the BIM costs as a pre-construction services fee.

Once the project has been given the go ahead to use BIM, the BIM department will create the model from 2D architect's drawings. Unlike the Psychology Building, most architects do not model their designs. Holder will also model the MEP systems since most engineers also do not use 3D modeling. The first place that the model is actually used is in the business development department to show the phasing of the project. The model is combined with a schedule using Naviswork's Timeliner as part of the business development.

The specific BIM coordination requirements and submission of models is written into the contracts of subcontractors. The coordination process starts during pre-construction and involves Holder, the architect, engineers, and necessary subcontractors. The coordination starts early so that the subcontractors can learn the ways that they have to use BIM and be fully self-sufficient by the time construction starts. Training is necessary by the Holder BIM department in some cases. Holder would like the MEP subcontractors to produce their own models once they have a grasp on the software. Until then, Holder must create the model and not simply just manage it.

The files for the model are kept in the main office, with an FTP site that may be accessed from anywhere with internet connection. This is how the field staff accesses the model and finds updates. Holder has a BIM field coordinator onsite to manage the model during construction. The costs for this person, creation of the model, and pre-construction BIM services are charged to the project, while the business development is charged as corporate overhead.

Holder also uses the model for quantity take offs. For verification, they also estimate quantities using traditional methods. Usually the model is created by Holder for estimation. Even if the architect designed in 3D, the model is not always usable for estimation and has to be recreated.

Holder hands the model over to the owner after the project is complete. This is an as built model but it can also be modified to include facility management services. The services are provided at an extra fee but include equipment manuals, warranties, and other information that they owner may need.

Although Holder has used BIM very well, there is still a learning curve associated with it. As recent as the Psychology Building, Holder was using Navisworks in a way that was inefficient. They have since fixed this and learned from their mistakes. Other than that, Holder claims that they see no pitfalls of BIM and fully support its use on their projects. They continue to learn more about BIM and what they can add to it as they continue to use it.

One thing that was mentioned that could have been used more frequently was a smart board. The smart board allows the user to project the model onto the board and navigate it through a computer. The board can be written on with a marker, then the mark ups can be printed off along with what else is on the screen. Holder feels that the use of this more often would have caused more efficiency.

Also, Holder would like to have the model be more accessible to all the workers who may need it onsite. Currently, if there is a coordination problem that needs to be visualized on the model, the worker must talk to their foreman, the foreman must go to Holder's trailer, and someone must bring up the model to look up the problem. A portable kiosk would eliminate this path and bring the worker directly to the model. The kiosk would be on site and available to all workers to use. The workers could solve their own problems immediately and be more efficient.

Construction Manager A BIM Practices

Construction Manager A analyzes the risks involved with each project before they decide to use BIM. The largest risk that they face is cost; if using BIM will eventually pay for itself on the project through increased coordination and a reduction in field clashes. Specifically what they look for is:

- MEP Complexity
- Site Logistics
- Structural Steel (complexity and quantity)
- Façade (complexity)
- Subcontractor Availability

There are several costs associated with the model and it must be established whether the model can be used for all of these things and pay off as well. CM A does not create the model in house and instead contracts a third party to create it for them. Also, CM A rarely finds an architect that designs in 3D and assumes that if they are going to use BIM that they will have to pay to have the model created. For them, the architect does not play a large role and while it is somewhat easier to be on a project earlier, it does not make or break the project. CM A is writing language into the contract to make sure that contractors will provide their models in the file types that they require. They are also finding that more owners are starting to get on board with BIM, but they still don't know how to articulate what they want from the model.

Some of the things that CM A likes about BIM are that it makes processes faster when they track RFIs and change bulletins to the model. The problems or unclear issues that may take a long time to describe can be shown easily through the model. This makes it easier to solve the problem, and get it worked out in the field. It also makes it easier to determine what work they are contracted to do and what they may be asked to do, but are not actually contractually obligated. They can bring this to the attention of the owner or contractor before the work gets done instead of rushing to do it and having to worry about who will pay for it afterwards.

One of the things that this CM has found extremely useful is tracking of materials through the model. Basically any material can be tracked, but this CM has had much success with tracking steel members on projects that are very large ($100 million +). The members can be tracked using bar codes, similar to how delivery companies like Fedex track packages. The model can actually display what that member is and what date it is scheduled to be delivered to site.

The software that they are using for this kind of tracking is actually fairly widely used throughout the construction industry. It is called Vela Systems and it was developed by an architect who had field experience. The software is used by so many because it is user friendly and reliable. They have been able to track steel as well as other long lead items that have the potential to be problematic. For one project it was used to track the façade shipments because the façade was composed of integral cast stone which was complex had a specific arrangement to be constructed. Through the model each component could be tagged to ease confusion during construction and ensure the quality that they desired.

Another innovation CM A is implementing is electronic closeout using BIM. Instead of collecting paper closeout documents and handing them over to the owner, CM A would like to have all these items linked to the model in PDF format. The documents would include owner's manuals, warranties, insurance information, and preventative maintenance information. The goal is to link the software to preventative maintenance software so that the model could tell the owner when they need to perform preventative maintenance, or if a warranty may soon expire. The model can actually be loaded onto a tablet PC, which can be carried around the building while doing inspections. The tablet PC has the ability to take notes, record audio, and take pictures. This would be used primarily by the end user's maintenance staff, but could also be used by CM A during construction for punch listing. This application is being implemented on a current project that has yet to reach the close out phase.

CM A thinks that there is still more that they could be using the model for. For instance, the model could be updated to show inspections of ducts and pipes throughout the building. The model would then easily display what has been inspected and what still needs to be inspected.

One of the pitfalls of BIM, although small, is that the model can hold too much information. The model has information for a lot of people, from the duct fabricators to the owner, but those people do not require the same information. The owner will not care what gauge the ductwork is, but the information is likely to be carried through the model and increase the file size. It is important for the CM to realize the owner's needs and adjust the model information accordingly.

Another challenge is that there are so many new technologies emerging that it is difficult to sift through them and find what will work best for their needs. Also, as a large company, the upper management wants to set guidelines and rules for using BIM, but they will not necessarily work for each project. Success with BIM on one project, for one application, may be a waste of time on another project for the same thing. Each project is unique, and the approach to BIM must be unique as well. If the use of BIM is forced, it will not present the amount of success that it is capable of achieving. There also has to be an understanding that the first couple of projects using BIM may not be profitable at first, but the payback will come learn after the users have passed the learning curve.

Construction Manager B BIM Practices

Construction Manager B's approach to BIM is slightly different than other CMs. They see potential to use BIM on every project. Their view is that even if BIM is only used for a small part of a small project, it will probably still help that project. Even if the magnitudes of the benefits are not as large, the benefit is there nonetheless. Their objective is to find out what part of a project may benefit from BIM, in apply BIM in any way that may help. The overarching goal is to use BIM in some way on every project.

The complexity of how building systems is somewhat of a factor in their decision making, but it is not the only thing. A project with a complex MEP system and tight spaces to fit it in would obviously benefit from using BIM, but it is not the only type of project that will benefit. A smaller project may have less coordination to do, but it will also have less time to invest with the model, so it still may be worthwhile to use BIM.

They start to think about how they may be able to use BIM while reviewing the RFP. The earlier that they know how there are going to use BIM, the sooner they can get the ball rolling and start to collect information that will help them build the model and apply information to it. Like on the Psychology Building, if much of the work can be completed in pre-construction, the construction phase will go smoother.

CM B is still finding that owners are apprehensive about using BIM. They have heard a lot about it, but what they have heard is that it is expensive and the benefits are hard to quantify. Their lack of BIM knowledge prevents them from wanting to implement BIM on projects, not necessarily the cost. Even if they do want to use BIM, they are still unsure about what that means, how to get it, and how to ask for it.

Like Holder, CM B assesses the project "players" when looking how to implement BIM. They use past experience and look at what the other players are required to provide to make their decision. For instance, the architect may be required to provide a model, which would immediately make the project a good candidate for BIM use. Knowledge of the owner, engineers, and subcontractors also helps because the whole group will work as a collaborative team with the BIM. Without full cooperation and collaboration, it is almost impossible for a BIM project to reach its full potential.

CM B will use the model that an architect has created if it is available but is also capable of creating a model on their own. Getting the model from the architect can give the CM a head start on their on BIM even if there is no information linked to it. It is a help, but whether the CM gets the model from the architect or not is not going to determine whether or not they use BIM. Another thing that may affect the architect's model is interoperability. The program that the architect is using may not always be useful for

CM B and what they want to use it for, so they may have to create a new model anyway. Interoperability is always a concern since there are always new products coming out, but there are enough people paying attention to interoperability that problems are becoming less and less frequent. Subcontractors are expected to create a model of their own system for clash detection.

In addition to clash detection, CM B has been able to use BIM for 4D modeling (for proposal presentation, assessing schedule scenarios, and virtual mock-ups), material tracking, and automated quantity estimating. CM B has been very happy with the results of all their applications of BIM and predict that there will be even more uses in the future, they just have not thought of them yet.

CM B is realizing the benefits of BIM in several ways. Clash detection decreases field modifications and improves field productivity; 4D modeling improves understanding by visualization; automated material estimating decreases the time it takes to complete a material take-off. However, BIM's greater positive effect is on a broader level. BIM is facilitating integrated project delivery, an approach where owners, architects, engineers, contactors, and subcontractor together form an integrated project team. This is a fundamental change from tradition in how a team is structured and how information is shared and exchanged. It promotes a level of collaboration that really allows the specific benefits of BIM to be realized.

For CM B, BIM is something that could be implemented on every project at some point, but that point still may be 15-20 years away. They view BIM as CAD was viewed several years ago. At first it was slow to catch on, but eventually it became used industry wide. Of course, that means BIM could be overtaken by another tool several years from now and become obsolete itself.

Most of the issues that CM B has faced with BIM thus far have stemmed from either lack of experience with the new software and tools or from software limitations. The industry as a whole is still towards the beginning of the learning curve, so lack of experience with the tools can impede success. BIM technologies and programs are also fairly new and not necessarily time-tested. As experience is gained with the tools, the limitations are discovered. Communicating these limitations back to the developers helps mold future versions of the technologies.

Construction Manager C BIM Practices

Construction Manager C was asked about how they are using BIM on a large, multi-phased hospital project. CM C has been the contractor for every phase, but they did not implement BIM until the second phase. Each phase was awarded separately, so it was hard to tell if BIM would have been cost effective on the first phase. At the start of the second phase CM C realized that there was a tool available that could save time and money on the complex job. It was at that time that they decided to convince the owner and subcontractors that BIM was they way to go for the project.

CM C has a BIM department, but they do not create the model. The modeling services are purchased from a third party contractor who converts the architect’s and structural engineer’s drawings from 2D to 3D. The subcontractors then received the model and updated their discipline to it. CM C’s BIM department works out of their regional office and attempts to sell owners on the benefits of BIM.

There was a premium to pay by starting a new group on BIM use. The premium comes by having to educate the subcontractors, purchase the model, purchase the clash detection programs, and making sure the subcontractors are up to speed and know what is expected of them. The CM believes that with the superior coordination, the BIM has already more than paid for itself.

The BIM use on this building started with MEP coordination. The interstitial floors of the hospital contained complex MEP systems that were tightly fitted into the space. BIM was used to make sure that everything fit with no clashes. With the success of those areas, CM C decided to use the BIM in more ways. There was a pavilion area with a lot of materials and different building aspects coming together that was hard to visualize from the 2D drawings. The CM C project executive decided that using BIM was worth a shot since it had been so successful before. Right away, the BIM revealed that there was a gutter running through the façade's stone through several parts of the building. The stone that arrived on site was pre-cut, so if the BIM did not catch this, the stone would have all been delivered and ready to install, but would have had to been cut on site. This would've led to an enormous cost increase and a considerable delay to the schedule. Instead, it was sorted out in the model and the stone cutters were able to cut the stone offsite.

The subcontractors on the project also realize the benefits of BIM use. Although displeased with having to change at first, they soon found that the BIM was saving them time and money. There was an initial learning curve, but the time and material savings in the field were tremendous. One mechanical contractor mentioned that they hadn't had to take even a pickup truckload of wasted piping out of the building due to field clashes and rework. For a building with a mechanical package coming in at around $90 million, that is saying something. Another mechanical contractor, a 30 year veteran, said that without BIM there was absolutely no way that they would have been able to get air handlers into the interstitial spaces with traditional methods. CM C estimates that 90% of the contractors are very impressed with BIM and that they will not go back to their traditional methods.

One small problem that CM C has seen with the BIM use is the owner's expectations. The owner paid for the modeling and clash detection, saw the model and was under the impression that there would be zero field clashes and would not have to pay a dime for additional delays or design problems. With today's technology, this is simply not practical. The BIM is very accurate and will greatly reduce field clashes, but there is no guarantee that it will catch them all.

CM C started using BIM on larger projects, but is starting to see the usage trickle down to smaller buildings. They see BIM is a tool that can help them build better. Since there is so much hype around BIM and it is widely talked about it, they first must understand what is tangible and what can be used for each project. They also see that investing in BIM now is one of the smartest things a CM and the subs can do. After the recession the prediction is that there will be an explosion in the number of projects being built. If the contractors want to get a piece of the pie, they need to have the tools in place already so they can get jobs, build them faster and move on to the next ones.

Appendix E: Construction Manager BIM Practices Comparison Chart

	Holder	CM A	CM B	CM C	Psychology Building
First Inquiry	BIM Assessment Meeting, during RFP review	During RFP review	During RFP Review	After risks are analyzed	During RFP review, architect already using BIM
Risks Analyzed	Building type, if owner is bought in, what other players are involved, if the trade contractors are using 3D	MEP Complexity, site logistics, structural steel quantity and complexity, architectural complexity, subcontractor availability	Overall look at building to find BIM potential, project players, requirements of other players, complex coordination	Complex MEP systems, architectural complexity	Owner was already on board, architect was already using BIM, very few extra risks to analyze
Production of the model	BIM Department creates model	Third party creates model	BIM Department capable of creating model if not provided by architect	Third party creates model	Architect Created
Architect Provided Model	Rare	Very Rare	Sometimes	Very Rare	Yes
Subcontractor Model Creation	Expected to create model for their discipline	Expected to create model for their discipline	Expected to create model for their discipline	Expected to create model for their discipline	Yes, each discipline created own model
Owner Reactions	Positive	Like BIM but still don't know a lot about it and can't always articulate wha they want from the model	Tend to be apprehensive, lack of awareness prevents them from wanting to use BIM, not cost	High expectations, expect zero field clashes since they have paid for software to eliminate this problem	Positive, enthusiastic, anticipate using BIM exclusively in the near future
MEP Clash Detection	Most common use	Most common use	Most common use	Primary Use	Used
IPD	Used if possible, but will not make or break the project	Used if possible, but will not make or break the project	Seen as a major benefit of using BIM, like to get as many project players on board early as possible	Unclear if used or not	Implemented and proved to be very successful
Material Tracking	Not used	Used frequently, a major part of the BIM implementation	Used if right for the project	Not used	Not used
Facilities Management	Has the capability, will use if owner feels the need, internally created software program to link O&Ms, warranties to the model	Tracking manuals, warranties, and insurance info to equipment, also implementing preventative maintenance software linked to BIM for owner	Used on some projects but unknown as to what degree	Unclear if used or not	Model given to Emory, but without FM software linked to it
Subcontractor Reaction	Have been met with little resistance, subcontractors benefit from learning	Positive, some contractors have been 3D modeling for years	Positive, some contractors have been 3D modeling for years	Skeptical at first but now realizing benefits after being past learning curve	Positive, mechanical contractor plans on using BIM for prefabrication in the future

	Holder	CM A	CM B	CM C	Psychology Building
4D	Have been using for planning and visualization successfully	Using 4D and even 5D (cost) for some projects	Using for proposal presentations, assessing schedule scenarios, and virtual mockups	Unclear if used or not	Used for planning different stages of the project and visualization to Emory
Estimation	Used but verified through traditional methods	Used but verified through traditional methods	Used but verified through traditional methods	Not used	Used but verified through traditional methods, Emory also contracted a separate estimator
Problems	Navisworks was not used as effectively as it could have been in the past	Corporate mentality limits experimental usage of BIM and different technologies	Interoperability can be an issue but enough people are aware of it now that it can be worked around	Very few problems, educating subcontractors was necessary to make them effective	Very few problems, the model wasn't as accessible onsite as was expected, but did not pose any problems
Room for Improvement	Using resources effectively, smartboard usage could have been increased	Unlinking old information from the model that is no longer necessary	Industry as a whole is still in the beginning of the learning curve, technology and expertise is developing	Implenting BIM earlier on in the project timeline	More use of smartboard to convey ideas
Possible New Uses	Kiosk onsite for general use	Linking inspections of duct and pipe to the model for easy visualization	Undetermined, many possible uses, new projects will bring along new methods	None presented	MEP contractor plans to use 3D model for fabrication
RFIS	Saw increase in speed of response due to visual aids	Reduction in number and time of response	Undetermined, assumed to reduce number	Decrease in number of RFIs	Saw increase in speed of response due to visual aids
Getting on Board Early	It is a help to be on earlier since things can get started and ironed out faster, but not crucial	Getting on board earlier allows for more uses early on such as 4D and 5D, estimating and value engineering	Imperative to get started as early as possible to add as much data to the model as possible	Better to get on earlier and be past learning curve by the time construction is in full operation	Entire team was brought on very earler which helped tremendously
Strongest Benefits	Experience has led to more ideas for new uses and awareness allows them to adapt technology to fit their needs	Use of material tracking and preventative maintenance software is enabling them to give the owner more of what they want	BIM facilitates IPD which helps to promote enhanced communication and will ultimately make building more efficient	Coordination on very complex and large project has made benefits huge on such a large scale	Architect and CM were both brought on board early and all players were willing to learn and use BIM to its full potential

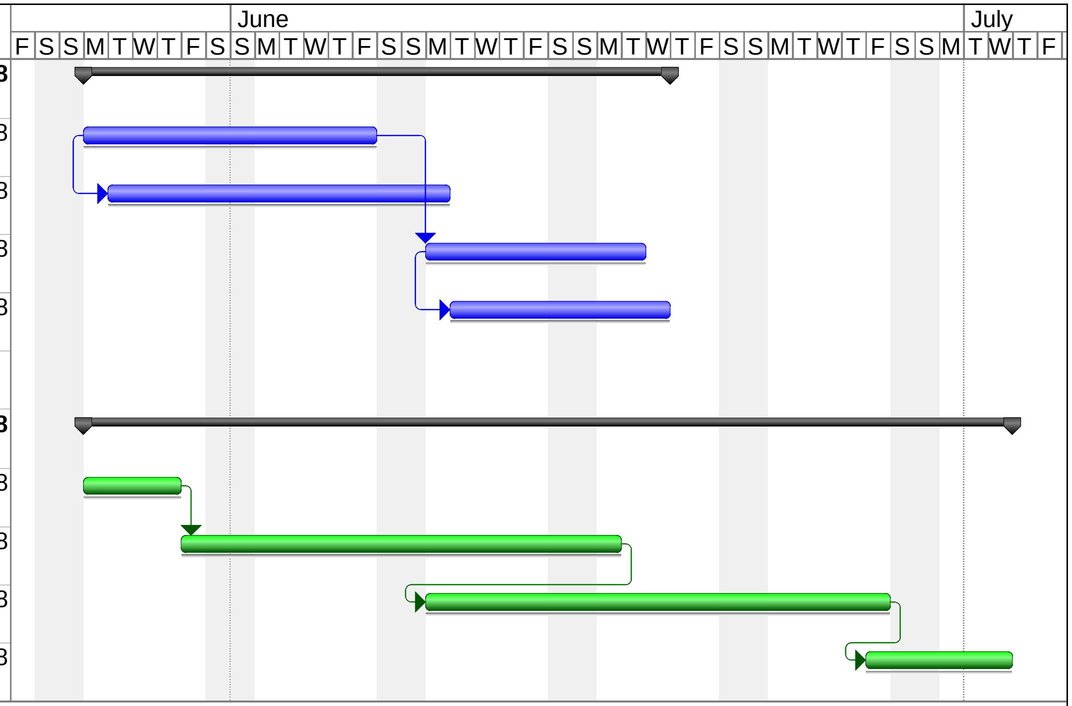
Appendix F: Green Roof Plant List

1. Sedum Kamtchaticum
2. Sedum spurium 'Fuldaglut'
3. Sedum spurium 'John Creech'
4. Sedum takesimense
5. Sedum spurium 'White Form'
6. Sedum spurium 'Eco Mt. Emei'
7. Delosperma nubigenum
8. Delosperma oberge
9. Delosperma cooperii
10. Delosperma 'Kelaidis'
11. Allium schoenoprasum
12. Talinum calycinum
13. Sedum Album 'Murale'
14. Sedum Floriferum 'W. Gold'
15. Sedum Reflexum
16. Dianthus firewitch

All plants to be provided by Saul Nurseries, Atlanta, Ga.

Appendix G: Green Roof Schedule

ID	Task Name	Duration	Start	Finish
1	**Original Roof**	**18 days**	**Mon 5/26/08**	**Wed 6/18/08**
2	Built Up Roof South	10 days	Mon 5/26/08	Fri 6/6/08
3	Roof Membrane South	10 days	Tue 5/27/08	Mon 6/9/08
4	Built Up Roof North	7 days	Mon 6/9/08	Tue 6/17/08
5	Roof Membrane North	7 days	Tue 6/10/08	Wed 6/18/08
6				
7	**Green Roof**	**28 days**	**Mon 5/26/08**	**Wed 7/2/08**
8	Vapor Barrier	4 days	Mon 5/26/08	Thu 5/29/08
9	Flashing	12 days	Fri 5/30/08	Mon 6/16/08
10	Garden Rooftop System	15 days	Mon 6/9/08	Fri 6/27/08
11	Pavers	4 days	Fri 6/27/08	Wed 7/2/08



Project: Green Roof Schedule
Date: Sat 4/4/09

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

Appendix H: Redesigned Concrete Calculations

$b_{original}$ = 12” $b_{redesign}$ = 16”

d = 28”-1.5”-0.375”- (0.875” / 2) = 25.7”

#7 bar = 0.6 in^2

f_y = 60 ksi

f'_c = 5,000 psi

Redesign

Moment

$a = (A_s*f_y) / (0.85*f'_c*b)$

a = (2.4 in^2*60,000 psi) / (0.85*5,000 psi*16”) = 2.118 in

$M_n = (A_s*f_y)*(d-(^a/_2))$

M_n = (2.4 in^2*60,000 psi)*(25.7” - ($^{2.118”}/_2$)) = 295.7 ft.-kips

□M_n = (0.9)*295.7 ft.-kips = 266.1 ft.-kips

$A_{s(min)}$ = (3*b*d*√(f'c)) / f_y = (3 * 16” *25.7” * √5,000 psi) / 60,000 psi

$A_{s(min)}$ = 1.45” (this one applies) 2.4” ≥ 1.45”

$A_{s(min)}$ = (b*d*200) / f_y = (200 * 16” *25.7”) / 60,000 psi

$A_{s(min)}$ = 1.03”

c = a/β = 2.118/0.8 = 2.65

c_{max} = 0.375*25.7 = 9.64 ≥ 2.65 (Tension Controlled)

Shear

V_c = 2*b*d*√(f'_c) = 58.15 kips

$V_s = n*A_v*f_y$

n = number of stirrups A_v = area of stirrups (#3 stirrup)

V_s = 2*(0.11 in^2)*(60,000 psi) = 13.2 kips

$\Phi(V_c + V_s)$ = 0.75*(58.15 kips + 13.2 kips) = 53.15 kips

b_{min} = 2*(1.5”) + 2*(0.375) + 4*(0.875) + 3*(1.27) = 11.06” ≤ 16”

Appendix I: Fifth Floor Roof Structural Member Take offs

Formwork:

Member	Qty.	Length (ft)	Total (ft)	Width (in)	Depth (in)	Factor	Revised Width	Added Width (in)	SFCA Increase
CB 65	4	36	144	12	22	1.33	16	4	48
CB 77	24	28	672	12	22	1.33	16	4	224
CB 77	11	26	286	12	22	1.33	16	4	95
CB 99	2	36	72	24	22	1.33	32	8	48
CB152	5	26	130	24	22	1.33	32	8	87
CB 155	5	28	140	24	22	1.33	32	8	93
CB 160	5	28	140	18	22	1.33	24	6	70
CB 165	4	28	112	24	22	1.33	32	8	75
PTB 76	1	52	52	42	22	1.33	56	14	61
PTB 78	1	52	52	18	22	1.33	24	6	26
PTB 80	1	36	36	30	22	1.33	40	10	30
PTB 85	3	36	108	30	22	1.33	40	10	90
PTB 88	1	82	82	30	22	1.33	40	10	68
PTB 100	6	70	420	33	22	1.33	44	11	385
			2446					Total =	1400
								10% waste	**1540**

Redesigned Concrete Takeoffs																
Member	Qty.	Length (ft)	Total (ft)	Width (in)	Depth (in)	Factor	Revised Width	Rebar	Qty.	Factor	Revised Rebar	Original CY	New CY	Increase	Original Tons	Revised Tons
CB 65	4	36	144	12	22	1.33	16	#8	3	2	6	10	13	3	0.5767	1.1534
CB 77	24	28	672	12	22	1.33	16	#7	2	2	4	46	61	15	1.3736	2.7471
CB 77	11	26	286	12	22	1.33	16	#7	2	2	4	19	26	6	0.5846	1.1692
CB 99	2	36	72	24	22	1.33	32	#9	4	2	8	10	13	3	0.4896	0.9792
CB152	5	26	130	24	22	1.33	32	#7	4	2	8	18	23	6	0.5314	1.0629
CB 155	5	28	140	24	22	1.33	32	#7	4	2	4	19	25	6	0.5723	1.1446
CB 160	5	28	140	18	22	1.33	24	#7	3	2	6	14	19	5	0.4292	0.8585
CB 165	4	28	112	24	22	1.33	32	#8	3	2	6	15	20	5	0.4486	0.8971
PTB 76	1	52	52	42	22	1.33	56	-	-	2	-	12	16	4	-	-
PTB 78	1	52	52	18	22	1.33	24	-	-	2	-	5	7	2	-	-
PTB 80	1	36	36	30	22	1.33	40	-	-	2	-	6	8	2	-	-
PTB 85	3	36	108	30	22	1.33	40	-	-	2	-	18	24	6	-	-
PTB 88	1	82	82	30	22	1.33	40	-	-	2	-	14	19	5	-	-
PTB 100	6	70	420	33	22	1.33	44	-	-	2	-	78	104	26	-	-
			2446											94	5.006	10.012
														98.8		**5.006**

Appendix J: Concrete Column Estimate

Item	***Labor***	***Material***	***Equipment***	***Total***
Drilled Pier Excavation	$ 26,827.20	$ -	$ 38,154.24	$ 64,981.44
Drilled Pier Concrete	$ 37,250.70	$ 357,738.00	$ 1,214.34	$ 396,203.04
Drilled Pier Rebar	$ 31,757.60	$ 92,876.00	$ 1,348.20	$ 125,981.80
Grade Beams Concrete	$ 1,147.98	$ 11,804.70	$ 969.29	$ 13,921.97
Grade Beams Rebar	$ 4,107.20	$ 8,909.00	$ 135.90	$ 13,152.10
Retaining Wall Forms	$ 95,035.15	$ 134,335.40	$ -	$ 229,370.55
Retaining Wall Conc.	$ 144,076.00	$ 867,640.00	$ 52,536.00	$ 1,064,252.00
Retaining Wall Rebar	$ 11,271.15	$ 32,085.00	$ 465.75	$ 43,821.90
SOG Forms	$ 1,900.80	$ 6,388.80	$ -	$ 8,289.60
SOG Concrete	$ 8,266.50	$ 53,955.00	$ 3,019.50	$ 65,241.00
SOG Rebar	$ 7,676.25	$ 10,132.65	$ -	$ 17,808.90
SOG Finish	$ 11,481.00	$ -	$ -	$ 11,481.00
Column Forms	**$ 55,527.57**	**$ 17,631.72**	**$ -**	**$ 73,159.29**
Column Concrete	**$ 10,626.70**	**$ 57,429.40**	**$ 3,888.92**	**$ 71,945.02**
Column Rebar	**$ 14,973.00**	**$ 37,432.50**	**$ -**	**$ 52,405.50**
Elev. Slab Forms	$ 245,540.88	$ 108,391.92	$ -	$ 353,932.80
Elev. Beam Forms	$ 304,963.15	$ 69,795.69	$ -	$ 374,758.84
Elev. Slab Concrete	$ 47,368.00	$ 339,216.00	$ 17,266.40	$ 403,850.40
Elev. Slab Rebar	$ 22,579.20	$ 71,424.00	$ -	$ 94,003.20
Elev. Beam Rebar	$ 18,562.80	$ 46,407.00	$ -	$ 64,969.80
Elev. Slab Finish	$ 51,299.00	$ -	$ -	$ 51,299.00
Structural Steel W	$ 17,236.85	$ 301,498.80	$ 12,328.73	$ 331,064.38
Structural Steel C	$ 13,996.80	$ 4,561.92	$ 1,736.64	$ 20,295.36
Decking	$ 2,485.36	$ 16,181.28	$ 264.40	$ 18,931.04
PT Allowance	$ 20,000.00	$ 50,000.00	$ 10,000.00	$ 80,000.00
Total	**$ 1,205,956.84**	**$ 2,695,834.78**	**$ 143,328.31**	**$ 4,045,119.93**

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