FINAL REPORT

The Mary J. Drexel Home Assisted Living Addition

Bala Cynwyd, PA

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Construction Option
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4/9/2014

The Mary J. Drexel Home Assisted Living Addition

Bala Cynwyd, PA

Special Thanks To:

Liberty Lutheran

SFCS

WOHLSEN CONSTRUCTION

-- Building Information --

Name: Mary J. Drexel Home
Location: 238 Belmont Ave
Bala Cynwyd, PA 19004
Occupancy Type: Assisted Living Residence
Size of West Wing: 34,100 GSF
Size of East Wing: 40,600 GSF
Number of Stories: 2 Stories
Size of Existing Mansion: 21,000 GSF
Number of Stories: 3 Stories

- GMP Contract
- 14 Month Construction Duration
- $14.6 Million Total Construction Cost

-- Project Information --

Owner: Liberty Lutheran Servives
Architect: SFCS, Inc.
GC/CM: Wohlsen Construction Company
Structural Engineer: Fitzpatrick Engineering
Site/Civil Engineer: Site Engineering Concepts
Site Contractor: Schlouch Incorporated
Mechanical Engineer: DJ Wagner Heating & AC
Electrical Engineer: Neshaminy Electrical
Plumbing Engineer: Worth & Company

-- Architecture --

- Existing three-story Mansion constructed in 1878.
- Historic Mansion receiving new attached two-story east and west wings that will serve as the Assisted Living residence.
- Each two-story wing consists of two separate "households" with each household serving 20 residents for a total Assisted Living resident population of 80 residents.

-- Structure --

- Infinity Structural Steel System: Pre-fabricated load-bearing structural metal stud walls with concrete decks.
- Structural Steel Members for longer spans for Foyer, Community Living Area, Dining Area, & Activity Kitchens

-- Mechanical --

- Variable Refrigerant Flow System (VRF)
- Rooftop Air Handling Units supply multiple indoor units, each individually controllable by its user
- Capable of cooling some spaces while heating others. These systems can recover heat from spaces being cooled for use in spaced being heated and vice versa.
- Allows for an increase in useable floor space by removing mechanical equipment from inside the main building areas.

-- Electrical --

- 3000A 208/120V 3 Phase-4 wire MDP
- 200 kW Natural Gas Emergency Generator

Gjon Tomaj | Construction Option

<http://www.engr.psu.edu/ae/thesis/portfolios/2014/gqt5013/index.html>

Executive Summary

Over the course of the 2013/2014 academic calendar year, The Mary J. Drexel Assisted Living Additions Project was analyzed and studied to identify areas in which alternate means and methods could have resolved any challenges or problems that may have affected the efficiency of the project. After careful investigation, four areas that could have improved the project include; re-sequencing the project schedule, implementing a green roof to improve value engineering efforts, utilizing MEP prefabrication, and altering the project delivery method. This final report presents the four analyses performed by including details of the challenge presented, suggesting solutions, and analyzing the solutions on the project. This report is not meant to critique the already effective project team but to study their project for educational purposes.

Analysis #1: Project Sequencing

The first analyses focused on reducing the overall project schedule duration by altering the original schedule sequencing. Any reduction to the schedule will result in general condition costs savings on the project. The goal of the analysis was to improve the schedule by two weeks; however the proposed project schedule resulted in a savings of four weeks. This was done without altering manpower and activity durations and resulting in savings of $57,000.

Analysis 2: MEP Prefabrication

The second analysis focused on implementing prefabricated MEP corridor racks. The MEP trades were brought onto the project at an early stage under the design-build contract. The goal of this analysis is determine the feasibility of allowing some of the MEP work to be fabricated at an off-site facility. This method of construction was feasible given project conditions and resulted in expediting the project schedule by one week and cost savings of $14,257 for general conditions and $20,875 in labor costs.

Analysis 3: Green Roof Implementation

The third analysis focused on implementing a green roof system design. A value engineering effort was made to reduce initial costs and not much consideration was taken into other factors such as lifecycle costs. The goal of the analysis was to provide a system that will be able to reduce noise levels and provide cost savings for the owner over its life. The proposed system did result in being feasible with the current structure and provided $41,723 in costs savings over 18 years and did not increase the project schedule duration.

Analysis 4: Alternate Delivery Method

The final analysis focused on providing an alternate delivery method that could have been used. A hybrid approach was used with a combination of Design-Bid-Build and Design-Build for the MEP systems. Due to many design changes throughout the construction of the buildings, many issues arose regarding the stakeholders communicating amongst each other. The goal of this analysis is to provide new information for the owner on an approach such as IPD that could have been used. Although IPD is a new approach to the design and construction of buildings, lower cost and lower risk are the greatest result of this approach. Integrating working relationships and sharing risk and reward among all members improves the exchange of information, thus leading to shorter design and construction schedules and overall improvement in the productivity and efficiency of the project.

Acknowledgments

Academic

Penn State Architectural Engineering Faculty

Dr. Ed Gannon

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Dr. Craig Dubler

Project Team

Liberty Lutheran

WOHLSEN CONSTRUCTION

SFCS

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Wohlsen Construction Project Team

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Family and Friends

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Project Information

Background

The Mary J. Drexel Home Assisted Living Addition project is located just outside of Philadelphia, PA and is owned and operated by Liberty Lutheran Services. The campus consists of a three-story mansion that was constructed in 1878 and has been providing senior-care center and nursing home services. However, these services were suspended in mid-2008, pending renovation and new construction.

The historic mansion is receiving new attached two-story East and West wings that will serve as the assisted living residence. Each two-story wing consists of two separate "households" with each household serving 20 residents for a total assisted living resident population of 80 residents. The existing historic mansion will be used as the focal point for Liberty Lutheran Services marketing and business aspects as well as a connection between the new wings.

General Building Data

Building Name: The Mary J. Drexel Home Assisted Living Addition
Location: 238 Belmont Ave | Bala Cynwyd, PA 19004
Occupancy Type: Assisted Living Residence (ALR)
Size of West Wing: 34,108 gross square feet
Size of East Wing: 40,600 gross square feet
Number of Stories above ground: 2
Size of Existing Mansion: 21,000 gross square feet
Number of Stories above ground: 3

Construction Information

Construction Start: November, 2012
Construction Completion: December, 2013
Cost Information: $14.6 Million
Project Delivery Method: Design-Bid-Build*
*MEP Systems were Design-Build

Owner: Liberty Lutheran Services
Architect: SFCS, Inc.
CM/GC: Wohlsen Construction Company

The goal of this project is to construct a high quality senior-care living facility at a budgeted cost value. The owner wants the residents to have an "at-home" feeling instead of the traditional institutional/hospital feeling as many senior-care facilities have.

Rendering of the Mary J. Drexel Project. Courtesy of SFCS, Inc.

Client Information

Liberty Lutheran Services is a Human Service Organization founded in 1887 that create communities and change lives by offering their help and support for people of all ages. In 2005, Liberty Lutheran expanded their services to help seniors in communities who desire to maintain their independence but require in-home assistance. This led to the acquisition of The Mary J. Drexel Home located in Bala Cynwyd, PA in 2008. The Mary J. Drexel Home (MJD) is a 150 year old facility where Liberty Lutheran wants its residents to feel as if they were home instead of a traditional institutional assisted living concept.

Existing Conditions

When purchased in 2008 the campus consisted of a three-story mansion constructed in 1878. It will continue to be used for various organized events. There was a single story Nursing Home and existing Cottage that were not in use that are being demolished so the new East and West Wing additions can be built in its place. An existing barn will remain to be used as storage for both construction and post-construction purposes. The site will become very congested and tight once the additions start going up since the topography of the site slopes down away from the construction boundary/silt fence that will be put up.

The Mary J. Drexel Project is located off a heavily traveled Belmont Ave. just outside of Philadelphia, PA. **Figure 1.1** below shows the Mary J. Drexel home before any demolition or construction has started. It is very evident that the site will bring about a few issues when considering laying out the site for construction work to be completed

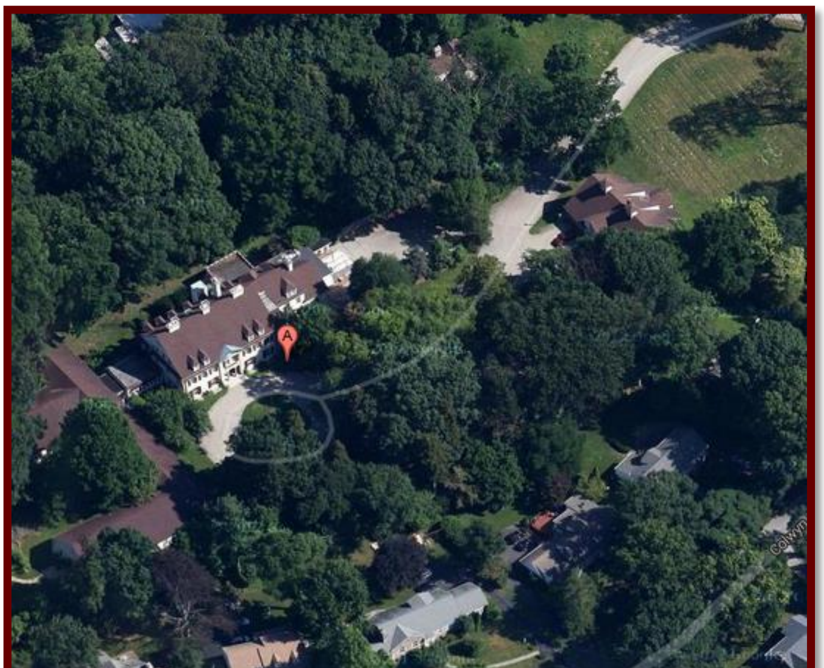

Figure 1.1 – 3D View of Site before construction – Image from Google

The other case to be considered for this project is the fact that it is located in the middle of a residential community. Having a restricted site such as this will require current vegetation to be removed and will also restrict certain equipment from being able to be placed on site.

***See Appendix A for the existing conditions plan.**

Building Systems Overview

Structural System

This project used a load-bearing metal stud wall system known as "The Infinity Structural System". This system is ideal for mid-rise residential projects such as Apartments, Condos, Lofts, Student Housing, Hotels and Senior Living Facilities up to seven or eight stories in height. The Infinity wall panels are pre-fabricated off-site and are delivered on trailers and sometimes laid down on site or stay on the trailer and are lifted off and placed in their proper location. **Figures 1.2 & 1.3** below show the panels installed on the East Wing and how they are temporarily braced with light gauge metal framing until the deck is installed.

Figure 1.2 – East Wing Infinity Panels

Figure 1.3 – Temporary Bracing for Infinity Panels

* Photos for Figure 2 & 3 taken by Gjon Tomaj

In order to allow for some larger spans some structural steel is used in the middle common areas of each wing for the foyer, community living area, dining area and activity kitchen. These columns and beams were installed using a truck mounted mobile crane due to its ease of accessibility around the congested and small site.

The only concrete work that was placed is cast in place for the slab on grade and slab on deck which used 4" normal weight concrete with strength of 4,000 PSI. The formwork consisted of a light gauge edge screed and the concrete was placed using concrete pumps with a trowel & fine broom finish.

Although most of the structure consisted of load-bearing metal panels, the basement walls, elevator shafts and stair towers are all constructed using reinforced load-bearing CMU walls varying with 8" and 12" thicknesses.

Mechanical System

The mechanical system used was a Variable Refrigerant Flow System (VRF). The system contains two 30 ton outdoor Rooftop Air Handling condensing units and one 13 ton Rooftop Air Handling Unit. Each of the 30 ton units supplies 6,200 CFM while the 13 ton unit supplies 2,870 CFM. Throughout the two wings, the Rooftop Air Handling Units are connected to multiple indoor fan coil units, each individually controllable by each resident unit. This segmentation of the distribution system allows greater comfort control of each individual resident unit as it is capable of cooling some spaces while heating others. A benefit of this system is that it allows for an increase in useable floor space by removing mechanical equipment from inside the main building areas and only needing vertical mechanical shafts where necessary.

Electrical System

The Electrical System contains a 3000A 208/120V 3 Phase-4 wire MDP that connects to the two new wings as well as into the existing mansion. The MDP is then split into six different feeds varying from 100A to 1200A that services areas such as the existing barn, existing mansion, new wing additions, miscellaneous equipment such as automatic transfer switches and the emergency generator. All of the panel boards that are supplied via the 3000A distribution panel are rated at 208/120 volts. The only redundancy system within the electrical systems of this project is a 200 kW Natural Gas Emergency Generator. This generator ties directly into the main service feed to the building and can be used for the existing Mansion, new additions, and even the existing storage barn.

Building Façade

The basis of design for this project is to provide the residents with a more residential home aesthetic environment than the traditional institutional nursing environment. The major components of the building enclosure include stucco and stone veneer as the inspiration is taken from the existing Mansion. The stucco and stone veneer enclosure consist of stucco/stone veneer, tyvek commercial wrap air barrier, gypsum sheathing, steel stud 'Infinity' wall system, and unfaced batt insulation. See **Figure 1.4** for façade system.

Figure 1.4 – Building Façade matching the existing mansion – Image by SFCS, Inc.

As stated before, much of the inspiration of the façade was taken from the existing mansion. This is because The Lower Merion Township Historical Commission and Architects met on several occasions discussing the design intent, materials, colors, relationship to the mansion, etc. The Historical Commission was involved to insure the new additions were compatible with the existing Mansion. Some requirements listed by the Historical Commission included:

- The eave of the additions had to be lower than the eave of the mansion by at least a foot so that the mansion appeared to be more prominent.
- The window shutters had to be historically correct (raised panels on the lower floor & louvered on the upper floor) & had to be half the width of the window opening so that they looked like they would close off the opening but the shutters did not have to actually function.
- EIFS was not acceptable as a façade and was required to be changed to stucco.
- The downspouts and downspouts had to be round as rectangular was not acceptable.

Cost Overview

When evaluating the cost of the project, breaking down the total project cost verses the total construction costs is an important first step to take. **Table 1.1** below outlines the actual building costs provided.

Actual Building Costs Summary		
Description	**Cost $**	**Cost $ per SF**
Construction Costs	$ 12,677,090	$ 169.03
Total Project Costs	$ 14,609,579	$ 194.79
*Owner did not disclose land & site work costs (total cost data provided by GC)		

Table 1.1 – Actual Cost Data – Provided by Wohlsen Construction

As shown by the table, most of the project cost was derived from the construction costs. In fact, almost 87% of the total project comes from the construction of the project. Using RS Means Costs data to compare the construction cost of this project to a typical assisted living facility was the next step in the evaluation. As shown below in Table 1.2, similar projects throughout the United States have an average construction cost of $10,400,000.

Square Foot Building Estimate		
Description	**Cost $**	**Cost $ per SF**
Construction Costs	$ 10,400,000	$ 138.67

Table 1.2 – SF Cost Data – RS Means

It is evident that this project was a relatively expensive facility compared to the average of $ 10.4 million. The Mary J. Drexel Assisted Living Addition project cost is relatively higher due to the state-of-the-art high quality finishes and equipment that were used.

Schedule Overview

The detailed project schedule is broken down into three main headings: preconstruction/design, construction, and final inspections & closeout. The construction phase is then broken down further into six different parts. The following **Table 1.3** gives a summary of the major categories with a few significant milestones shown as well.

The Mary J. Drexel Project schedule begins on June 7, 2011 and owner turnover is on February 6, 2014.

Description	Duration (d)	Start	Finish
Preconstruction/Design	408	07-Jun-11	11-Jan-13
Construction	251	26-Nov-12	18-Nov-13
Mobilization	3	26-Nov-12	28-Nov-12
Excavation	33	30-Nov-12	17-Jan-13
Structure	110	04-Dec-12	08-May-13
West Wing SOD Finished	-	20-Mar-13	
East Wing SOD Finished	-	29-Apr-13	
Building Envelope	120	11-Mar-13	27-Aug-13
West Wing – Roof Trusses & Sheathing Complete	-	08-May-13	
West Wing – Dried In	-	31-May-13	
East Wing – Roof Trusses & Sheathing Complete	-	03-Jun-13	
East Wing – Dried In	-	24-Jun-13	
Interior Fit-Outs	158	08-Apr-13	18-Nov-13
Permanent Power	-	17-Jul-13	
Complete Elevators	-	06-Aug-13	
Finishes	148	08-Apr-13	04-Nov-13
West Wing – Drywall Complete	-	31-Aug-13	
East Wing – Drywall Complete	-	26-Sep-13	
Sitework	92	24-Jun-13	31-Oct-13
Final Inspections & Closeout	123	15-Aug-13	06-Feb-14
Substantial Completion	-	24-Dec-13	24-Dec-13

Table 1.3 – Project Milestone & Critical Item Overview

***See Appendix B for the complete original detailed project schedule.**

Preconstruction / Design

The Mary J. Drexel Project began the design process in the beginning of June 2011 with a mindset to start construction within a year or two and being complete a year after starting. The longest and most important aspect of this project was the preconstruction and design phase. Throughout this phase many meetings and discussions took place between the Owner, Architect, and The Lower Merion Township Historical Commission specifically about the building façade. Another large part of this phase was the MEP Design-Build aspect that Wohlsen Construction coordinated which was completed 61 days after the design development was complete.

Upon completion of the design, the focus shifted to estimating the GMP contract that was reviewed and approved by the owner on September 17, 2012. This allowed Wohlsen to turn their focus on finishing the procurement process and coordinate the demolition work with the third party contractor hired by the owner.

Construction

-- Mobilization & Excavation --

It is important to note that the demolition work to the existing buildings on the site started at the end of August 2012. As this work was completed by a third party contractor, it is not shown on the detailed project schedule. The demolition of the existing Cottage and Nursing Home was completed and removed from site by October 2012. Mobilization started on November 26, 2012. Once the site was cleared and the excavation was complete, small quantities of rebar and lumber showed up on site for the concrete layout work to begin.

-- Structure --

The structural phase began in the beginning of December 2012 and ended in the beginning of May 2013. The foundations of the new additions are very simple as it began with the placing of footings and CMU Masonry bearing walls. All underground MEP work was placed and inspected prior to any concrete slab being poured. The south half of the West Wing was the first part to be placed. The typical sequence can be seen in **Figure 1.5**. The substructure of the West Wing took 60 days and was completed on February 27, 2013.

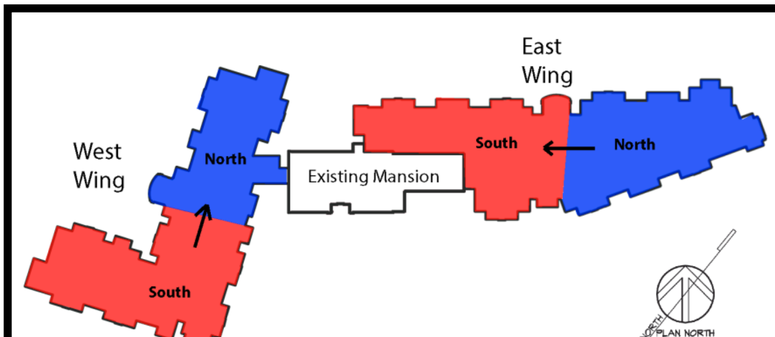

Figure 1.5 – Typical Flow of Work

The East Wing followed a similar sequence but rather than starting on the south end, the north end was the starting point. The sequencing was phased to have the two new additions be erected toward the existing Mansion. Each wing averages about 60-70 days to complete the substructure and 25-28 days for the superstructure to be complete. The superstructure is composed of prefabricated load bearing wall panels that are placed on site allowing for a swift erecting sequence. Two critical dates arise when the elevated floor slabs are complete so the building envelope work can commence.

-- Building Envelope & Enclosure --

As mentioned earlier, the most time was spent in the design phase on the building envelope system due to Historical Commission requirements and recommendations. Comprised of stucco and stone veneer, careful inspections needed to be made after the lath for the stucco was placed. Work on the façade system began in mid-March 2013 with the West Wing and the East Wing following four weeks behind in mid-April 2013. Each wing is first completely sheathed and wrapped before the windows are installed and flashed properly. Once the roof trusses were installed and sheathed, three weeks later the roof would be shingled and membrane roofing was installed. It was critical that the dried in dates for each wing were met so interior fit-outs and finishes can begin since these have the second longest durations.

-- Fit-Outs --

MEP rough-ins were the first to start once the building envelope in dried-in. The work sequence follows the same flow from south to north on the West Wing and north to south for the East Wing. The four week lag may have seemed as a big gap, but this was done to minimize scheduling risks. A major milestone in this section is Permanent Power. With the many different amount of trades being on site, the earlier that permanent power can be on site the better. Having the finish trades using temporary power to finish two buildings is not very efficient and can slow down the production.

-- Finishes --

Throughout the initial design development phase this project contained high quality finishes. This process follows the same flow of south-north West Wing and north-south East Wing to meet at the existing Mansion. After the rough-ins were complete, activities such as blocking, drywall, flooring, woodwork, fixtures, painting, and doors are included in this phase. Having the high quality finishes means that longer installation times are required when planning durations and lead times were greatly considered.

Final Inspections & Closeout

As each wing came to completion, a typical punch list walkthrough was performed by the Contractor, Architect, and Owner. All testing and inspections were completed at this time as well. Once substantial completion is met and the certificate of occupancy is issued the owner can move in. Substantial completion was schedule for December 24, 2013.

Analysis #1: Improve Project Schedule

Problem Identification

For this construction project, significant emphasis was placed on the cost and quality of the project with less on the overall project schedule. With the project criterion focused on cost and quality, no urgency was placed on completing the project at a faster rate if it would have risked the criterion. Upon quick observation over the Mary J. Drexel Project's 14 month construction schedule, it was recognizable that improvements could be made without risking cost or quality.

One of the aspects that hinted to the possibility of improvement is the activity sequencing. Many of the construction activities were scheduled with one following another without any overlap between trades. Although this does minimize scheduling risks throughout the project, it is not an efficient way to develop a project schedule. Unnecessary gaps between activities were also recognized in the schedule that could be removed and further more improve the schedule.

***See Appendix B for the complete original detailed project schedule.**

Background Information

Although schedule duration was not a significant point of emphasis on the project, there still could have been added benefits from a compressed schedule in a cost perspective. With the owner being concerned about cost, the simplest and cheapest way for the project team to accelerate the schedule is through re-sequencing the entire project schedule.

The simplest and cheapest way for the project team to accelerate the schedule is through re-sequencing the entire project schedule. The current schedule is set up so that the East wing is delayed four weeks after the West wing and for the trades to start right after another trade was finished working.

Any compression of the project schedule would result in direct savings of general conditions costs for the owner. The general conditions estimate originally had a total cost of $1,596,477. The monthly paid line items that would be affected by reducing the schedule account for $798,384, or 50% of the total general conditions estimate at a 14 month project duration. Thus, any reduction in the project schedule will result in decreasing costs for the owner.

***See Appendix C for the complete original general conditions estimate.**

Analysis Goals

As previously mentioned, the project schedule was structured in a way where most activities were finish to start rather than having some overlap. With this analysis, the main goal is to sequence the project's construction schedule to reduce the total project duration. The minimum goal of this analysis will be to reduce the schedule duration by at least two weeks. During this analysis, the original activity durations that were set from the project team will not be altered. With reducing the schedule duration by two weeks, the original duration of 14 months (56 weeks) will adjust to 13.5 months (54 weeks).

Any reduction in the overall project schedule without the addition of additional resources will result in cost savings on the project. If the two week schedule reduction is achieved, the result will provide a $28,514 cost savings in general conditions to the owner as shown in **Table 2.1** below.

Two Week General Conditions Cost				
Description	**Quantity**	**Unit**	**Cost/Unit**	**Amount**
Project Management Team				**$26,475**
Project Executive (10%)	0.5	Mo.	$2,050.00	$1,025
Field Operations Manager (10%)	0.5	Mo.	$1,700.00	$850
Project Manager	0.5	Mo.	$16,000.00	$8,000
Superintendent	0.5	Mo.	$15,500.00	$7,750
Project Engineer	0.5	Mo.	$11,200.00	$5,600
Project Assistant (50%)	0.5	Mo.	$4,000.00	$2,000
Laborer (50%)	0.5	Mo.	$2,500.00	$1,250
Site Conditions				**$2,000**
Temporary Phone	0.5	Mo.	$750.00	$375
Temporary Toilets (4)	0.5	Mo.	$600.00	$300
Drinking Water	0.5	Mo.	$150.00	$75
Dumpsters (2)	0.5	Mo.	$2,500.00	$1,250
Field Operations				**$39**
Field Office/Trailer - use existing facilities	0	Mo.	$0.00	$0
Storage Trailers - use existing facilities	0	Mo.	$0.00	$0
Job Office Supplies	0.5	Mo.	$77.40	$39
			TOTAL	**$28,514**

Table 2.1 – General Conditions Estimate - Cost Savings (two week goal)

This is quite a significant cost savings for reducing the schedule by only two weeks. Ultimately when analyzing and re-sequencing the schedule, the goal will be to provide the most cost savings available by reducing the duration as much as possible. Although not easily quantifiable, this will be done by ensuring that the quality of the project will not be at risk either. The process that this could be done is by ensuring that tradesman are on site completing activities one after another without leaving the site and having to re-mobilize often. Allowing a continuous workflow for trades will increase the efficiency of the schedule and project quality while also minimizing costs.

Process

-- Analysis of Original Schedule --

Analyzing the original schedule and identifying areas that could be re-sequenced and adjusted is the first step in the analysis. The original major construction sections that are outlined in the project schedule are summarized below in **Table 2.2**.

Description	Duration (d)	Start	Finish
1. Preconstruction/Design	**408**	**07-Jun-11**	**11-Jan-13**
2. Construction	**251**	**26-Nov-12**	**18-Nov-13**
2.1 Mobilization	*3*	*26-Nov-12*	*28-Nov-12*
2.2 Excavation	*33*	*30-Nov-12*	*17-Jan-13*
West Wing	-	30-Nov-12	12-Dec-12
East Wing	-	02-Jan-13	17-Jan-13
2.3 Structure	*110*	*04-Dec-12*	*08-May-13*
West Wing	-	04-Dec-12	08-Apr-13
East Wing	-	04-Jan-13	08-May-13
2.4 Building Envelope	*120*	*11-Mar-13*	*27-Aug-13*
West Wing	-	11-Mar-13	22-Jul-13
East Wing	-	09-May-13	27-Aug-13
2.5 Interior Fit-Outs	*158*	*08-Apr-13*	*18-Nov-13*
West Wing	-	08-Apr-13	21-Oct-13
East Wing	-	09-May-13	18-Nov-13
2.6 Finishes	*148*	*08-Apr-13*	*04-Nov-13*
West Wing	-	08-Apr-13	14-Oct-13
East Wing	-	09-May-13	04-Nov-13
2.7 Sitework	*92*	*24-Jun-13*	*31-Oct-13*
3. Final Inspections & Closeout	**123**	**15-Aug-13**	**06-Feb-14**
Substantial Completion	-	24-Dec-13	
Owner Move-In	-	26-Dec-13	06-Feb-14

Table 2.2 – Original Schedule Summary Outline

Of the schedule sections outline above, Sitework and Preconstruction/Design were not analyzed because they did not affect the substantial completion date. Also, the Sitework schedule was in control of the owner and was only listed on the project schedule for coordination purposes. The basement area was not analyzed either as it was not on the critical path.

The first aspect of the project schedule that attracted attention for further improvement was the gap between the start dates for the East and West wings being constructed. The East Wing construction started four weeks after the West Wing. With these two buildings being approximately the same size and shape, this gap between start dates could easily be reduced. The unnecessary float between the excavation of the two wings is an example of the how this gap was discovered when analyzing the schedule. Gaps like this were then further investigated in order to evaluate if they were required for construction purposes.

After discussions with the project team, it was realized that starting the excavation for the East Wing right after the West Wing would have been feasible. As stated before, the reason for this gap was to minimize scheduling risks especially since the excavation was being performed in the winter. The four week construction gap between the two wings was also discussed in terms of attempting to reduce the gap. A three week difference between buildings would have been adequate for this project instead of the four. Although the gap between the two buildings was a quick discovery when analyzing the schedule, gaps between specific construction activities were also noticed in other areas of the schedule and evaluated as well. Some were more prominent than others and those gaps were easily removed if feasible, while other gaps were not as obvious.

-- Re-Sequence Original Schedule --

After the gaps between activities were removed and adjusted, the next part of the analysis was to improve the sequencing of activities by overlapping them. There are many instances throughout the entire project schedule where activities are start-to-finish without any overlap. This technique does allow for schedule risks to be minimized as mentioned earlier. An example of this can be seen in **Figure 2.1** below which outlines the original structural phase of the project. It is shown here that the substructure crew and superstructure setting crew were scheduled one after another. This allowed for each crew to install their work without any worry of another trade interfering.

MJD.2.3	Structure	110	04-Dec-12	08-May-13
MJD.2.3.1	Substructure - West Wing	60	04-Dec-12	27-Feb-13
A1130	Footer Rebar and Concrete	7	04-Dec-12	12-Dec-12
A1140	Spread Footer and Piers	7	27-Dec-12	07-Jan-13
A1150	CMU Bearing Walls	4	07-Jan-13	10-Jan-13
A1160	Plumbing Underground Piping & Inspection - South Half	8	07-Jan-13	16-Jan-13
A1170	Electric Underground Rough-In & Inspection - South Half	3	17-Jan-13	21-Jan-13
A1180	SOG Prep & Pour - South Half	4	28-Jan-13	31-Jan-13
A1190	Plumbing Underground Piping & Inspection - North Half	3	18-Feb-13	20-Feb-13
A1200	Electric Underground Rough-In & Inspection - North Half	3	18-Feb-13	20-Feb-13
A1210	SOG Prep & Pour - North Half	5	21-Feb-13	27-Feb-13
MJD.2.3.2	Superstructure - West Wing	28	28-Feb-13	08-Apr-13
A1220	Infinity Bearing Walls - 1st Floor	7	28-Feb-13	08-Mar-13
A1230	Set Structural Steel - 1st Floor	3	05-Mar-13	07-Mar-13
A1240	Infinity Shoring - 1st Floor	5	05-Mar-13	11-Mar-13
A1250	Infinity 2nd Floor Deck	7	07-Mar-13	15-Mar-13
A1260	Set MEP Deck Penetration Sleeves	3	11-Mar-13	13-Mar-13
A1270	SOD Prep - 2nd Floor	7	11-Mar-13	19-Mar-13
A1280	SOD Poured - 2nd Floor	0	20-Mar-13	
A1290	Infinity Bearing Walls - 2nd Floor	7	29-Mar-13	08-Apr-13
A1300	Set Structural Roof Steel	3	03-Apr-13	05-Apr-13
A1310	Infinity Shoring Removal - 1st Floor	3	03-Apr-13	05-Apr-13

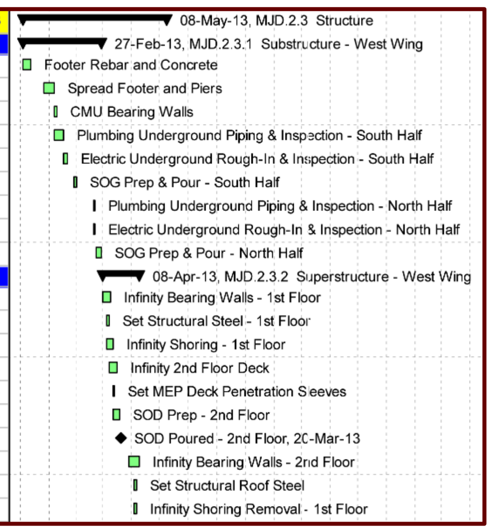

Figure 2.1 – Original Structure Phase Schedule

The sequence of the project schedule was improved by reorganizing the activities for each crew so they overlapped one another. Some examples shown above such as the CMU bearing walls waiting until the spread footers and piers were installed is an activity can be completed simultaneously. The largest factor that allowed for the large 60 day duration of the substructure of the West Wing was the three week gap between the two slab-on-grade pours. Although the West Wing did not affect the critical path, the scheduling sequence for the East Wing is the same. Any improvement to the sequence of the West Wing will allow the East Wing to start earlier and thus, reducing the total schedule duration. Understanding that improving this 60 day duration and overlapping activities would be beneficial, activities such as starting the structural wall panels after the first half of the concrete slab is poured would be a significant improvement.

MJD_-1.2.3	Structure	84	04-Dec-12	02-Apr-13
MJD_-1.2.3.1	Substructure - West Wing	30	04-Dec-12	16-Jan-13
A1130	Footer Rebar and Concrete	7	04-Dec-12	12-Dec-12
A1140	Spread Footer and Piers	7	13-Dec-12	21-Dec-12
A1150	CMU Bearing Walls	7	18-Dec-12	27-Dec-12
A1160	Plumbing Underground Piping & Inspection - South Ha	8	20-Dec-12	02-Jan-13
A1170	Electric Underground Rough-In & Inspection - South H	3	20-Dec-12	24-Dec-12
A1180	SOG Prep & Pour - South Half	4	03-Jan-13	08-Jan-13
A1190	Plumbing Underground Piping & Inspection - North Ha	3	07-Jan-13	09-Jan-13
A1200	Electric Underground Rough-In & Inspection - North H	3	07-Jan-13	09-Jan-13
A1210	SOG Prep & Pour - North Half	5	10-Jan-13	16-Jan-13
MJD_-1.2.3.2	Superstructure - West Wing	28	09-Jan-13	15-Feb-13
A1220	Infinity Bearing Walls - 1st Floor (South)	4	09-Jan-13	14-Jan-13
A1225	Infinity Bearing Walls - 1st Floor (North)	4	16-Jan-13	21-Jan-13
A1230	Set Structural Steel - 1st Floor	3	16-Jan-13	18-Jan-13
A1240	Infinity Shoring - 1st Floor	5	16-Jan-13	22-Jan-13
A1250	Infinity 2nd Floor Deck	7	16-Jan-13	24-Jan-13
A1260	Set MEP Deck Penetration Sleeves	3	25-Jan-13	29-Jan-13
A1270	SOD Prep - 2nd Floor	7	29-Jan-13	06-Feb-13
A1280	SOD Poured - 2nd Floor	0	06-Feb-13	
A1290	Infinity Bearing Walls - 2nd Floor	7	07-Feb-13	15-Feb-13
A1300	Set Structural Roof Steel	3	07-Feb-13	11-Feb-13
A1310	Infinity Shoring Removal - 1st Floor	3	11-Feb-13	13-Feb-13

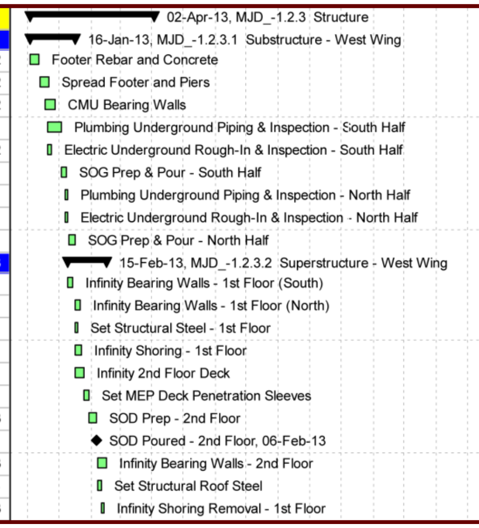

Figure 2.2 – Revised Structure Phase Schedule

Figure 2.2 above demonstrates the improved re-sequencing for the structural phase example. Other phases of the construction schedule were re-sequenced following the same process with the mindset of increasing efficiency of work and reducing any possibilities of crews having to re-mobilize after another crew was complete. This scheduling technique of overlapping activities and improving the sequence resulted in reducing the most time off the schedule.

Results

-- Schedule Savings --

Re-sequencing construction activities so there are overlapping activities is the simplest and most cost effective way to reduce construction costs. The potential scheduling changes outlined above should help shorten the overall project schedule duration leading to a decrease in the general conditions costs on the project, saving money for the owner.

As a result of analyzing and improving the sequence of the schedule, the revised major construction sections that were outlined previously are summarized below in **Table 2.3**.

Description	Duration (d)	Start	Finish
1. Preconstruction/Design	**408**	**07-Jun-11**	**11-Jan-13**
2. Construction	**242**	**26-Nov-12**	**05-Nov-13**
2.1 Mobilization	*3*	*26-Nov-12*	*28-Nov-12*
2.2 Excavation	*22*	*30-Nov-12*	*02-Jan-13*
West Wing	-	30-Nov-12	12-Dec-12
East Wing	-	14-Dec-12	02-Jan-13
2.3 Structure	*84*	*04-Dec-12*	*02-Apr-13*
West Wing	-	04-Dec-12	15-Feb-13
East Wing	-	26-Dec-12	14-Mar-13
2.4 Building Envelope	*92*	*19-Feb-13*	*27-Jun-13*
West Wing	-	19-Feb-13	04-Jun-13
East Wing	-	14-Mar-13	27-Jun-13
2.5 Interior Fit-Outs	*150*	*25-Mar-13*	*23-Oct-13*
West Wing	-	25-Mar-13	02-Oct-13
East Wing	-	15-Apr-13	23-Oct-13
2.6 Finishes	*148*	*08-Apr-13*	*30-Oct-13*
West Wing	-	01-Apr-13	17-Oct-13
East Wing	-	29-Apr-13	05-Nov-13
2.7 Sitework	*92*	*24-Jun-13*	*31-Oct-13*
3. Final Inspections & Closeout	**103**	**14-Aug-13**	**08-Jan-14**
Substantial Completion	-	25-Nov-13	
Owner Move In	-	25-Nov-13	06-Jan-14

Table 2.3 – Revised Schedule Summary Outline

By improving the sequencing of the original project schedule, the substantial completion date was moved from Dec 24, 2013 to November 25, 2013. The largest significant changed that allowed these results was the gap between the start dates for construction between the two wings. Reducing that gap from one month to three weeks and overlapping activities resulted in saving four weeks off the project schedule.

***See Appendix D** for the complete revised detailed project schedule.**

-- Cost Savings --

The structure and finishes of the wings impacted the critical path the most. Even though the duration for the finishes part of the project did not change, the alteration to the structural phase allowed for finishes to be completed with the original duration but start sooner.

As stated earlier, the main goal of this analysis was to hopefully reduce two weeks from the project schedule. This analysis proved to be successful and had the project team and owner implemented an improved project schedule such as this the resulting general conditions cost savings are outlined below in **Table 2.4**.

General Conditions – *Potential Cost Savings*				
Description	Quantity	Unit	Cost/Unit	Amount
Project Management Team				**$52,950**
Project Executive (10%)	1	Mo.	$2,050.00	$2,050
Field Operations Manager (10%)	1	Mo.	$1,700.00	$1,700
Project Manager	1	Mo.	$16,000.00	$16,000
Superintendent	1	Mo.	$15,500.00	$15,500
Project Engineer	1	Mo.	$11,200.00	$11,200
Project Assistant (50%)	1	Mo.	$4,000.00	$4,000
Laborer (50%)	1	Mo.	$2,500.00	$2,500
Site Conditions				**$4,000**
Temporary Phone	1	Mo.	$750.00	$750
Temporary Toilets (4)	1	Mo.	$600.00	$600
Drinking Water	1	Mo.	$150.00	$150
Dumpsters (2)	1	Mo.	$2,500.00	$2,500
Field Operations				**$77**
Field Office/Trailer - use existing facilities	0	Mo.	$0.00	$0
Storage Trailers - use existing facilities	0	Mo.	$0.00	$0
Job Office Supplies	1	Mo.	$77.40	$77
			TOTAL	**$57,027**

Table 2.4 – Total Potential General Conditions Cost Savings (4 week results)

Implementing the improved project schedule and using the techniques outlined prior, the resulting savings to the general conditions costs would have been $57,027 due to the four week reduction. The cost savings of the reduction of four weeks results in approximately 3.6% of the original general condition costs of $1,596,477.

Conclusion

In conclusion of this analysis, it is recommended that the project team should have considered improving the project schedule and implementing some schedule re-sequencing and removing unnecessary gaps. Any time that can be saved on the project will result in cost savings for the project. The revised schedule outlined in this analysis does not incur any additional expenses on the project and resulted in a savings of $57,027 in general condition costs. Although significant emphasis was not placed on the project schedule by either the owner or contractor, the time savings result in lower costs which could benefit the owner in allowing extra time to choose higher quality furnishings for the senior residents.

Analysis #2: MEP Prefabrication

Problem Identification

Throughout the project, many unforeseen delays arose that led to a need for an increase in manpower and productivity in regards to the installation of the MEP systems. Although these delays were not a direct result from the performance of the MEP trades, they were forced to employ extra crews during the week and start overtime work on the weekends in order to meet the schedule. The MEP trades were brought onto the project at an early stage under a design-build contract and this analysis will examine how the implementation of a prefabricated MEP corridor rack would have benefited the project.

Background Information

The extra efforts mentioned above could have been avoided if the MEP systems were fabricated at an off-site fabrication facility and then transported to the construction site. The main focus of implementing prefabrication will be placed on MEP corridor racks for both wings since they each have identical layouts respectively as shown in **Figure 3.1** below.

Figure 3.1 – Floor Plan layout for West Wing (left) and East Wing (right)

As stated in Technical Report 3, a majority of the project was assembled in place. This is standard, but not as efficient in terms of schedule durations. After having discussions with the project team and industry members at the 2013 PACE Roundtable, the idea of using a different installation methods such as prefabrication could have been beneficial to everyone on the project. The MEP systems could have been constructed off-site then transported and connected on site which would have increased productivity and been more efficient in terms of schedule duration. The main areas that will be focused on in order to implement a prefabricated corridor rack will be parts of the corridors of the wings. Any areas where a corridor rack will not be feasible will be stick built depending on restrictions that may be presented during the design process.

Analysis Goals

The main goal of this analysis is to research and provide a more efficient method of construction for this project that may expedite the project completion date. Since the construction site is restricted in size, it is expected that the prefabrication of MEP corridor racks will reduce site congestion, improve efficiency and productivity.

In order to complete the analysis and determine how the implementation of prefabricated MEP corridor racks will benefit the project; the following steps would need to be performed.

- Acquire AutoCad models (if any).
- Review modeling of MEP corridor.
- Research how BIM is used to facilitate prefabrication techniques.
- Contact industry members from either Worth & Company or Truland to discuss typical techniques when prefabricating.
- Determine which components of the MEP systems can be fabricated into a common corridor rack to be used throughout each wing.
- Determine feasibility of implementing MEP Prefabrication and cost and schedule savings associated.

Upon completion of this analysis, the possible solutions that could be reached include:

- The prefabrication of MEP corridor racks will be feasible for this project and can be used to reduce installation time.
- There will be areas of the corridors where a MEP corridor rack design will not be feasible and these areas will need to be stick built.
- There may be additional up-front costs that are associated with using prefabrication techniques such as this, but this will most likely be overcome by potential cost savings by reducing the schedule completion date or even the amount of labor the subcontractors will need for installation time.

Process

-- Multi-Trade Prefabrication --

The multi-trade prefabrication process allows multiple building systems to be constructed in a controlled environment off-site while other building systems such as the structure are being constructed on-site. There are many types of building projects that have repetitive elements that are well suited for this process. The use of multi-trade prefabrication is a process that revamps the building delivery process and produces high quality projects more quickly, safely, and cost effectively.

BIM is the enabler of prefabrication that can be used on many project types. Designs of prefabricated units are developed in the beginning stages with all building system trades heavily involved in coordinating and setting tolerances.

In discussion at the 2013 PACE Roundtable, one of the largest concerns regarding the use of multi-trade prefabrication is actually getting paid for the work completed during pre-fabrication. It can be difficult to receive payment for a module that is completed, but is not necessarily installed out on the actual project yet. Other criteria and drivers for effective multi-trade prefabrication and modularization discussed at the meeting include:

- Contract type
- Project type
- Site restrictions
- Trucking to and from site and laws associated (size of assembly can be effected)
- Permits and hoisting
- Liability

Many concerns can be mitigated with the increased level of pre-planning that takes place with the contracts and such. The goal of researching multi-trade prefabrication for this project will not only help identify the advantages and disadvantages, but also how BIM enables the production of prefabricated building components. Prefabrication techniques have been applied to many projects and have been found to improve safety, quality and reduce waste compared to the traditional stick-built method. The process of applying prefabrication methods to a project's highly repetitive MEP systems, typically found in hotels and apartment buildings, has great potential to allow the construction project to be delivered in a more efficient manner. With this research, future owners could understand the benefits of utilizing prefabrication techniques for their projects.

History of Prefabrication

The construction process of using prefabrication and modularization has been used for many years now and is not a new method. This process of prefabricating building components off-site and sending the components to be assembled on-site has been used in America since the 17th century. It started back in 1624 when a disassembled house in England was shipped to Cape Ann, Massachusetts. This is because English building techniques were trusted and familiar to those who had just settled and arrived in America. Also, in the 1850s, the balloon frame system of construction revolutionized the speed with which new housing could be built. From this, in the 20th century, companies such as Aladdin Readi-Cut Houses and Sears Roebuck & Company were the first to offer prefabricated houses to many families. These houses were delivered to families by mail-order and were chosen from catalogs developed by the companies, specifically Sears Roebuck and Company. A greater effort for prefabrication techniques was seen during World War II because soldiers were being housed in mobile shelters and then upon returning were being housed in prefabricated suburb homes.[2]

The technique has further been improved as architects and developers pushed to find new applications beyond just single family homes. Now, urban towers can be constructed using prefabricated and modular components. A great example of this is the 32-story Atlantic Yards B2 Tower being constructed in Brooklyn, New York (see **Figure 3.2** below). This tower will be known as the largest modular/prefabricated tower in the world once construction is complete in the summer of 2014.

Figure 3.2 – 32-story Atlantic Yards B2 Modular Tower in Brooklyn, NY – Image from Skansa

By the developer's estimate, the modular tower would move 60% of the work from the field to the factory floor. Although high-rise modular construction may be untested and the developer may be taking a huge gamble with this project, its parts are based on tried-and-true modular components. With this development, it is clear how far the technology has been advanced.

This reemergence of prefabrication and modular construction as a “new” trend is largely tied to the rise of Building Information Modeling (BIM) and green building practices. The emergence of BIM is greatly influencing design and construction processes and how project teams collaborate. Recent studies show that this technique has been starting to gain popularity again and is becoming widely accepted by many industry members.

Key Members in Prefabrication

Although prefabrication is becoming increasingly popular by a wide range of key industry members, it currently is not accepted by all. **Figure 3.3** below shows the recent amount of prefabrication users according to McGraw-Hill Construction survey in 2011.

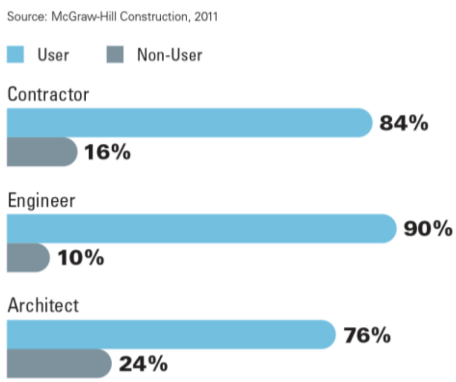

Figure 3.3 – Key Users of Prefabrication
Image from McGraw Hill Construction[1]

Industry members are becoming more and more aware that in order to complete in this highly competitive market, the adoption of these "new" methods is necessary since projects are continuously starting to be delivered cheaper and faster. 63% of those using prefabrication techniques have been using it for five years or more and most believe that 98% are expected to use some sort of prefabrication on some projects in the future[1]. With growing acceptance, utilizing prefabrication and modular construction is less costly, faster, and provides a simpler means of construction

Key Drivers for Prefabrication

There are many drivers that owners, designers, and builders consider when implementing the use of prefabrication and modularization. **Figure 3.4** on the right shows the percentages of what the key player believe to be the main driver for using prefabrication. As shown, the most important driver to the usage of prefabrication is the ability to improve productivity. This is extremely important to contractors as 92% of them believe this. All key players also see these techniques as increasing their competitive advantage in the marketplace. Among all players, the primary reason they are not using prefabrication and modularization on some or all of their projects is that the architect did not design it into their projects. Owner resistance was the primary reason given by architect users for not including prefabrication and modularization into their designs.[1] This is most likely due to the fact that many owners still believe in the rumor of modular structures being of poor quality.

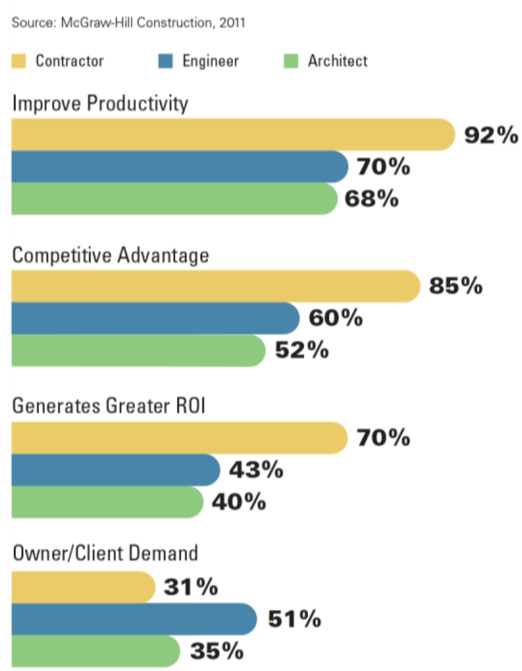

Figure 3.4 – Key Drivers of Prefabrication
Image from McGraw Hill Construction[1]

Model-Driven (BIM) Prefabrication

As stated earlier, the use of BIM is on the rise in the industry and is expected to drive the increased use of prefabrication and modularization. BIM models provide the project team with the ability to experience the project before it's built. Design intent can thus be interpreted and the information can be used to create instructions for fabricating building components. The design of prefabricated units are developed in the beginning stages with all necessary building system trades heavily involved in coordinating and setting tolerances. BIM enabling prefabrication is projected to increase as the years go by. **Figure 3.5** below shows the percentage of respondents that used BIM to help with prefabrication. The survey was taken in 2011 and projects those percentages for 2013.

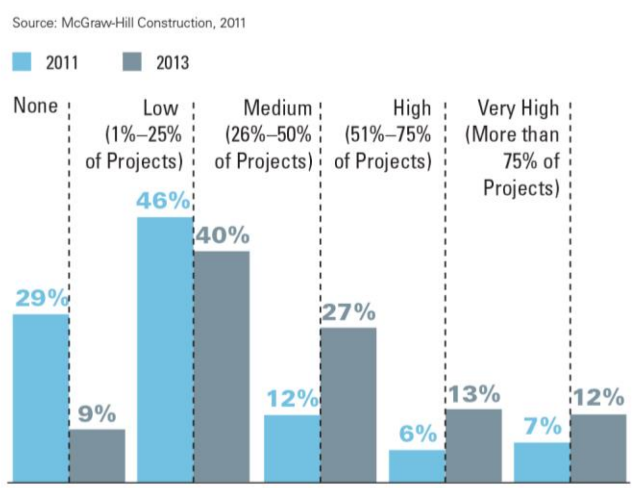

Figure 3.5 – BIM use for Prefabrication
Image from McGraw Hill Construction[1]

In a recent study about the use of BIM on green projects, McGraw-Hill Construction found that the use of BIM model-driven prefabrication on more than one quarter of their projects is expected to increase from 37% to 73% among practitioners who use BIM for green work. Even those who are currently not using green BIM expect an increase from 22% to 57%. BIM helps enable prefabrication of tightly integrated MEP systems, allowing designers to maximize space for other uses in high-tech buildings like hospitals.[1]

Respondents also stated that when using BIM on their projects, they experienced a schedule decrease of four weeks or more due to their use of prefabrication methods.

Advantages of Applying Prefabrication

Prefabrication provides multiple benefits to all members involved in the project. Productivity improvement is the primary advantage of using prefabrication as shown above; it was the primary driver that all key members agreed upon. Improved productivity results in providing benefits to the project schedule, cost, safety, and quality. Since prefabricated units are built off-site, laborers have the benefit of having all the necessary tools and equipment readily available at all times without the worry of needing to walk back and forth from their site trailers to the building. This process can also begin at the earliest stages of the project simultaneously while on-site building components are being stick-built.

The overall cost for a prefabricated project can be less as a result compared to the traditional stick-built under certain instances. The ability to have an off-site assembling warehouse provides a safe location where work can continue even during severe conditions and weather problems that would have caused major delays during stick-built construction. Most importantly, project safety is increased significantly as the risk of on-site accidents occurring is minimized. The warehouse provides a safe and productive environment for laborers. This controlled environment also improves the quality as repetitive procedures and activities can be complete with the use of automated machinery which is not possible on-site. Waste is also reduced since laborers have access to precise shapes and sizes of the necessary material that may be needed. As can be seen, prefabrication and modularization has many benefits, thus the reason for the increase in popularity throughout the years.

Application of Prefabrication

With the increase in popularity of prefabrication and modularization, many types of different building projects demonstrate its feasibility for projects other than single homes. As shown in **Figure 3.6** on the right, the largest sectors utilizing prefabrication methods are:

- Healthcare (49%)
- Higher education (42%)
- Manufacturing (42%)
- Low-Rise Office (40%)
- Public (40%)

Healthcare is the largest sector that uses prefabrication due to the interior layout of hospital rooms being very similar. The use of prefabrication allows for greater high-tech design for these projects as more space is available due to the efficient use of the design of the modularized component. Higher education projects such as dormitories are also well-suited for prefabrication. Dorms and classrooms allow for whole room designs to be modularized. All of these projects as a result benefit with faster construction schedules due to the implementation of prefabrication.

Some sectors that have the greatest chance to increase prefabrication use include hotels and commercial warehouses. The repetition of architectural designs and building system components drive prefabrication, but jobsite conditions are another influence that must be considered.

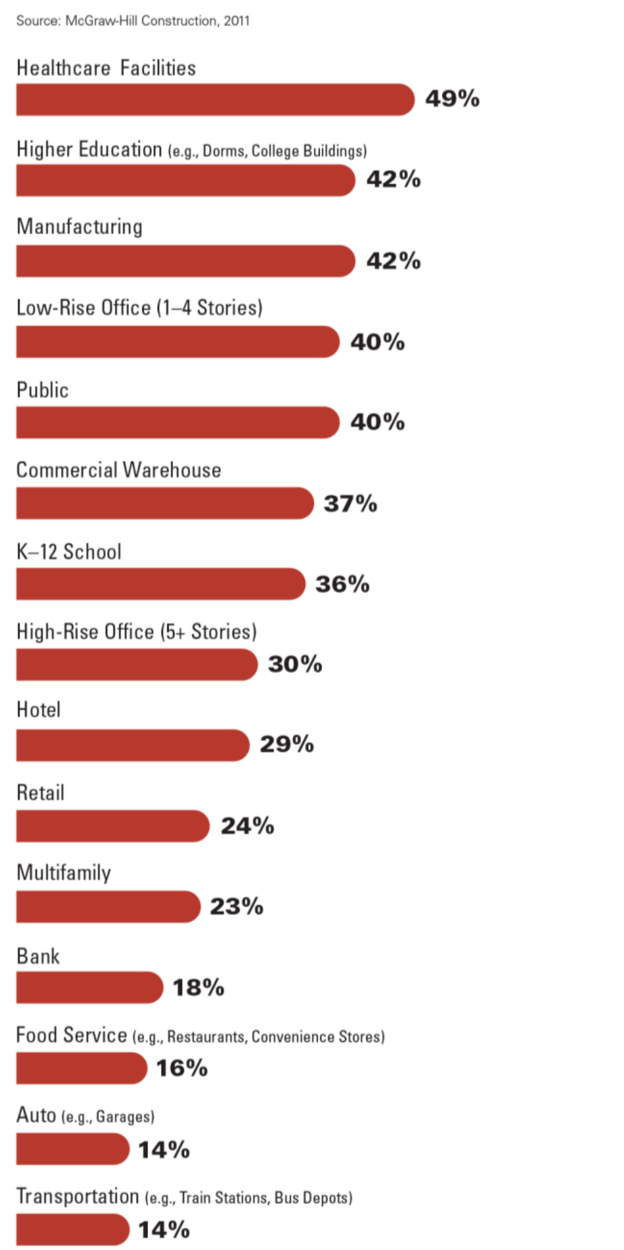

Figure 3.6 – Building Sector use of Prefabrication
Image from McGraw Hill Construction[1]

Jobsite Influence on Prefabrication

Jobsite conditions can greatly influence the need for a project to use prefabrication methods. This influence is also joined by any critical issues of site logistics that may be present. It is important to carefully analyze the jobsite conditions in order for prefabrication methods to be successfully used. The important factors that need to be considered include: jobsite accessibility, number of stories, building layout, and the type of build exterior.

Jobsite accessibility is critical due to the fact that many trips may be necessary for the delivery of the prefabricated components. However, prefabrication is beneficial for projects with severe site restrictions since it can prevent site congestion throughout the construction process. The number of stories is a factor due to the lifting requirements that will be associated with higher structures. Greater coordination and consideration in crane lifting capacities will need to be considered with modules and components being delivered to site. Depending on the sizes and weights of these modularized components, they may not be feasible for the project if a large crane will not fit on site.

Most Commonly Used Prefabrication Building Elements

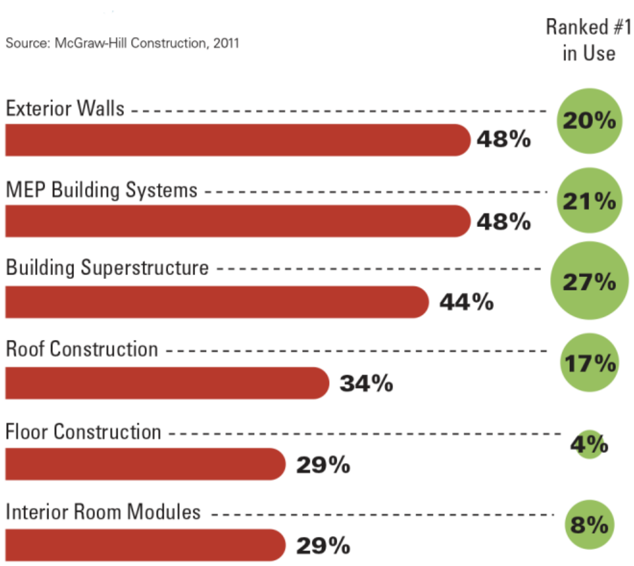

Figure 3.7 – Common Prefabricated Systems
Image from McGraw Hill Construction[1]

The most commonly used building elements that are typically prefabricated include: MEP systems, exterior wall assemblies, and the building superstructure. As shown in **Figure 3.7**, the building system that uses the most prefabrication is the building superstructure (27%). Following that is MEP systems (21%) and Exterior Walls (20%). The black percentage numbers outline the percentage of respondents that use that specific building system for prefabrication.

Prefabricated building superstructures normally consist of components above the foundation of the building. Prefabricated MEP systems, the main focus of this analysis, can consist of all MEP related materials such as conduit, duct banks, dampers, elbows, etc. These MEP components are typically prefabricated on racks where they can just be installed right on site in the corridor and the necessary attachments between each rack are made. Complete exterior wall assemblies can also be prefabricated in a controlled environment. These assemblies can be made with a variety of finishes which include brick, tile, culture stone, stucco, or EIFS. All the systems outlined possess the opportunity for prefabrication and have a great chance of saving time and cost to any project.

Research Conclusion

Although the technique of modularization and prefabrication dates back to the 17th century, it has started to increase in popularity again as many key members in the construction industry are realizing the benefits it provides. Some of these benefits include improved productivity, lower costs, reduced schedules, and increased safety. The emergence of BIM is greatly influencing design and construction processes and how project teams collaborate. BIM is a great enabler for prefabrication as BIM models provide the project team with the ability to experience the project before it's built. Thus, design intent can be interpreted and the information can be used to create instructions for fabricating building components. Although prefabrication is not suited for every type of project, jobsite conditions must be carefully analyzed when considering prefabrication. Almost every major building system that goes into the construction of a project can be prefabricated at an off-site warehouse and shipped to site, reducing the amount of traditional stick-built construction taking place. After conducting extensive research on prefabrication and the project influences and systems that can be prefabricated, the feasibility of utilizing a corridor MEP rack the Mary J. Drexel project is possible.

References

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[2] Marquit, Amanda. 2013. "From Sears & Roebuck to Skyscraper: A History of Prefabricated and Modular Housing", NYC Buildings. New York, NY.

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-- Mary J. Drexel Project & Prefabricated MEP Corridor Racks --

The MEP systems for the Mary J. Drexel project were constructed under a Design-Build contract utilizing BIM. This allows for 3D modeling and clash detection to be used when designing the systems. Although there was no problem with the design of the systems and the layout, many unforeseen delays arose prior to the start of the MEP trades starting their work. This led to a need for an increase in manpower and productivity in regards to the MEP systems installation. Thus, extra crews were forced to be employed for the MEP trades in order to meet the scheduled deadlines. This aspect of the project may have benefitted if prefabrication techniques were used such as a prefabricated MEP corridor rack. In order for a better understanding to be reached for the potential success of this implementation, some of the prefabrication drivers need to be further analyzed.

Jobsite

As mentioned, it is important to carefully analyze the jobsite conditions in order for prefabrication methods to be successfully used. The Mary J. Drexel site can become a congested site very quickly if careful consideration is not taken when subcontractors and others are arriving on site. Utilizing prefabrication will allow for this congestion to be reduced since the amounts of MEP materials do not need to be stored or placed on site during construction. Not only will this allow the construction site to become less congested, it will also allow for the MEP trades to start their work at an off-site warehouse before any significant milestones are reached such a building dry-in. The best approach to bring in the MEP corridor racks will be to utilize “just-in-time” (JIT) delivery from the prefabrication shop to the construction site. Any transportation restrictions and requirements might complicate deliveries to the site as well. Fortunately, the plumbing subcontractor, Worth and Company, has the capability to use a prefabrication shop of their own.

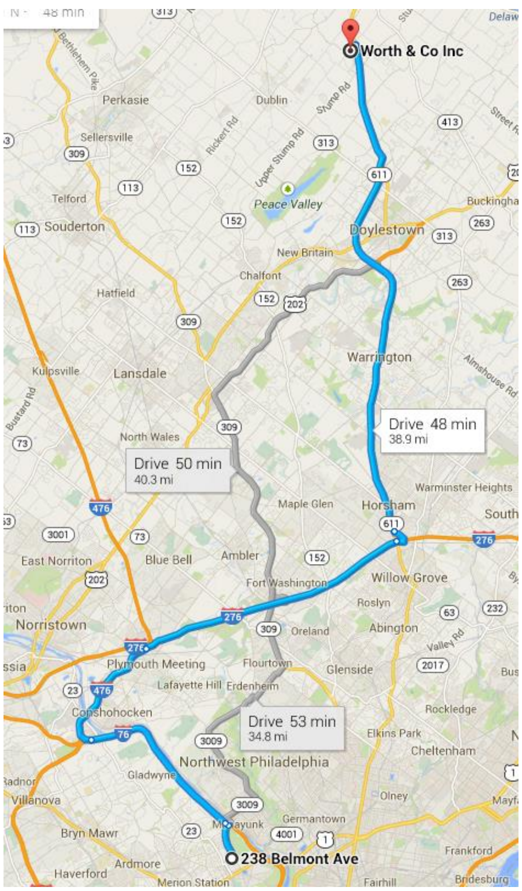


Figure 3.8 – Prefab Facility Route to Jobsite
Image from Google Maps

Prefabrication Warehouse Location

Worth and Company is a full-service mechanical and plumbing contractor in the Mid-Atlantic region. Knowing that one of the contractors on the project has the capability of using a prefabrication facility is a major factor that will allow for a push for the fabrication of the proposed corridor racks. As shown in **Figure 3.8** on the left, the facility is only located approximately 39 miles away from the jobsite. Having this capability and only being 50 minutes away from the jobsite is a great benefit to have.

Project Design & Area of Implementation

In determining which areas of the corridor will best be suited for the MEP corridor rack, it is critical to understand and consider logistical issues that may be associated. The number of stories, building exterior, and the layout of the interior are important aspects that may impact whether or not the MEP corridor racks can be prefabricated. Fortunately, the project is only two stories and there are plenty of areas where an opening can be left for the racks to be brought in. The easiest location to bring in the racks would be from the centrally located terraces in each floor of each wing as shown in **Figure 3.9** below.

Figure 3.9 – Terrace location for West Wing (left) and East Wing (right)

The terraces (shown in green above) are a perfect location for any large component to be brought into the building after or during the exterior of the building is being completed. The three bay window opening highlighted in red allows for anything with a width of 10 feet to be brought in. The corridors have a width of 6 feet, thus the maximum width that the corridor racks can be are 6 feet. The MEP corridor racks will easily fit through into the large open lobby space during construction. They will be able to be wheeled to the necessary location in the corridor and then jacked up and installed in place when the time is necessary.

MEP Corridor Rack Design

When considering the design of the interior, ceiling height is important. Throughout the corridors there are areas that have varying arched ceilings which will make it difficult for designing MEP corridor racks. Since these varying ceiling heights will make it the design a challenge, these areas will not implement MEP corridor racks and will be stick-built prior to the MEP racks being installed. Tolerances will be left so that once the racks are installed; easy connections between the stick-built construction and prefabricated construction can be made. The typical corridor ceiling height above the finished floor is 8'6" leaving approximately three feet above the ceiling for all MEP and other building system work. These areas are marked in green on **Figure 3.10** on the following page. Areas marked in red represent the arched ceiling areas where a corridor rack will not be feasible.

Figure 3.10 – Ceiling Heights West Wing (left) and East Wing (right)

The following design constraints are then developed for the rack design.

Design Basis for Corridor Rack:

- Width = 6' (max width of corridor)
- Height = 2.5' (11'6" – 8'6" = 3' – 6" for extra clearance AFF)
- Length = 10'*

* Lengths can be adjusted to different lengths if necessary (under professional design)

In order to design the placement of MEP components for the rack design, coordination drawings that were developed during the Design Build phase of the project. As stated earlier, clash detection allowed many of the MEP systems to be worked around each other. Analyzing the corridor components was important to determine if there was too much variation of the systems. If there was, then implementing a prefabricated MEP corridor rack would have proven to be more difficult. However, this proved not to be the case and much of the MEP system components were designed identical throughout each corridor and floor. The only differences that were noticed included small variations of duct sizes, amount of electrical raceway conduit running along parts of the corridor, and areas where supply air ducts extended into the resident units. After taking all the necessary items into consideration, a sample corridor rack was designed as shown in **Figure 3.11** and **Figure 3.12**.

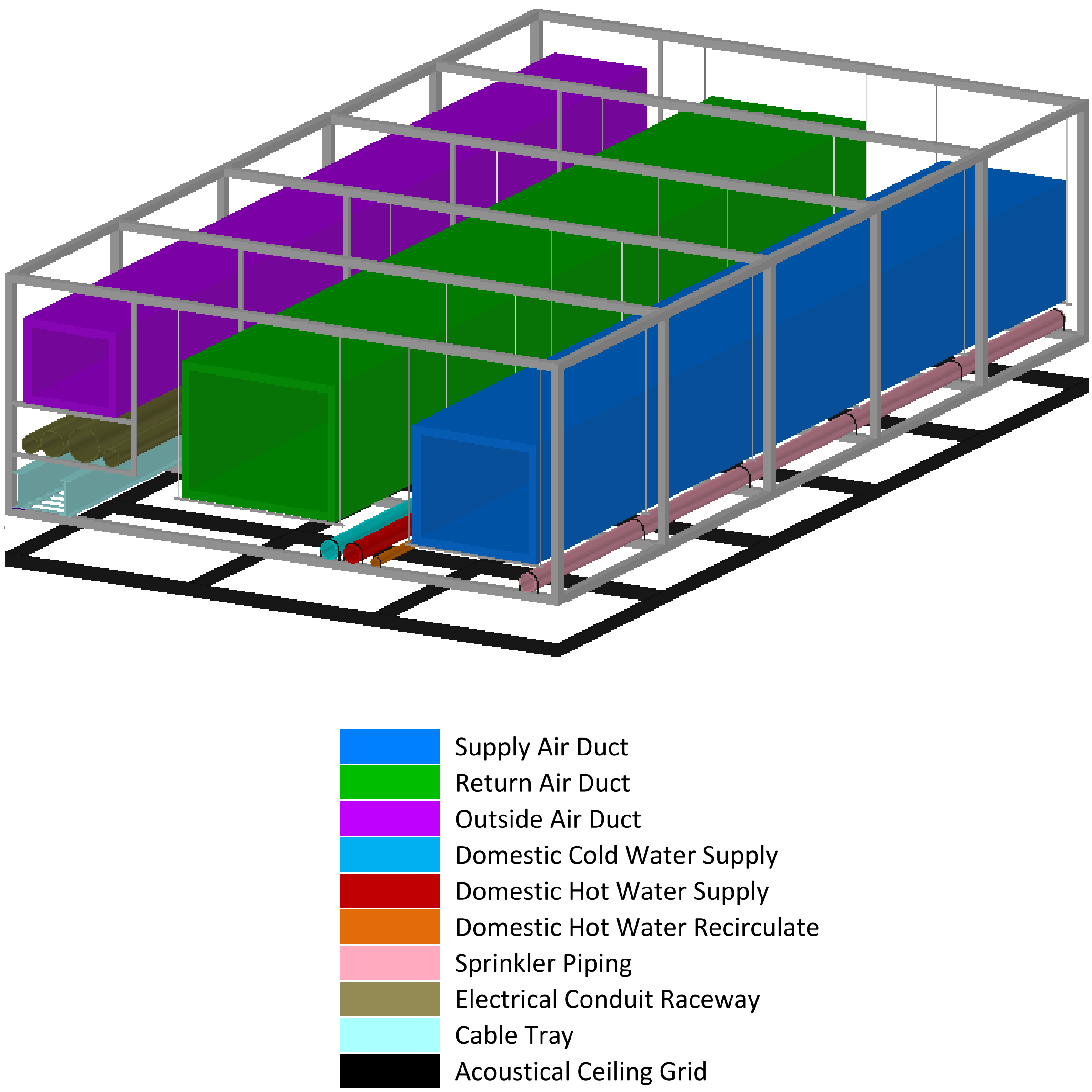


Figure 3.11 – Sample MEP Corridor Rack Design – 3D View

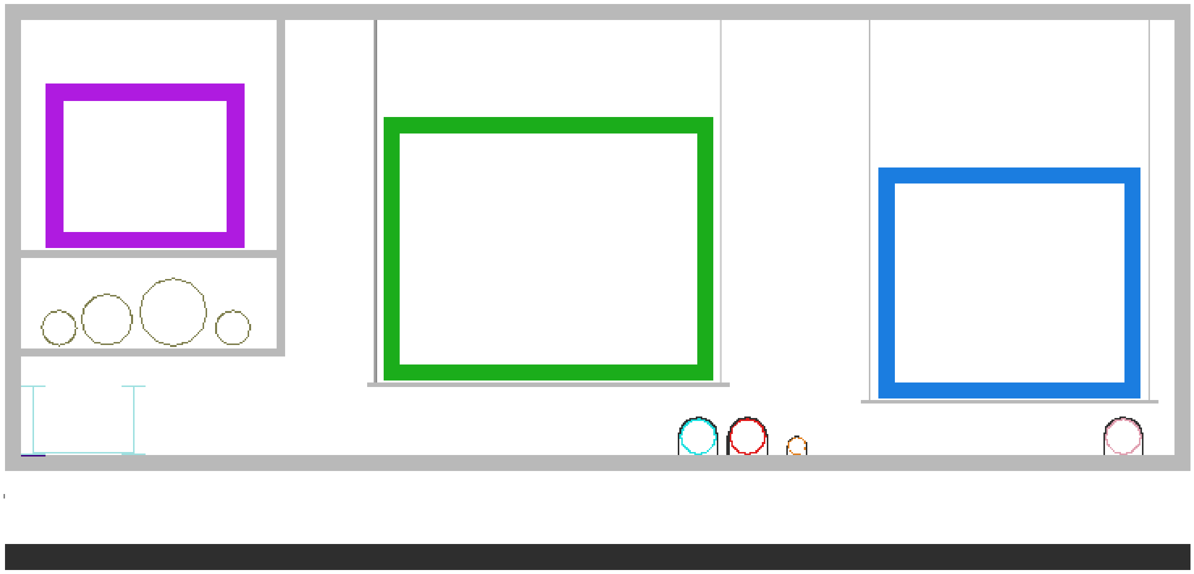


Figure 3.12 – Sample MEP Corridor Rack Design – Front View

As can be seen in the above figures, the sample corridor rack designed contains plenty of clearance where stick-built mechanical ductwork, piping, cabling, etc. can be installed and connected to the corridor. A great advantage of this design is that much of the ductwork connections that do extend out into the resident units are flexible ducts and those can be simply attached to the corridor rack. Although the project did not utilize a cabling rack like the one shown in the design above, it was built into this design to provide more visual on the amount of space that will be available in each rack. Having the large area of space for above ceiling work for the MEP and interior finish trades greatly increases the success of implementing MEP corridor racks for this project.

Results

-- Schedule Savings --

The primary reason to use prefabricated MEP corridor racks is to attempt to reduce the overall project schedule by achieving a higher quality of construction and doing so in a safer environment. Due to the schedule delays seen on the project, the MEP trades were forced to employ extra laborers to meet the project schedule demands. Implementing prefabrication would definitely not allow for the extra labor demand. From all the MEP work performed on the project, the corridors account for about 30% of it. Due to the repetitious nature of the corridor racks and each floor for this project, it is safe to assume that the prefabrication installation rates can reduce the labor durations for this area of work by at least 25%. **Table 3.1** below shows the breakdown of the schedule reductions that are a result of the implementation of prefabricated MEP corridor racks.

Activity	Original Total Work (d)	Original Corridor Work Duration (d)	Prefab Corridor Rack Duration (d)	Total Corridor Reduction (d)
Mechanical	20	6	4.5	1.5
Electrical	20	6	4.5	1.5
Plumbing	25	8	6	2
Fire Protection	15	5	3.75	1.25
TOTAL		25	18.75	**6.25**

Table 3.1 – Schedule Duration Summary for MEP Corridor Work per floor

As can be seen, by providing prefabricated MEP corridor racks on this project, an average of 1.5 days was saved for each trade per floor. Being on the critical path of the project, this allows for each floor to reduce their total construction duration by 6.25 days and allowing for the total project schedule to be reduced by this much as well.

-- Cost Savings --

To determine the total cost savings that can be achieved by implementing a prefabricated MEP corridor rack, analysis of labor costs and general conditions costs will be performed. One of the major benefits associated with prefabrication as stated many times above is the availability of using an off-site facility to complete work. Labor costs associated with on-site and off-site construction efforts can provide significant savings. By providing only 5 laborers for each trade to complete work off-site for the prefabrication of the MEP corridor racks, the average daily savings per day is $3,340. With the 6.25 day reduction summarized above, this results in a total of $20,875 in labor savings for one week. Table 3.2 on the following page outlines the total potential labor savings mentioned.

Labor Rates On-Site vs Off-Site (Prefabrication)					
Trade	Hourly Wages		# of Laborers	Daily Costs	
	On-Site ($/hr)	Off-Site ($/hr)		On-Site ($/hr)	Off-Site ($/hr)
Mechanical	$83.55	$62.66	5	$3,342.00	$2,506.50
Electrical	$79.85	$59.89	5	$3,194.00	$2,395.50
Plumbing	$86.90	$65.18	5	$3,476.00	$2,607.00
Fire Protection	$83.70	$62.78	5	$3,348.00	$2,511.00
			Total Daily Labor Costs	$13,360.00	$10,020.00
				Total Labor Savings / Day	**$3,340.00**
				Total Labor Savings (6.25 days)	**$20,875.00**

Table 3.2 – Total Potential Labor Savings (On-Site vs Off-Site) (6.25 days result)

This analysis proved to be successful in reducing the project schedule by one week. Had the project team and owner implemented prefabrication techniques such as MEP corridor racks on this project, the general conditions cost savings are outlined in **Table 3.3** below.

General Conditions – *Potential Cost Savings*				
Description	Quantity	Unit	Cost/Unit	Amount
Project Management Team				**$13,238**
Project Executive (10%)	.25	Mo.	$2,050.00	$513
Field Operations Manager (10%)	.25	Mo.	$1,700.00	$425
Project Manager	.25	Mo.	$16,000.00	$4,000
Superintendent	.25	Mo.	$15,500.00	$3,875
Project Engineer	.25	Mo.	$11,200.00	$2,800
Project Assistant (50%)	.25	Mo.	$4,000.00	$1,000
Laborer (50%)	.25	Mo.	$2,500.00	$625
Site Conditions				**$1,000**
Temporary Phone	.25	Mo.	$750.00	$188
Temporary Toilets (4)	.25	Mo.	$600.00	$150
Drinking Water	.25	Mo.	$150.00	$38
Dumpsters (2)	.25	Mo.	$2,500.00	$625
Field Operations				**$19**
Field Office/Trailer - use existing facilities	0	Mo.	$0.00	$0
Storage Trailers - use existing facilities	0	Mo.	$0.00	$0
Job Office Supplies	.25	Mo.	$77.40	$19
			TOTAL	**$14,257**

Table 3.3 – Total Potential General Conditions Cost Savings (1 week results)

Implementing the prefabricated MEP racks resulted in providing $14,257 in cost savings to general conditions due to the one week reduction in schedule. If the $57,027 cost savings from the improved project schedule from Analysis #1 is also implemented, these two analyses would have provided the owner with $71,284 in general conditions cost savings in total.

Conclusion

In conclusion of this analysis, it is recommended that the project team and owner should have considered using prefabrication techniques to improve the overall quality of the project while reducing cost control and schedule. Not only does prefabrication reduce the overall cost and time of the project, but also allows for the simplification of complex MEP work. Critical path items tend to be some of the most complex components of a building project, and by simplifying them; prefabrication reduces risk in safety by reducing site congestion and overhead work. The implementation of prefabricated MEP Corridor Racks resulted in reducing the overall project schedule by 1 week. This then results in a $14,257 cost savings in general conditions and $20,875 in labor costs based on work being performed on-site or off-site.

Analysis #3: Green Roof Implementation

Problem Identification

Although many value engineering efforts were made to benefit the owner, very few sustainable techniques were considered that could have provided more financial benefit to the owner over the life cycle of the facility. Many of the value engineering decisions were made based on lowering initial capital cost without much consideration into future economic advantages.

Background Information

The value engineering item that brought this analysis to consideration was the elimination of the concrete roof deck. Instead an EPDM roofing system was proposed and approved to be used. The implementation of an EPDM roofing system did allow for a significant cost savings to the owner, but the sole reason this was accepted was just to reduce the initial capital cost of the project.

This project is not achieving any LEED accreditation and not many sustainable features were employed. Incorporating a green roof into the project however not only benefits the owner, but also benefits the building occupants as well and the environment. Green roofs have become increasingly popular in building design because of their exceptional performance in reducing energy use, reducing air pollution and greenhouse gas emi0ssions, improving human health and comfort, and enhancing storm-water management and water quality. Since the occupants of this facility will house elderly persons, potential noise reduction would be another great advantage for the green roof system. This is especially beneficial since Belmont Avenue is a highly traveled road throughout the entire day.

Analysis Goals

The main goal of this analysis is to complete an in-depth study of green roofing systems and the possible implementation on the Mary J. Drexel project. Background information will be provided on the types of green roofing systems and the advantages and disadvantages between EPDM roofs and green roofs will be outlined as well. Ultimately, a recommendation will be given to the owner whether or not the facility could have benefited from the implementation of a green roof.

Furthermore, an analysis of the additional load that the green rood system will add to the existing structure will be performed to determine if this additional load can be supported. Additionally, an acoustical analysis will be conducted to determine the impact the green roof system might have on the elderly residents occupying the facility and if any noise reduction will follow this implementation. From here, costs associated with the green roof system will be calculated along with a lifecycle cost analysis to determine the feasibility of the implementation.

Upon completion of this analysis, it is expected that the Mary J. Drexel Home will benefit from incorporating a green roof system in lieu of the value engineered EPDM roof system. Although the start-up costs may be expensive, the lifecycle costs will outweigh that of the EPDM roof.

Green Roof System Information

In order to ensure the success of this analysis, background research on green roofing systems was completed. There are two major types of green roof systems; intensive and extensive. The main difference between the two types, as shown in **Figure 4.1** below, is in the amount of vegetation and growing medium.

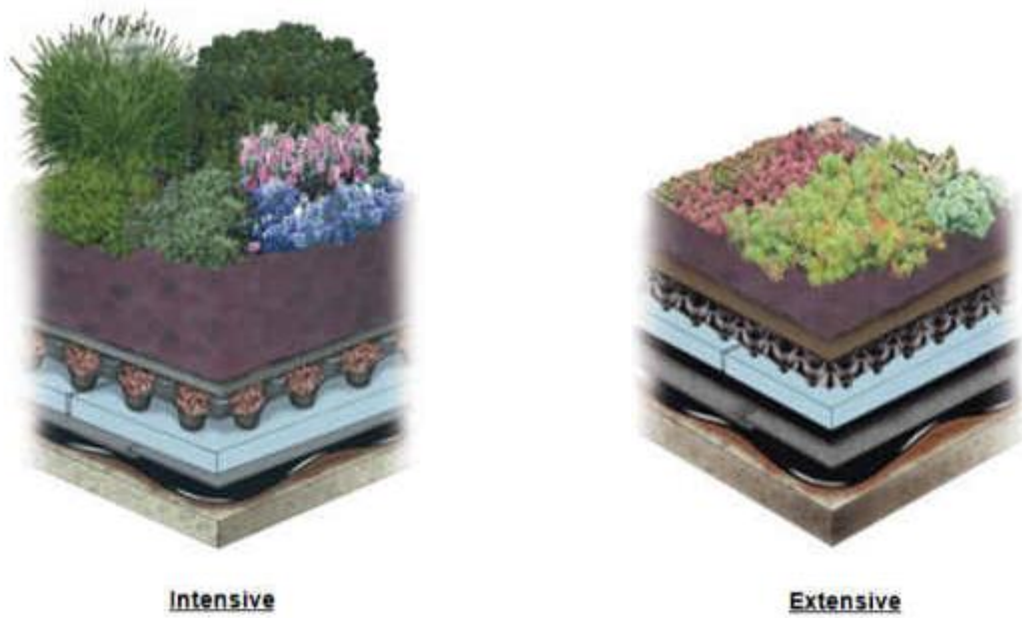


Figure 4.1 – Intensive vs. Extensive green roof systems – Image from University of Maryland SO GREEN Team

Intensive Green Roof Systems

As can be seen from **Figure 4.1** above, intensive green roof systems incorporate all sizes and types of plants. These planting mediums do have a greater depth than extensive roofing systems with a starting depth of 6". The deep soil allows for the larger vegetation to be accommodated. These types of roofs also may include paths and walkways to allow travel between the spaces for occupants depending on the building. When this type of roof is installed and the vegetation is moist, the typical added weight to a structure can range from 80-150 pounds per square foot (psf). The advantages of this system include better storm-water management, increased insulation properties, and greater plant diversity.

Extensive Green Roof Systems

On the other hand, extensive green roofs are often used on inaccessible roofs that are only accessible by maintenance personnel. The planting mediums associated with this type of roof have shallow depths of 3- 6" and support very lightweight plants and grass. Therefore, the design of this system is important to provide increased insulation properties and storm-water management, but not to the same extent as intensive systems. The benefit of using this system not only provides better thermal ratings and water usage, but keeps the overall weight of the roof system low with a range of 15-50 psf when fully saturated depending on medium depth. They also are less expensive than intensive systems and provide a better return on investment.

In addition to these two types of green roof systems, there are two construction methods that can be used when installing them. One way is the conventional way which involves the laying down of every layer of the system one by one. The other is a pre-manufactured system which allows for an increase in installation time. These pre-manufactured systems come in modular trays, as shown in **Figure 4.2** below, which contain most of the layers except for the waterproofing membrane and protection fabric.

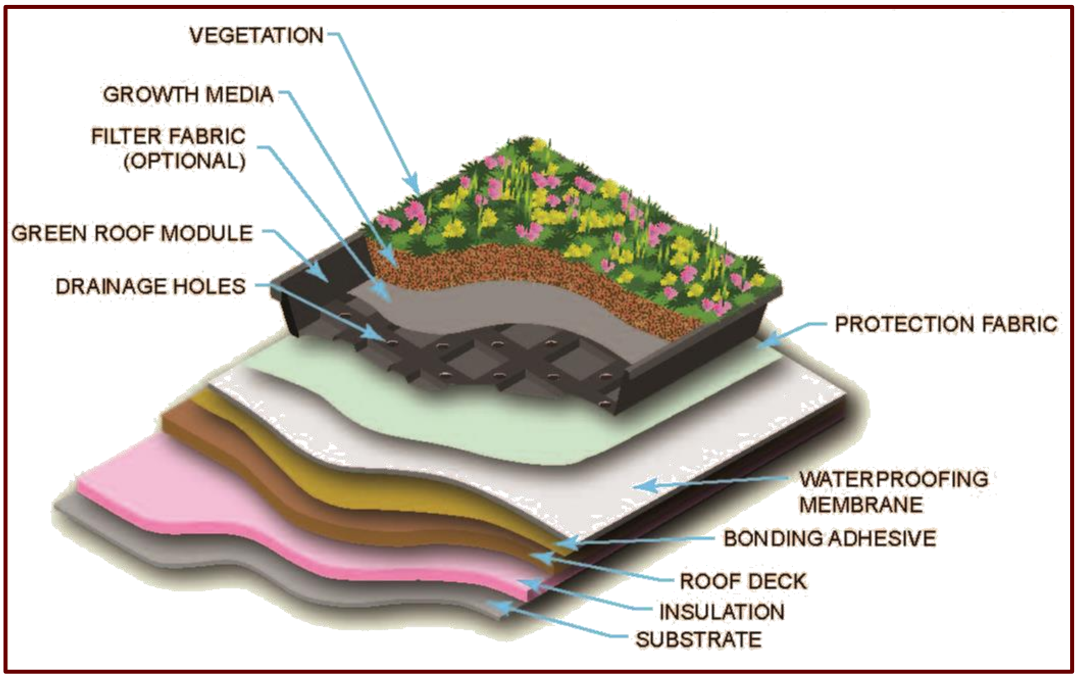


Figure 4.2 – Typical Modular Green Roof Tray – Image from EHS Journal

Advantages and Disadvantages of Green Roofs

-- Advantages --

- Energy Efficiency
  - Offers greater insulation properties, thus reducing amount of energy needed to control temperature of a building.
  - Traditional roofs are where most of the heat loss comes from in the winter and have the hottest temperatures in the summer.
- Storm-water Management
  - Water is stored by the substrate and absorbed by the plants.
  - Reduces amount of storm-water runoff, resulting in decreased stress on storm-water system.
- Increased Roofing Membrane Durability (Life-Cycle)
  - Reduces the amount of temperature fluctuation faced by the membrane.
  - Traditional roofs need to be replaced every 15-20 years due to direct sunlight exposure and temperature fluctuations.
- Fire Retardation
- Noise Reduction

-- Disadvantages --

- Initial Cost
  - Higher initial cost to build than traditional roofs
- Stronger structural system (if necessary)
- Maintenance required (depending on type of system used)

As described, green roofs have numerous advantages compared to disadvantages. However, please note that many of these advantages and disadvantages listed will vary by region, climate, and building type as each installation is unique.

Although green roof systems usually inquire a higher initial cost, the longer life-span compared to traditional roofs offsets this cost. Also, reduction in engineering costs for systems such as storm-water reduction, energy systems, and others are incentives to utilize a green roof system.

Green Roof System Design

For this analysis, an extensive green roof system will be utilized when comparing to the value engineering EPDM roof system. The proposed design of the green roof is located on both the East & West Wing of the project. The proposed green roof design will be implemented over the residential unit areas and not over the lobby areas due to the mechanical equipment in that area. Since there needs to be at least three feet of walking space for maintenance crews and the mechanical equipment on the rooftop take up area, it will not be reasonable to place a small amount of green roof pods in this area. Due to their similar size and shape a structural analysis will be performed on one of the wings to determine the feasibility of implementing such a system.

Figure 4.3 below outlines the areas of the West and East wing that will have the green roof system implemented. The proposed design will cover approximately 9,500 square feet.

Figure 4.3 – West Wing (above) - 4,500 SF & East Wing (below) - 5,000 SF – Image from SFCS

The green roof system chosen will also be a pre-manufactured system, specifically from Hydrotech USA®. The Garden Tray GT15® modular tray allows for quicker installation over conventional systems and can be installed directly on metal roof decks due their lightweight construction. Looking at the product data sheet provided by Hydrotech®, the Garden Tray GT15® is loose laid over the roofing membrane insulation and protection fabric. The following technical data is also given:

- Dimensions: 18 in. X 22 in.
- Coverage: 2.75 ft^2
- Height/Depth: 4 in.
- Weight: approx. 29 psf (filled,wet)

* Product Data taken from Hydrotech USA Resource Center

To perform a structural analysis, a saturated weight of 29 psf will be used.

Structural Analysis (Breadth #1)

With the implementation of the green roof system, a structural analysis must be performed to determine if the additional load can be supported by the existing structure. The roof currently consists of tapered rigid insulation averaging a depth of 10" on a 4-½" metal deck topped with a ½" insulation board. The majority of the building is composed of load-bearing metal stud wall panels. The additional loads on the metal stud panels will need to be analyzed to determine the feasibility of the green roof system. **Figure 4.4** below outlines a section of the EPDM roof system.

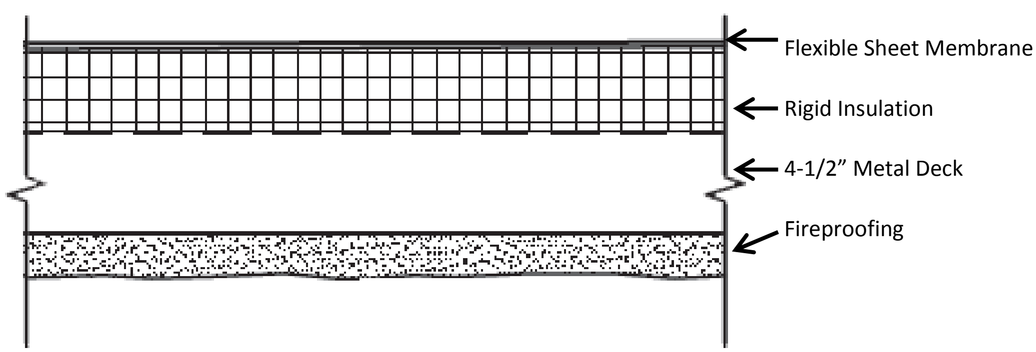


Figure 4.4 – EPDM Roof Section – Image from SFCS

Note: All calculations and sizing methods used in this breadth study were learned in Architectural Engineering (AE) 404: Building Structural Systems in Steel and Concrete & Civil Engineering (CE) 397A: Geotechnical Engineering. Outside advice was asked from advisors and structural students for any calculations and questions not learned in the courses mentioned above.

-- Design Loads --

The structural drawings provided by the architect and structural engineer dictated the loads that the load-bearing panel walls would provide throughout both buildings. These loads were used by the metal stud panel designer to size and design the prefabricated panels. Prior to analyzing the impact the green roof system may have on the wall panels, calculations were made to determine the average roof loading based on the loads given by the structural engineer on the drawings. **Figure 4.5** below shows some of the given loads that were used to determine the average roof load.

Note: Dimensions shown in red are not exact but approximates that were used for calculations.

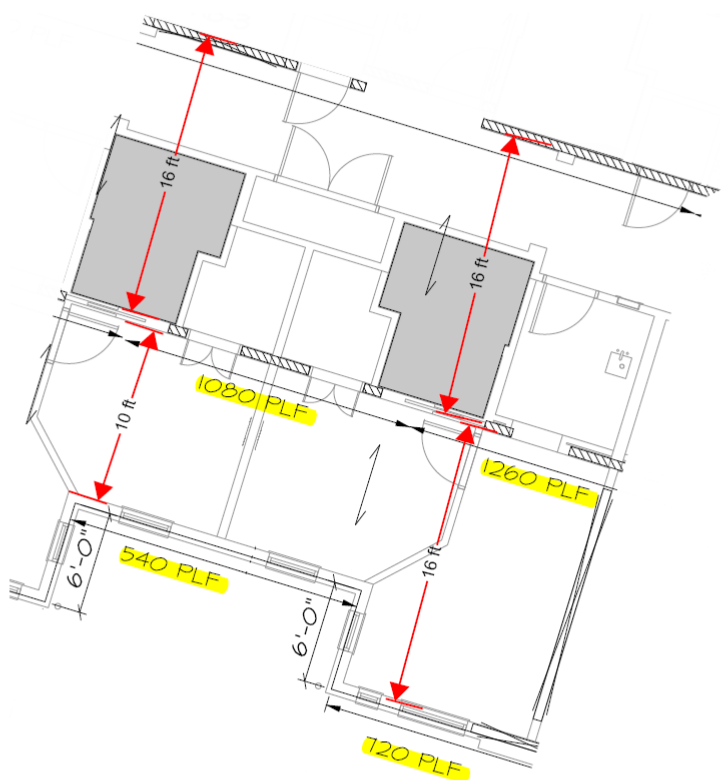


Figure 4.5 – 2nd Floor loads given on structural drawings for panel design – Image from project drawings

When determining the average roof load, each load given was divided by its respective tributary area as follows:

$$\text{Load (psf)} = \frac{P}{A_T}$$

$$\frac{720\ plf}{8'} = 90\ psf \qquad \frac{540\ plf}{5'} = 108\ psf \qquad \frac{1260\ plf}{(8' + 8')} = 79\ psf \qquad \frac{1080\ plf}{(5' + 8')} = 83\ psf$$

$$\text{Avg. roof load (psf)} = \frac{90 + 108 + 79 + 83}{4} = \mathbf{90\ psf}$$

Understanding that the average roof load was 90 psf, **Table 4.1** was developed to outline all the assumed roof loads of the current roof deck compared to the Hydrotech® green roof system. All design loads were obtained either from the structural drawings, product data sheets, or 2009 International Building Code.

***See Appendix E for the data sheets used to obtain design loads.**

Description	EPDM Roof	Hydrotech® GT15™ Module
4-½" 18 GA Metal Deck	5 psf	5 psf
Avg. 10" Rigid Insulation	5 psf	5 psf
MEP + Fire Protection	15 psf	15 psf
Ceiling	4 psf	4 psf
Miscellaneous	10 psf	10 psf
4" Garden Tray GT15™	-	29 psf
Total Dead Load	**39 psf**	**68 psf**
Total Roof Live Load	**20 psf**	**20 psf**
Total Snow Load	**23.1 psf**	**23.1 psf**

Table 4.1 – Assumed Dead and Live Loading of EPDM Roof and Hydrotech® Green Roof

As mentioned prior, the HydroTech® system increases the load by 29 psf which makes the total dead load on the roof increase form 39 psf to 68 psf.

-- Total Load --

Using Equation 16-2 in Section 1605 – Load Combinations of the 2009 International Building Code, the total load combination of dead and live loads can be calculated.

- Factored Distributed Load:
  - $W_{TOTAL} = 1.2D + 1.6L + 0.5S$ (Equation 16-2)
    - $W_{TOTAL} = (1.2)(68)+(1.6)(20)+(0.5)(23.1) =$ **125 psf**

-- Roof Deck Calculation Check --

After calculating the total load the existing roof structure is experiencing due to the addition of the green roof system, the current roof deck will be analyzed to ensure it is feasible for this application. The existing roof deck as mentioned before is composed of a 4-½" 18 gage metal deck. After searching for the product load tables from Epic Metals, it was realized that the load tables are based on ASD Design. All calculations and sizing methods that were learned in AE 404 were based on LRFD Design. Thus, a similar roof deck from Metal Dek Group® was found that used LRFD.

Using the total factored load of 125 psf and the data from the manufactures roof deck product sheet, the roof deck can be analyzed.

Deck Conditions: Double Span @ 16'-0" | 18 Gage | Weight = 4.20 psf

Strength and Deflection are the two conditions must be met in order for the current deck to be substantial enough for the additional load by the green roof system.

- Strength (Max superimposed factored LRFD dead + live load):
  - Allowable total (psf) ≥ $W_{TOTAL\ (factored)}$ (psf)
    - Allowable total = 138 psf
    - W_{TOTAL} = **125 psf** (calculated earlier in total load)
    - 138 psf ≥ 125 psf. ✓

Therefore, the addition of the green roof meets the strength limitation of the current roof deck.

- Deflection (Max. superimposed unfactored LRFD dead + live load):
  - Load causing deflection (psf) ≥ $W_{TOTAL\ (unfactored)}$
    - Load causing deflection = 138 psf
    - W_{TOTAL} = 68 psf + 20 psf + 23.1 psf = **111.1 psf**
    - 138 psf ≥ 111.1 psf. ✓

Therefore, the addition of the green roof meets the deflection limitation of the current roof deck.

After checking the conditions, the existing Epic Metal 4-½"18 gage metal deck is acceptable to accommodate the Hydrotech® GT15™ module green roof system.

***See Appendix E for the data sheets used to obtain design loads.**

-- Metal Stud Wall Panel Calculation Check --

After determining the green roof system's impact on the metal roof deck, the next logical step is to analyze how it affects the main structure composed of load-bearing metal stud wall panels. Although stud calculations were not learned in AE 404, extra research and guidance from structural students and advisors was necessary for this part of the structural analysis.

To start, a typical bay of a single residential unit was outlined to identify the wall panel layout throughout the areas that will be affected. This is shown in **Figure 4.6** below.

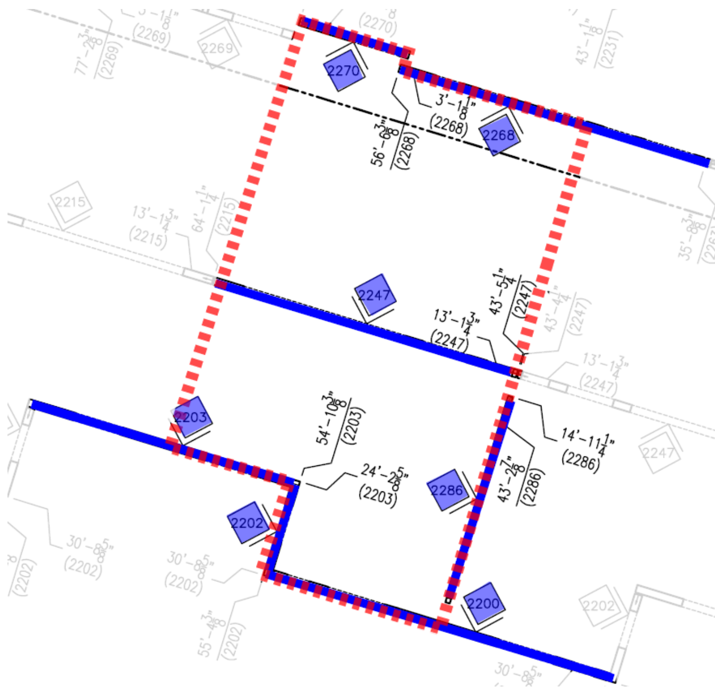


Figure 4.6 – 2nd Floor panel layout (2000 series) – Image from project shop drawings

The red dashed line outlines a typical residential unit and the blue lines highlight the panels affected in an individual room. The first floor panel layout (1000 series) is identical on the second floor (2000 series) as shown; the only difference is the numbering of panels, which help the erectors when installing them. In order for these wall panels to be designed, the structural engineer provides the load data to the metal fabricator who then performs their own structural calculations to determine the sizing and spacing of the metal studs in the panels. Each panel is given a wall type label that helps give a better understanding of the exact loads a certain panel will be experiencing. **Table 4.2** on the following page outlines the wall loads that each wall panel type will experience between the roof to second floor and from the second floor to the ground floor.

Gravity Wall Loads			
Wall Type	Interior / Exterior	Roof to 2nd Floor	2nd to Ground Floor
		Total Load (plf)	Total Load (plf)
W1	Interior	3050	1050
W2	Interior	3590	1290
W3	Exterior	2010	720
W4	Exterior	1440	540
W5	Interior	4300	1350
W6	Exterior	2350	720
W7	Interior	1380	440

Table 4.2 – Total Gravity Wall Loads

Using these given gravity loads, calculations were performed to determine the typical stud load for each type of wall panel (W1-W7). In order for these calculations to be performed, the wall panel designer used ClarkDietrich cold-formed structural framing products and the allowable axial & lateral load tables were necessary. Using these load tables to identify the axial load that can be supported by each metal stud member under the given wall lateral load conditions from **Table 4.2**, the stud capacity can be determined.

Stud Capacity

Design Criteria:

- Exterior Wall Panel Wind Pressure = 25 psf
- Interior Wall Panel Wind Pressure = 5 psf
- Overall Panel Height = 11’
- Spacing = 16” o.c.
- All loads are unfactored

The structural members that were used per each wall panel type are outlined in **Table 4.3** below:

Metal Studs Used for Design		
Wall Type	Roof to 2nd Floor	2nd to Ground Floor
W1	600-S-162-43	600-S-162-54
W2	600-S-162-43	600-S-162-54
W3	600-S-162-43	600-S-162-54
W4	600-S-162-43	600-S-250-43
W5	600-S-162-43	600-S-200-54
W6	600-S-162-43	600-S-162-54
W7	600-S-162-43	600-S-162-43

Table 4.3 – ClarkDietrich Structural Members used in wall panel design

The coding of the products used consists of four parts:

Depth = 600 = 6.00”

Structural Stud = S

Flange Width = 162 = 1.625”

Thickness = 54 mils

Since the load tables provide stud lengths in two foot intervals, in order to find the capacity for an 11’ length interpolation was needed. After interpolating for each wall panel type and given stud members, the following **Table 4.4** and **Table 4.5** give the maximum capacity a single metal stud member can support.

2000 Series (2nd Floor Panels)				
Wall Type	Total Load (plf)	Stud Spacing (in)	Interior / Exterior	Capacity (lbs)
W1	1050	16	Interior	3145
W2	1290	16	Interior	3145
W3	720	16	Exterior	1885
W4	540	16	Exterior	1885
W5	1350	16	Interior	3145
W6	720	16	Exterior	1885
W7	440	16	Interior	3145

Table 4.4 –Second floor panel load capacities

1000 Series (1st Floor Panels)				
Wall Type	Total Load (plf)	Stud Spacing (in)	Interior / Exterior	Capacity (lbs)
W1	3050	16	Interior	5355
W2	3590	16	Interior	5355
W3	2010	16	Exterior	4105
W4	1440	16	Exterior	2730
W5	4300	16	Interior	6800
W6	2350	16	Exterior	4105
W7	1380	16	Interior	3145

Table 4.5 – First floor panel load capacities

***See Appendix F for load tables from the Technical Design Guide for Cold-Formed Structural Framing**

Metal Wall Panel Calculation Check

With the capacity for each wall type calculated, the next step is to determine the impact the green roof load has on the existing wall panels. The best way to approach the additional load of the green roof is to add the 29 psf additional load to each wall type and check if the capacities of the metal studs originally designed are sufficient enough to support the new roof system. Note, the loads used are unfactored, so the 29 psf green roof load does not need to be factored when performing the calculations.

The green roof load is then multiplied by the respective tributary area that affects each wall panel type to find the additional load in pounds per linear foot. Referencing back to **Figure 4.5**, the tributary area that will be used for interior panels will be 16 feet and for exterior panels will be 8 feet. Panel 2247 in **Figure 4.5** is a W2 type wall panel and these panels will use a tributary width of 13 feet.

Wall panel type W2 on the first floor will be used as an example calculation:

Design Criteria:

- Original Total Load (TL) = 3590 plf
- Green Roof Load (GL) = 29 psf
- Tributary Width (T_w) = 8' + 5' = 13'
- Spacing (s) = 16" = 1.33'

Typical Stud Load (lbs):

- P = [TL + (GL)(T_w)] (s)
    - P = [3590 plf + (29 psf)(13')](1.33')
    - P = [3590 plf + 377 plf] (1.33')
    - P = (3967 plf)(1.33') = **5289 lbs**
    - 5289 lbs < 5535 lbs ✓

Comparing the 5289 lbs just calculated to the original design capacity of 5355 lbs, the additional green roof load checks out for this wall panel type. The same calculation was repeated for each wall panel type with their respective tributary areas and **Table 4.6** and **Table 4.7** below and on the following page show the results for each floor.

2000 Series (2nd Floor Panels)						
Wall Type	**TL (plf)**	**New TL (plf)**	**Stud Spacing (in)**	**Interior / Exterior**	**Typ Stud Load (lbs)**	**Capacity (lbs)**
W1	1050	1514	16	Interior	2019	3145
W2	1290	1522	16	Interior	2029	3145
W3	720	952	16	Exterior	1269	1885
W4	540	772	16	Exterior	1029	1885
W5	1350	1814	16	Interior	2419	3145
W6	720	952	16	Exterior	1269	1885
W7	440	904	16	Interior	1205	3145

Table 4.6 – Second floor panel load capacity calculation results

1000 Series (1st Floor Panels)						
Wall Type	TL (plf)	New TL (plf)	Stud Spacing (in)	Interior / Exterior	Typ Stud Load (lbs)	Capacity (lbs)
W1	3050	3514	16	Interior	4685	5355
W2	3590	3967	16	Interior	5289	5355
W3	2010	2242	16	Exterior	2989	4105
W4	1440	1672	16	Exterior	2229	2730
W5	4300	4764	16	Interior	6352	6800
W6	2350	2582	16	Exterior	3443	4105
W7	1380	1844	16	Interior	2459	3145

Table 4.7 – First floor panel load capacity calculation results

After performing the calculations and checking the loading conditions for the existing metal panels, the addition of the green roof system will not impact the structural integrity that was originally designed. Since the roof deck and structural system have been analyzed, the next aspect of the system will be the foundation footing/depressed slab condition.

-- Foundation Calculation Check --

It is important to check if the existing foundation slab will be able to support the additional load the green roof system added. The bearing capacity of the foundation and rebar sizing will be check with techniques learned from CE 209. The ultimate bearing capacity, q_u, is the load per unit area in which any increase in load will cause an increase in foundation settlement, leading to failure of the soil. **Figure 4.7** below represents the thickened slab detail for the load bearing metal studs.

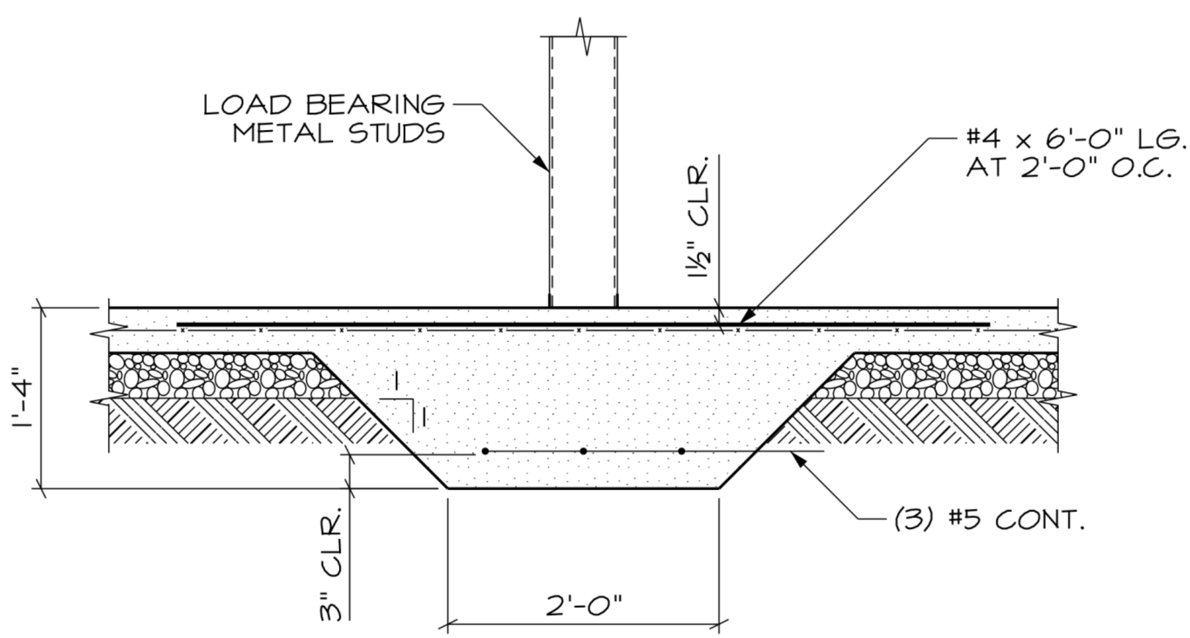
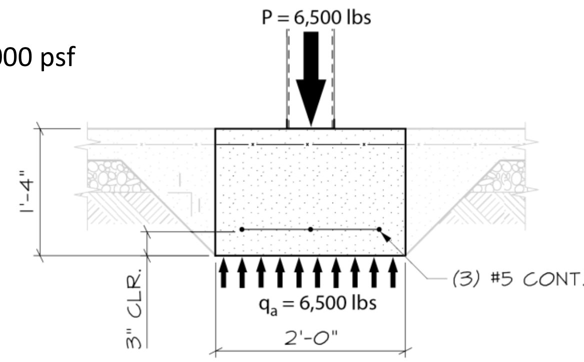


Figure 4.7 – Thickened Slab Detail – Image from project drawings



Design Criteria:

- Maximum Foundation Net Soil Bearing Pressure, q_a = 4000 psf
- Maximum Panel Load, *P* = 6,500 lbs (4800 plf)
    - Taken from max panel load at wall type W5
- Concrete: 4,000 psi, F_s = 60 ksi

Bearing

$$P = 6.5\ k$$

$$q_a = 4{,}000\ psf$$

$$4{,}000\ psf\ \times 2' = 8{,}000\ plf\ \geq 4{,}800\ plf\ \checkmark\ \therefore\ \text{OK}$$

$$P \leq q_a A$$

$$6{,}500\ lbs\ \leq 4{,}000\ psf(2')(1')$$

$$6{,}500\ lbs\ \leq 8{,}000\ lbs\ \checkmark\ \therefore\ \text{OK}$$

With the maximum bearing load equaling 8,000 lbs and a max panel load of 6,500 lbs, the bearing checks out for the existing foundation.

Rebar

$$l = \frac{48" - 6"}{2} = 21" = 1.75'$$

$$f'_c = 4{,}000\ psi$$

$$a = \frac{A_s F_y}{0.85 f'_c b} \qquad a = \frac{A_s(60\ ksi)}{0.85(4\ ksi)(12")} \qquad a = 1.47 A_s$$

$$d = \text{Depth} - \text{Cover} - \text{Rebar Dia.} \quad = 16" - 3" - 0.625" = 12.375"$$

$$M_u = \frac{(4\ ksf)(1.75')^2(1')}{2} = 6.13\ 'k$$

$$M_u \leq \emptyset M_n = \emptyset A_s F_y \left(d - \frac{a}{2}\right)$$

$$6.13\ 'k(12") = 0.9 A_s(60\ ksi)\left(12.375" - \frac{1.47 A_s}{2}\right)$$

$$73.56 = 54A_s\left(12.375" - \frac{1.47A_s}{2}\right)$$

$$73.56 = 668.25A_s - 39.69{A_s}^2$$

$$A_s \geq 0.111\ in^2$$

Existing Conditions Use #5 @ 8" $o.c.$

$$A_s = 0.49\ \text{in}^2\ \geq 0.11 \checkmark\ \therefore\ \text{OK}$$

$$A_{s\ min} = \rho_{min}bh = 0.0018(12")(16") = 0.35 \leq 0.46\ \ \checkmark\ \therefore\ \text{OK}$$

Shrinkage and Temperature

$$a = 1.47(0.46) = 0.6762$$

$$c = \frac{a}{\beta} = \frac{0.6762}{0.85} = 0.796"$$

$$\varepsilon_s = \frac{0.003}{c}(d - c)$$

$$\varepsilon_s = \frac{0.003}{0.796}(12.375" - 0.796")$$

$$\varepsilon_s = 0.0437\ \frac{\text{in}}{\text{in}} \geq 0.005\ \frac{\text{in}}{\text{in}}\ \ \therefore\ \emptyset = 0.9 \checkmark$$

$$S = 16"\ \leq\ 3d$$

$$S = 16"\ \leq\ 3(12.375")$$

$$S = 16 \leq 37.125\ \ \checkmark\ \therefore\ \text{OK}$$

Existing #5's used are acceptable for the depressed slab condition.

After performing a structural analysis, the current structural systems consisting of the metal roof deck, load-bearing metal panels, and depressed slab condition are all adequate enough to support the additional load of the green roof.

Acoustical Analysis (Breadth #2)

Now with the structural design checked and accepted, the next analysis to be completed is an acoustical analysis. Any construction "barrier" or wall/floor system will be able to provide some sort of sound isolation depending on the materials and objects used. Analyzing whether or not a green roof system will improve the sound isolation of the roofing system is important as it may prove to be beneficial for the elderly occupants of the building. It is believed that green roofs have great potential to providing excellent sound isolation. This is mainly due to their high mass and their surface absorption characteristics.

In analyzing sound reduction of partitions, the Sound Transmission Class (STC) is the most common measurement used. In order to understand STC furthermore, Transmission Loss (TL) is a measure of how much sound is reduced as it passes through a partition assembly. Transmission Loss data is report in decibels (dB), which is a simple measurement of how load a noise is. STC is measured by taking the TL data of a certain partition assembly and plotted on a Frequency vs TL plot. These TL data values are tested at 16 standard third-octave band frequencies over the range of 125 Hz to 4000 Hz. Typically; the STC value is the data point at the 500 Hz frequency level. The greater the STC value the greater, the more insulating the assembly is.

After performing some preliminary research on acoustical data for the current roof system and green roof system proposed, it seemed as if there was little to no actual data that could be found on the specific systems used on this project. In order to continue with this analysis, assumptions and typical/similar roof structures will have to be used to determine the impact of sound isolation. Since most STC values are given as one number and not much TL data is provided unless an actual acoustical experiment is performed, a general rule of a best fit curve formula that has been widely accepted by many acoustical researchers can be used for this analysis. **Figure 4.8** shows a standard STC contour[1] and the best fit curve formula.

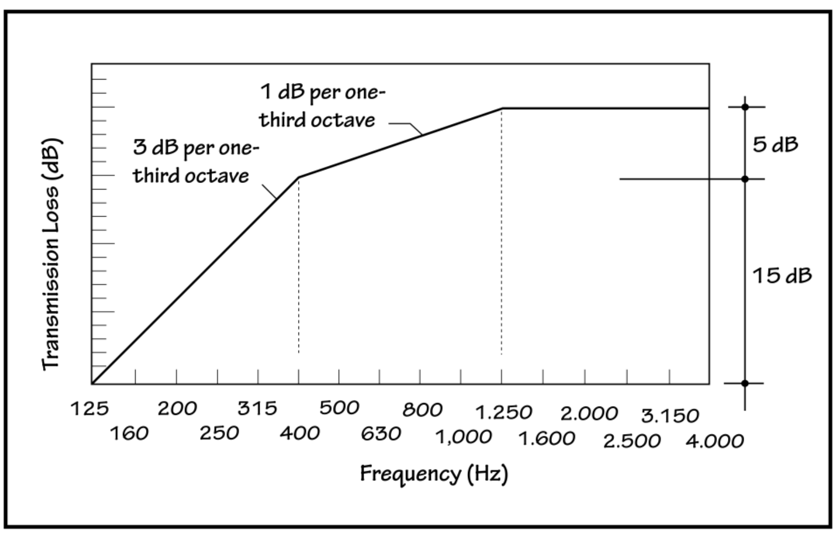


Figure 4.8 – Standard STC contour – Image from *Architectural Acoustics* by Madan Mehta, 2010

The best fit curve formula states the following: (1) The curve increases 3 dB every third-octave from 125 Hz to 400 Hz, (2) Increases 1 dB from 500 Hz to 1125 Hz, (3) Increases by 0 dB after 1125 Hz.

STC is not the only sound isolation value to be considered when calculating TL values. The Impact Insulation Class (IIC) is also used for predicting that amount of transmission loss. IIC measures the ability to block impact sounds such as people walking on the floor above, objects dropped, etc. For this project and current rood system, there will not be much structural impact noise where an IIC test would be needed. The rooftop air-handling units provide sound noise through the air and not much of a structural noise impact. It was decided that since the roof assembly does not have much impact noise that could be measured, analyzing the IIC would have a small impact or even how negligible data.

-- Transmission Loss --

EPDM Roof System

As mentioned earlier, with the lack of data that can be obtained on the current roof system and green roof system, similar structure assemblies have will have to be used. In regards to the current EPDM roofing system, the closest assembly that could be found was from SECUREROCK ®, the roof board manufacturer. A blog post on the website provided an overview of the STC for the typical EPDM roof assembly shown in **Figure 4.9** below. This roof assembly was tested and achieved an STC rating of 41[5].

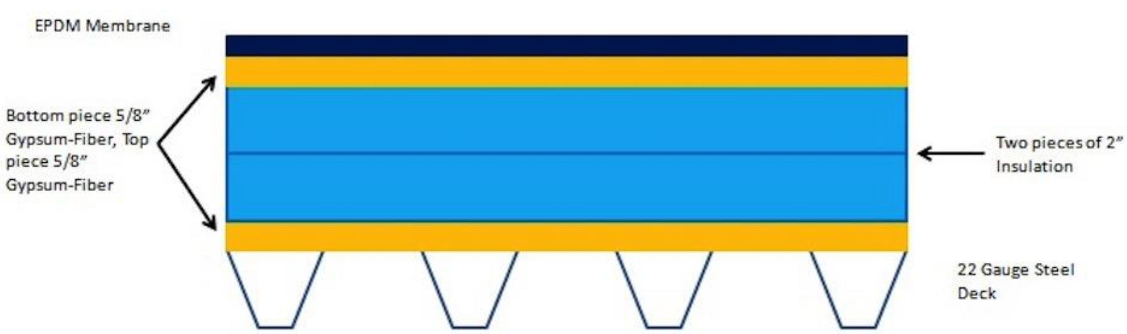


Figure 4.9 – Typical EPDM Roof Assembly – Image from *SECUREROCK®*

Although the current roof system has an average of 10" rigid insulation (that was used for the structural analysis) and an 18 gage steel deck, this system utilizes and extra piece of 5/8" SECUREROCK® roof board which increases the STC value. Overall this system seemed best to be used for this analysis as the minimum amount of insulation used on the current EPDM roof was 3.5" anyway.

Green Roof System

The best approach in approximating the STC of the green roof system is by using a proxy scale based loosely on the “mass law” of acoustics[2]. The mass law states the sound insulation increases with the surface density (pounds per cubic foot, pcf). Theoretically, doubling the density increases the sound isolation by 6dB.

"Actual growing media density and other variables such as the nature of the vegetation and the characteristics of the filter, drainage and protective layers obviously have an effect on the surface mass of a green roof system taken as a whole. Since the growing medium is typically the heaviest component of green roof systems, the density of the system is, for the sake of simplicity, defined here as its weight divided by the thickness of the growing medium layer. To compare green roof systems of various thickness, the weight of green roof systems in pounds per square foot must be divided by their thickness to yield density in pounds per cubic foot. Two materials with the same density and the same thickness will have the same mass for a given surface area[2].”

Using the 29 psf green roof load and the 4” planting medium thickness the density of the green roof is:

$$\text{Green Roof Density} = \frac{29\text{ psf}}{\left(\frac{4"}{12}\right)} = \mathbf{87\ pcf}$$

Since the mass law is based on the surface mass of materials, a comparison of the density of green roof to other materials will be able to identify whether or not the STC ratings of the material may be used as a proxy for the expected STC ratings of green roof systems. The material that was studied in Elizabeth Grant’s dissertation, "A Decision-Making Framework for Vegetated Roofing System Selection”, to have a similar density to green roof systems was that of lightweight concrete masonry unit (CMU) blocks.

A 4” x 8” x 16” solid CMU block weighs 24.5 lbs. Calculating the density of the CMU block yields:

$$4"\text{ CMU Density} = \frac{24.5\text{ lbs}}{\left[\left(\frac{4"}{12}\right)\left(\frac{8"}{12}\right)\left(\frac{16"}{12}\right)\right]} = \mathbf{83\ pcf}$$

Comparing the two densities of the green roof medium and the CMU, it is apparent that the densities of these two components are similar. Thus, permitting the use of STC ratings of CMU as a close approximation for the green roof system proposed in this analysis. According to “Sound Transmission Class Ratings for Masonry Walls*”* by the National Concrete Masonry Association, the STC value for a 4” solid CMU block is 45.[4] Adding one piece of 2” insulation further increases the STC rating by 3 dB for a total STC rating of 48 for the green roof system. This is assuming a 1/2" gypsum board provides the same STC value for the rigid insulation.

Referencing back to the best fit curve rule in **Figure 4.8**, the next step will be to plot the STC contour lines for the EPDM roof system and the green roof system. However, the 48 STC rating being used for the green roof system is only for the green roof and does not include the rest of the roof structure. Below **Figure 4.10** shows each roof system's STC contour individually.

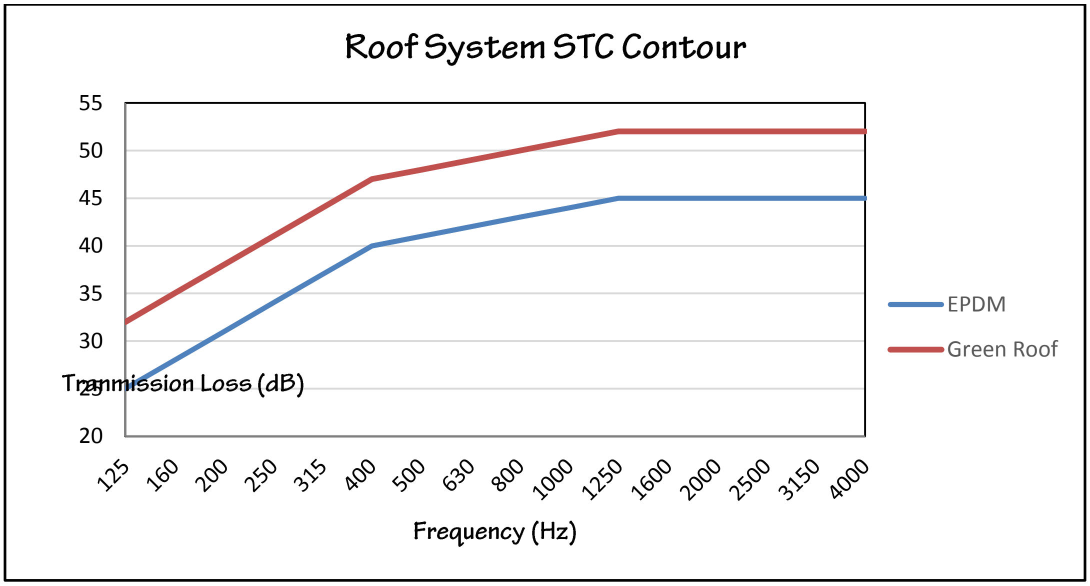


Figure 4.10 – STC Contour of EPDM and Green Roof

Since the STC values are logarithmic values, they cannot simply be added. For example, since the green roof has an STC rating of 48 and the EPDM a rating of 41, the complete roof system STC rating is not equal to 89. In order for the complete roof system STC rating to be calculated, the STC contours of both the EPDM and green roof systems need to be plotted and the TL values will be used to find the *intensity transmission coefficient*, τ using the equation below.

$$\mathrm{TL} = -10\log_{10}(\tau)$$

$$\tau = 10^{\left(\frac{\mathrm{TL}}{-10}\right)}$$

Once the transmission coefficient is found for each roof system, new TL values for the complete roof structure will be calculated using the composite transmission loss equation below.

$$\tau_{\mathrm{eff}} = \frac{A_1\tau_1 + A_2\tau_2}{A_T}$$

τ_{eff} = effective transmission coefficient
A_1 = EPDM Roof Area | τ_1 = EPDM Transmission Coefficient
A_2 = Green Roof Area | τ_2 = Green Roof Transmission Coefficient

The new TL values will then be calculated by using the TL equation with the new effective transmission coefficient found. These values will then be plotted and the STC value of the complete green roof system and EPDM roof combined will be determined. **Figure 4.11** depicts the results obtained from performing the calculations mentioned and shows the STC Contour of the complete roof system.

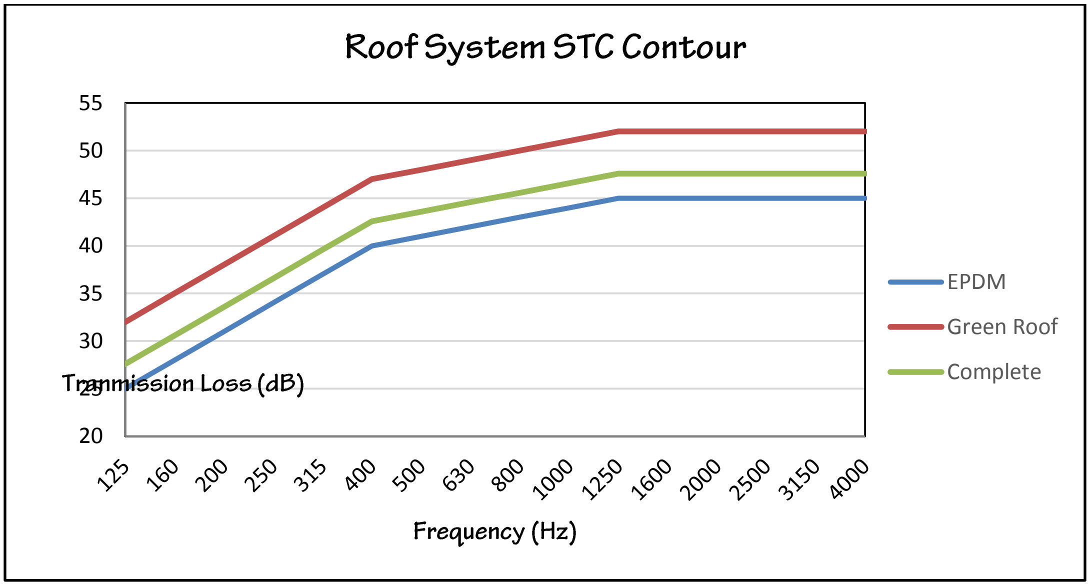


Figure 4.11 – STC Contour of EPDM and Green Roof and Complete System

As shown above, the complete STC system of the roof increases from the original STC rating of 41 to 44 after the green roof is placed over the resident units throughout the East and West wings. Any change in STC level will cause a change in apparent loudness that can be heard. As a general rule of thumb, the Changes in STC/Changes in Apparent Loudness table below outlines how much loudness can be heard.

Changes in STC Rating	Changes in Apparent Loudness
+/- 1 dB	Almost imperceptible
+/- 3 dB	Just Imperceptible
+/- 5 dB	Clearly noticeable
+/- 10 dB	Twice (or half) as loud

Clearly the green roof system with an STC rating of 48 compared to the EPDM STC rating of 41 has a noticeable sound reduction. Thus, providing a quieter atmosphere for the elderly occupant's inside their units by 7 dB.

***See Appendix G for all calculation tables and pages referenced in acoustical analysis.**

References

[1]Connelly, Maureen, and Murray Hodgson. "Thermal and Acoustical Performance of Green Roofs.". Vancouver, British Columbia Canada: University of British Columbia, 2008. Web. 27 Feb. 2014. <http://commons.bcit.ca/greenroof/files/2012/01/2008_grhc_connelly_hodgson.pdf>.

[2]Grant, Elizabeth. "A Decision-Making Framework for Vegetated Roofing System Selection." Diss. Doctor of Philosophy in Architecture and Design Research, 2007. Web.

[3]Mehta, Madan, James Johnson, and Jorge Rocafort. *Architectural Acoustics: Principles and Design*. 1st ed. Prentice Hall, 1998. Print.

[4]National Concrete Masonry Association, "Sound Transmission Class Ratings For Concrete Masonry Walls.". National Concrete Masonry Association, 2008. Web. 3 Mar 2014. <http://www.ncma.org/etek/Pages/Manualviewer.aspx?filename=TEK 13-01B.pdf>.

[5]Usgweb, . "STC and SECUROCK® Roof Boards: Do You Hear What I Hear?." USG, 08 Apr 2013. Web. 27 Feb. 2014. <http://securockroofboardsblog.usg.com/tag/gypsum-fiber-roof-board/>.

Results

-- Cost Impact --

A lifecycle cost analysis of green roof system being proposed should be conducted to determine the financial feasibility. Since the original concrete roof deck system was value engineered out and replaced with an EPDM roofing system, the green roof system may prove to be a better value engineering alternative system.

Initial Up-Front Costs

When comparing the Hydrotech® Green Roof system to the EPDM system, the initial cost of each system is a key factor that will be discussed when considering implementing the systems. Originally quoted in 2012 the cost for the EPDM membrane system was $274,700. Utilizing the CPI Inflation Calculator on the United States Department of Labor webpage, the 2014 value is equivalent to $279,870. This value will be used to compare it to the 2014 cost data received for the green roof system. With the roof area equal to approximately 17,000 square feet, the EPDM roof system has a cost of $16.46 per square foot.

After speaking to a Hydrotech® representative the average cost of the modular green roof tray system ranges from $26-$32 per square foot depending on the project and location. For this analysis an average of $29 per square foot will be used. Applying this figure to the 9,500 square feet proposed green roof system design will yield an initial cost of $275,500. With 7,500 square feet left over of the EPDM roof system, the complete cost for the proposed green roof design combined with the EPDM system will be $398,972. **Table 4.8** briefly outlines the costs noted above.

Initial Roof System Cost			
	EPDM	**Green Roof**	**Total New System**
	17,000 SF	9,500 SF	(Green Roof=9500 SF) + (EPDM=7500 SF)
Total	$279,870	$275,500	$398,972
$ / SF	$16.46	$29.00	$23.47
Cost Difference			$119,102

Table 4.8 – Initial Costs of EPDM roof system and Green roof system

The initial cost difference in implement the new green roof design is $119,102. All the costs mentioned include all equipment and labor costs as well.

Longevity & Incentives

Green roof systems are said to last almost twice as long as any other conventional roofing system available. Implementing a green roof system thus results in the owner saving costs by not having to replace the entire roofing system periodically. The factor that must be considered most in the lifespan of a roof is the roofing membrane that is used. A fully adhered EDPM membrane has a lifespan of about 18 years while the membrane that Hydrotech® uses for their green roof system has a life span of 39+ years.

Thus, making an investment in a green roof implementation will result in cost savings since the owner does not have to replace the roof as often.

Currently proposed in the state of Pennsylvania is legislation that will provide tax credit for green roofs in the amount of 25% of the costs for six years[6]. This would mean that approximately, prior to taxes, $69,000 would be saved in the first year alone. After taxes, assuming a 30 percent tax rate, the incentive will provide $20,700 a year for a total of $124,200 in tax savings over six years.

Cost Analysis

The Hydrotech® green roof system is expected to have a life span of 39+ years. The cost analysis will calculate how much, if any, cost savings will be provided over the first 18 years (EPDM lifespan) of the building. After applying the $20,700 tax credit savings to the initial costs of the green roof system for the first six years and assuming no cost difference in maintenance between the systems, **Table 4.9** below outlines the total amount the two roof systems will cost the owner.

Note: monetary value is in current (2014) values. Inflation was not considered.

Years	EPDM	New Roof
0	$279,870	$378,272
1	$0	-$20,700
2	$0	-$20,700
3	$0	-$20,700
4	$0	-$20,700
5	$0	-$20,700
6-17	$0	$0
18	$279,870	$123,143
Total	**$559,740**	**$397,915**
Cost Difference	$161,825	
Initial Cost Diff.	$119,102	
TOTAL SAVINGS	**$42,723**	

Table 4.9 – Cost analysis over 18 year period of each roof system

As shown in **Table 4.9**, the owner will see a cost savings of approximately $43,000 when time comes to replace the original EPDM roof system after 18 years.

References

[6]"Green Roof Legislation, Policies, and Tax Incentives." Plant Connection, Inc, 2014. <http://www.myplantconnection.com/green-roofs-legislation.php>

-- Schedule Impact --

The reason for the implementation of a modular green roof system was the increased installation time compared to conventional. Since roofing activities are on the critical path, any duration change will impact the completion date for the project. For this analysis, schedule impacts will be considered for the original project schedule and the improved project schedule from Analysis #1. Both schedules show durations of 15 days for each wing for the EPDM system being installed. Any duration over 15 days will impact the completion date and necessary changes and general conditions savings/extra costs will be calculated.

After speaking with a Hydrotech® representative, a typical modular installation for 9,500 square feet will take 3-4 days for the trays to be placed. However, this does not include the waterproofing membrane that must be placed prior. Approximately 900 square feet of waterproofing membrane can be installed in one day. Therefore, for the modular green roof system the total duration of installation time will take 15 days for 9,500 square feet. This leaves another 7,500 square feet for the rest of the EPDM to be installed. Since this is about half of the original roof design, the duration for the EPDM would be 7 days. These two activities can be completed simultaneously, thus concluding that the modular green roof system will be able to be installed in the same amount of time as the EPDM system was originally scheduled. Therefore, no general condition cost data will be impacted since the completion date will not be affected by the installation of the green roof system.

***See Appendix B & Appendix D for original project schedule and revised project schedule.**

Conclusion

In conclusion of this analysis, it is recommended that the project team and owner should have considered implementing a green roof system when value engineering discussions took place. After deciding that an extensive modular green roof system was best for this project, structural and acoustical analyses were performed to determine the feasibility of the system.

Although, the green roof applied an increased load to the existing structure, it was calculated that the existing roof deck, metal panel walls, and foundation were able to withstand that additional load. Considering the fact that the majority of the building occupants will be senior citizens, an acoustical analysis seemed best to be performed when considering the green roof. Although the green roof was not applied to the lobby area and only to the residential units, the STC rating increased from 41 to 48. An increase in 7dB is a clearly noticeable difference in reducing noise levels, especially for elderly persons. The initial cost of the green roof was initially higher by $119,102. But when considering the life span of the two roofing systems, after 18 years the EPDM roof would need to be replaced while the green roof can handle another 21 year after. When the 18 year period arrives, the owner would see a $161,825 in cost difference and see a $42,723 savings between the initial cost and the replacement costs. There are many advantages when implementing a green roof system on any project and this project could have benefited if it was considered during the value engineering process.

Analysis #4: Alternate Delivery Method

Problem Identification

This project had an interesting approach to the delivery method used. It can be describes as some sort of hybrid method where two delivery methods were used. The owner had an architect designing most of the project except for the MEP aspects. A general contractor, in this case Wohlsen Construction, was brought in to Design-Build the MEP systems. However, during the process Wohlsen was offered to complete the rest of the project using a Design-Bid-Build delivery method. This was an interesting way to approach the project; however, the only way it could have worked is with no design changes going forward. Of course there were design changes that took place and this caused delays as well as coordination and communication issues.

Background Information

As stated many times throughout all the reports written this semester, Liberty Lutheran's main priorities in the new construction of the Mary J. Drexel project consisted of cost and quality. By using the Design-Bid-Build project delivery system they focused their greatest amount of time to work on the design with their contracted Architect, SFCS, Inc. and the Lower Merion Township Historical Commission. Wohlsen Construction was appointed with a GMP Contract to provide construction management services due to their prior success in Assisted Living Projects. The major MEP Systems were contracted in the GMP Contract as Design/Build services at first and then Wohlsen was asked to manage the construction of the MEP trades as well.

Analysis Goals

The goal if this analysis is to determine a better project delivery approach that could have been taken for this project. By reformatting the way in which subcontractors were chosen and possibly having one or two more trades involved earlier in the project, constructability issues and schedule concerns could have been avoided. Ultimately, a recommendation will be given to the owner whether or not the project could have been delivered differently and the impacts that a different method may have had.

Furthermore, in order for this analysis to be performed a few aspects need to be considered. One of which involves interviewing the project management team to determine which single delivery method would have been more feasible on the project; whether it be Design-Bid-Build, Design-Build, or an Integrated Project Delivery approach. This chosen project delivery approach will be researched to understand advantages and disadvantages between them and process maps will be created to compare the necessary steps that need to be taken from start to finish of the project.

Upon completion of this analysis, it is expected that by further integrating work processes and choosing a single delivery method, it would have been more beneficial and efficient than the path that was chosen. Also, it would show how the project players would be able to resolve problems more efficiently and easily. A recommendation will be made based on the findings of this analysis.

Process

-- Choosing a Delivery System --

When choosing delivery system to be utilized for a project, there are many factors that need to be considered. These factors include: budget, design, schedule, risk assessment and owner's level of expertise. Being the owner, this can be a tough decision to make as the ultimate decision can be both good and bad.

-- Current Delivery Approach --

The delivery system used for this project, as stated before, is somewhat of a hybrid approach. The majority of the project was Design-Bid-Build (DBB) with a GMP contract and the MEP systems were Design-Build (DB). Liberty Lutheran holds a contract with a variety of parties such as the architect, site contractor, civil engineer, and the general contractor/construction manager. Wohlsen Construction held Lump Sum contracts with all their subcontractors. **Figure 5.1** below outlines the hybrid project delivery system utilized for this project.

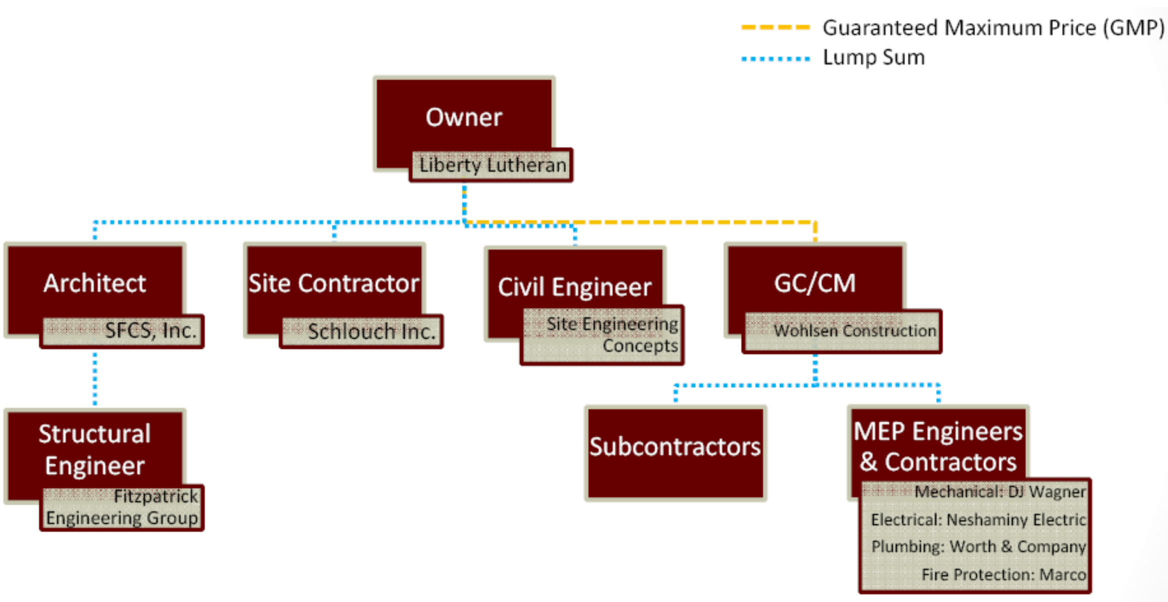


Figure 5.1 – Project Delivery w/Contract Types

This figure depicts all the different trades involved in the project and how easily any coordination issue could have caused problems. However, there was extreme confidence that there would not be many changes to the original bid documents once the contracts were awarded. The approach of using two delivery methods did end up causing coordination issues amongst the project members that could have been avoided.

The DBB delivery method is the most standard delivery method used throughout many projects. The largest advantage the owner has utilizing this method is reliable price information before construction starts. This allowed the owner to be in control of the design and utilize proper budgeting necessary for the project. The DB aspect arrived when it was necessary to complete the MEP systems for the project and the owner contracted Wohlsen to complete it with their MEP subcontractors as the designers. Although this may seem as a very simple combination of two delivery methods, problems begin when design changes start occurring and each project party attempts to transfer risk to one another.

Advantages and Disadvantages (Design-Bid-Build)[1]

Advantages

- Most common approach used and many understand it.
- Owner has significant amount of control over the end product.
- DBB is well-established and has defined roles for all the parties involved.

Disadvantages

- Owner must accept cost changes and change orders due to design changes and constructability issues that may come up.
- Adversarial relationships may develop among the contractor, designer, and owner.
- The absence of construction expertise in the design of the project will limit the effectiveness and constructability of the design.
- The designer may have limited ability to assess scheduling and cost ramifications as the design is developed, which can lead to a more costly final product.
- No contractual relationship between the contractor and designer which can lead to no collaboration between them.

Advantages and Disadvantages (Design-Build)[1]

Advantages

- Owner essentially has no risk since there is a single point of accountability for the design and construction of the project.
- Earlier interaction/collaboration allows for increased efficiency and prevents future conflicts.
- Greater cost control since the contractor and designers are working together throughout the entire process.

Disadvantages

- Less design control by owner.
- No balance of the checks and balances that exist when a designer and contractor have separate contracts.
- May be problematic when there is a requirement for multiple agency design approvals.

The largest problem this project faced is the last item mentioned: May be problematic when there is a requirement for multiple agency design approvals. This is not only a disadvantage for DB methods but also for DBB. Many delays arise due to this and any communication issues can lead to more problems. **Figure 5.2** below shows a process map that closely represents the hybrid delivery method used when combining the DBB and DB approach on this project.

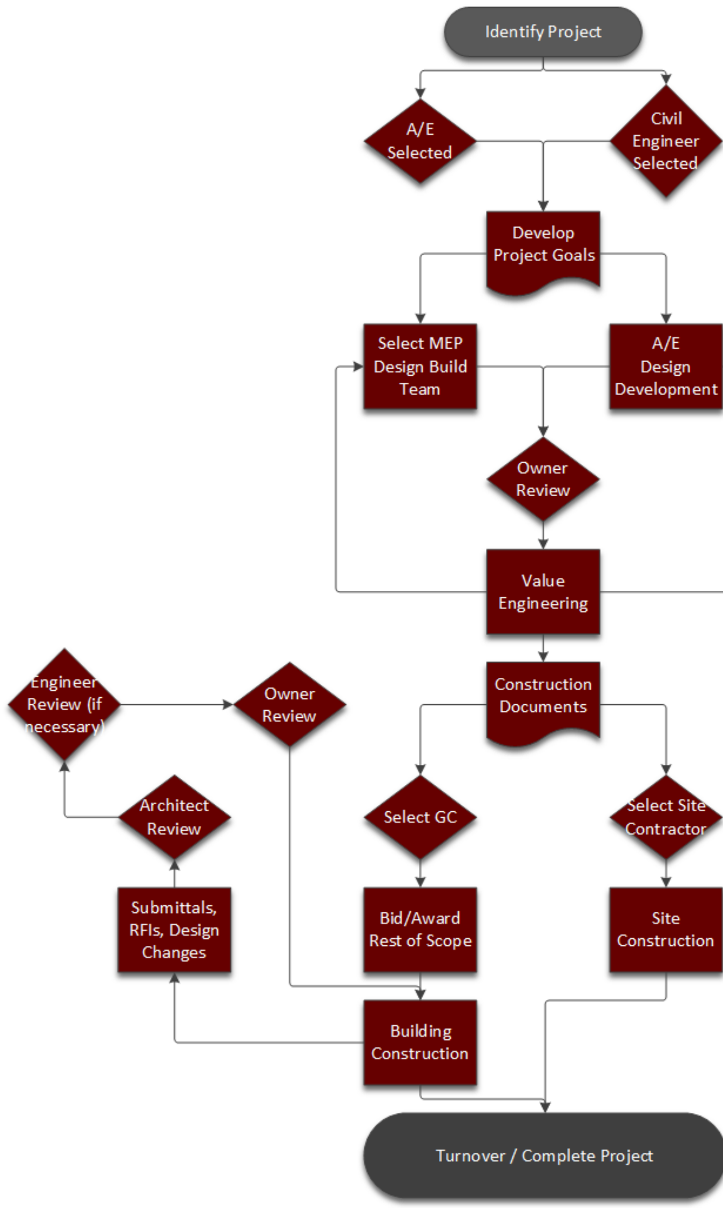


Figure 5.2 – Hybrid Project Delivery (DBB + DB) Process Map for MJD

As can be seen, the owner has the greatest responsibility in ensuring that communication between the architect, site contractor, and GC/CM is effectively accomplished. In order for this hybrid approach to have effectively worked, any communication or changes made from the owner should be evenly disbursed to all parties so everyone is on the same page and can take their respective action to complete it in a timely manner. This delivery method combination definitely may have had some impact on the success on the project due to all the phases and steps that must be taken in order for something to go through. In discussing the project delivery approach with GC/CM, it was advised that a single approach such as Design-Build be utilized. However, due to the relationship between the architect and owner, utilizing an Integrated Delivery Approach should provide more advantages and be more beneficial for this project.

-- Alternate Delivery Approach: Integrated Project Delivery --

After interviewing members on the construction management team, it was concluded that utilizing a single delivery method for the entire project would have been more beneficial. Since the MEP systems were Design Build, it seemed reasonable that having the entire project be Design Build would have been the best choice. However, as stated before, due to the relationship between the owner and architect, this may not be as reasonable. An alternate delivery method approach that could be used would be Integrated Project Delivery (IPD).

IPD is a relatively new idea in the construction industry and is gaining more and more popularity quickly. In a contractual sense, "Pure IPD" requires an agreement amongst all the prime members in the entire design and construction process. Typically, this includes the owner, architect, and builder. However, many major subcontractors and consultants may be in the agreement as well. This allows for a team approach in which incentives and goals are agreed to by the entire team and can only be met when effective communication is used. **Figure 5.3** below outlines the contract setup that this project could have developed if an Integrated Project Delivery approach was used.

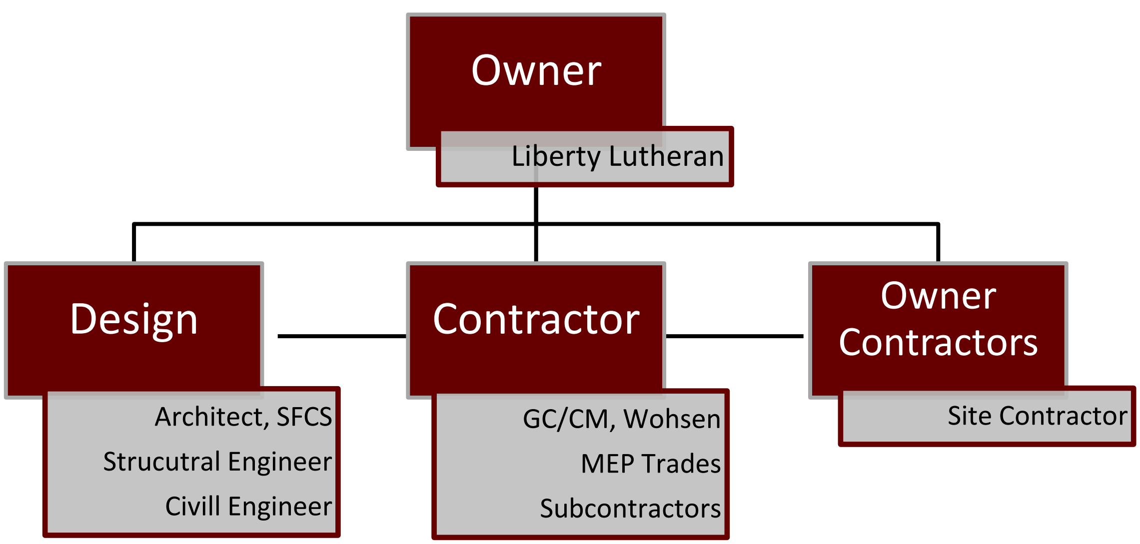


Figure 5.3 – Integrated Project Delivery Contract Setup

The most common contracting method used in IPD is a joint agreement between all major parties. The typical contract is a cost-plus-incentive based arrangement. In this arrangement the owner agrees to pay the actual costs of construction of the project plus a predetermined fee or incentive. This would be suitable for both parties as the contractor can provide services such as estimating and value engineering to help the owner. The guaranteed maximum price contract is essential the same as the cost-plus contract but has a cap on the total amount of construction costs that the owner will pay. With incentive clauses written in, using the IPD delivery method with a GMP contract can also be feasible.

The struggle with IPD is that the owner must have an entire project team established in the very beginning of the project before everything starts so that the multiparty agreements can be established. This allows for the entire team's interests to be aligned with those of the owner which greatly increases project success.

<u>Advantages and Disadvantages (IPD)</u>[1]

Advantages

- Chance of project success is very high due to entire team's interests aligned with the project goals.
- Owner gains the same advantages as Design-Build
- Owner gains advantages of Construction Management at Risk delivery method as well:
    - Owner has input from the contractor's perspective and input in planning and design decisions.
    - The ability to "fast-track" early components of construction prior to the full completion of design.

Disadvantages

- Actual agreement on the criteria and final contract may be difficult and take increased time and effort.
- Chance of failure is most dependent on the behavior of individuals within the team and damaging behavior is very hard to control which could breakdown the collaborative process.
- IPD contracts have not yet been tested in law, so the result of a failure within the team is unpredictable.

Successful IPD projects require a leader to keep the entire team on track and focused on the project goals. Typically the owner would have the CM be this leader but in the case of this project, Liberty Lutheran utilized their own representative for managing the construction process and gave input to each party. The owner's representative can still be utilized using the IPD approach as well. Communication between parties would greatly increase as all parties are seeking to achieve the same exact goals and allows parties to go out their ways to help each other. **Figure 5.4** on the following page represents a process map that would be used when utilizing an IPD approach for this project.

Figure 5.4 is a great representative in showing how less complex the delivery process can be when using an IPD approach. Not only does the process seem less complex, but this approach provides positive propositions for the major stakeholders in the project. These stakeholders include the owner, builders, and designers. Liberty Lutheran would benefit as this approach strengthens the entire project team's understanding of their desired outcomes which improves the team's ability then to control costs and manage the budget. All this in turn increases the success rate of all aspects of the project. Wohlsen and their subcontractors provide their expertise in the early stages which enables for a strong pre-construction plan with greater understanding of the design and any issues that may arise during the project. Again, this in turn increases the success that the project will have. SFCS and their engineers are able to understand how their design impacts budget estimate with the help of the builders and will increase the level of effort taken in the early design phases. This results in improved cost control and reduced documentation time. And again, all of which increase the likelihood of success.

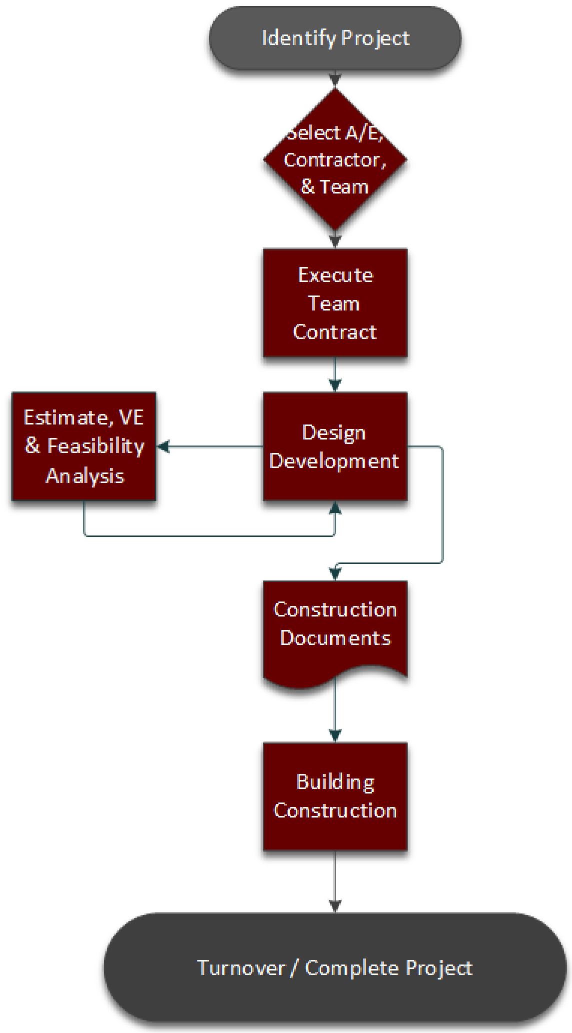


Figure 5.4 – IPD Project Delivery Process Map

Collaboration and effective communication is the key factor in the success of this delivery approach. In order for this to be promoted and successfully utilized, a collaboratively set schedule is necessary. Not only does this require more regularly set meetings, but also a greater amount of sharing information than is customary under traditional methods. This entire method is built on collaboration, which in turn is built on trust. With the strong relationship between the major stakeholders in the project, this delivery approach promises a better outcome.

References

[1]CMAA, "An Owner's Guide To Project Delivery Methods." The Construction Management Association of America , 2012. Web. 11 Mar 2014.

Results

This project is definitely not a common type of project when considering the delivery approach utilized, thus schedule and budget impacts may be hard to quantify as there is no similar project to compare it to. However, using an IPD approach provides quite a substantial amount of fundamental improvements when compared to the hybrid approach used for this project. **Figure 5.5** below outlines some of these fundamental improvements over a traditional project delivery method.

TRADITIONAL PROJECT DELIVERY		INTEGRATED PROJECT DELIVERY
Fragmented, ad-hoc, hierarchical, controlled	**Project participants**	Team of project constituencies, open, collaborative
Linear, segregated, silo-oriented, limited information exchange	**Process**	Concurrent, project life-cycle oriented, shared information, collaborative
Individually managed	**Risk**	Collectively shared and managed
Cost-based, individually focused	**Compensation**	Performance and value based
Paper-based and/or digital 2D representations, spreadsheets, domain-centric software silos, email, FTP sites	**Technology**	Object oriented, centralized data repository linked with complementary knowledge-based systems, 2D, 3D, and 4D BIM, IPD/JOC software, shared model

Figure 5.5 – Traditional Delivery vs. IPD – Image from Building Information Management

The major phase of the project where the benefits of IPD are realized most is during the construction phase. Because of the greater effort that is put in the design phases, the construction phase under IPD is much more efficient. The owner is given the power to make their own decision and build a project team where everyone's interest is aligned and ideas can flow freely and the amount of stress in making decisions is reduced. This leads to reduced design and construction costs.

The amounts of change orders and RFI's throughout the project are also reduced due to the well-informed and effective decision making that was accomplished in the beginning stages of the project. Not only does this allow for quality improvements for the project, risk is mitigated among all parties due to the greater amount of information available so less mistakes occur.

Although IPD is a new approach to the design and construction of buildings, "Integrated Project Delivery: A Guide" by The American Institute of Architects outlines steps of what can be done to improve the popularity and common necessities needed to accomplish a complete IPD project. These steps are outline on the following page.

Improving IPD Steps[2]

- Develop confidence in information sharing.
- Break down traditional barriers or silos of effort.
- Actively participate in discussion groups that push toward an effective, collaborative approach to information sharing.
- Require the project team to utilize BIM technology.
- Propose new approached to team compensation based on value and long term outcomes.
- Seek resources.
- Talk. Share. Collaborate. Experiment.

References

[2]AIA, "Integrated Project Delivery: A Guide." The American Institute of Architects, 2007. Web. 13 Mar 2014. <http://info.aia.org/siteobjects/files/ipd_guide_2007.pdf>

Conclusion

IPD principles can be applied to a variety of contractual arrangements and teams can include stakeholders well beyond the basic owner, designer, and builder. The success of IPD is ultimately distinguished by the highly effective collaboration between the project members, commencing at early design and continuing through project turnover. It is very important that all stakeholders not only agree on the contract, but also believe in the IPD process as well. This entire method is built on collaboration, which in turn is built on trust. IPD is definitely a cultural shift because of the much different than conventional project experience and with the strong relationship between the major stakeholders in the project, this delivery approach promises a better outcome. Although IPD is a new approach to the design and construction of buildings, lower cost and lower risk are the greatest result of this approach. Integrating working relationships and sharing risk and reward among all members improves the exchange of information, thus leading to shorter design and construction schedules and overall improvement in the productivity and efficiency of the project.

Conclusion

Over the course of the 2013/2014 academic calendar year, The Mary J. Drexel Assisted Living Additions Project was analyzed and studied to identify areas in which alternate means and methods could have resolved any challenges or problems that may have affected the efficiency of the project. After careful investigation, four areas that could have improved the project include; re-sequencing the project schedule, implementing a green roof to improve value engineering efforts, utilizing MEP prefabrication, and altering the project delivery method. This final report presents the four analyses performed by including details of the challenge presented, suggesting solutions, and analyzing the solutions on the project. This report is not meant to critique the already effective project team but to study their project for educational purposes.

Analysis #1: Project Sequencing

The first analyses focused on reducing the overall project schedule duration by altering the original schedule sequencing. Significant emphasis was placed on the cost and quality of the project with less on the overall project schedule. The general conditions estimate originally had a total cost of $1,596,477. The monthly paid line items that would be affected by reducing the schedule account for $798,384, or 50% of the total general conditions estimate at a 14 month project duration. Thus, any reduction in the project schedule will result in decreasing costs for the owner.

The goal of the analysis was to improve the schedule by two weeks; however the proposed project schedule resulted in a savings of four weeks. This was done without altering manpower and activity durations and resulting in savings of $57,000.

Analysis 2: MEP Prefabrication

The second analysis focused on implementing prefabricated MEP corridor racks. The MEP trades were brought onto the project at an early stage under the design-build contract. Due to schedule delays, the MEP trades were forced to employ extra crews during the week and start overtime work on the weekends in order to meet the schedule. Implementing prefabrication techniques would have avoided this situation.

After performing research, it proved that this is a more efficient method of construction given the project conditions. Some of these benefits include improved productivity, lower costs, reduced schedules, and increased safety. This method of construction was feasible given project conditions and resulted in expediting the project schedule by one week and providing cost savings of $14,257 for general conditions and $20,875 in labor costs.

Analysis 3: Green Roof Implementation

The third analysis focused on implementing a green roof system design. A value engineering effort was made to reduce initial costs and not much consideration was taken into other factors such as lifecycle costs. Before any conclusions can be made from this analysis, structural load calculations were completed to ensure the feasibility of the new green roof. The proposed system did result in being feasible with the current structure. Although green roof systems usually inquire a higher initial cost, the longer life-span compared to traditional roofs offsets this cost. The chosen system provided $41,723 in costs savings over 18 years and did not increase the project schedule duration.

Analysis 4: Alternate Delivery Method

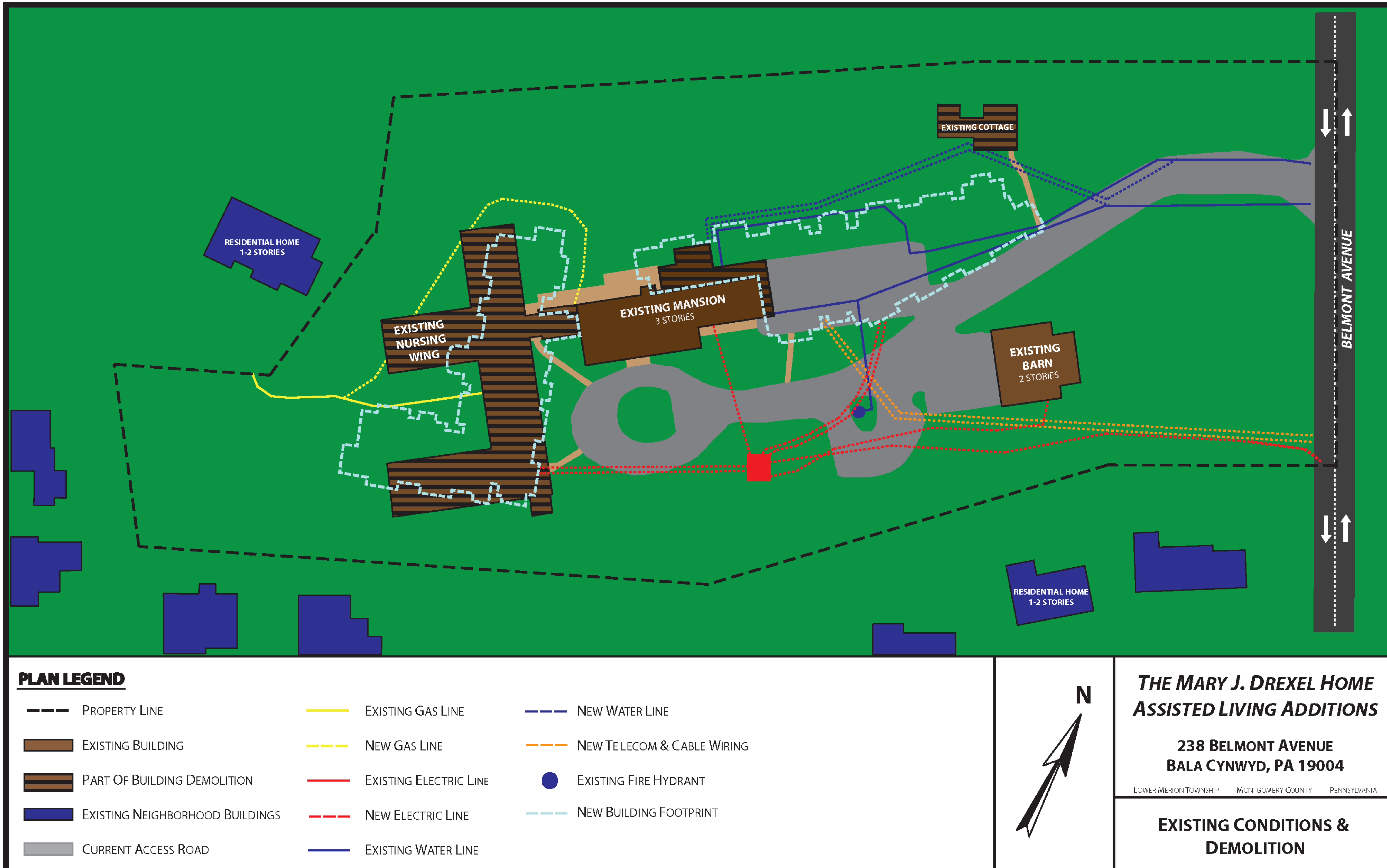
The final analysis focused on providing an alternate delivery method that could have been used. A hybrid approach was used with a combination of Design-Bid-Build and Design-Build for the MEP systems. Due to many design changes throughout the construction of the buildings, many issues arose regarding the stakeholders communicating amongst each other.

This analysis provided new information for the owner on an approach such as Integrated Project Delivery (IPD) that could have been used and the advantages and disadvantages associated with it. Although IPD is a new approach to the design and construction of buildings, lower cost and lower risk are the greatest result of this approach. Integrating working relationships and sharing risk and reward among all members improves the exchange of information, thus leading to shorter design and construction schedules and overall improvement in the productivity and efficiency of the project.

Final Recommendation

In conclusion, it is recommended that all four of the proposed analyses be adopted for the Mary J. Drexel project. By spending a little extra time and improving the project schedule along with providing some prefabrication techniques, a total of $71,284 in just general conditions costs could have been saved. Although the project was not pursuing LEED accreditation, implementing a green roof system proved to be beneficial to both the owner and occupants. When time would come for the original roof system to be replaced, the owner would see $42,723 in savings between the initial cost of the new system and the replacement costs of the old system. The senior residents would greatly benefit with the increase in STC levels as an increase in 7dB is clearly noticeable in reducing noise levels. Using an IPD delivery approach would have provided highly effective collaboration between the project members, commencing at early design and continuing through project turnover. With this delivery approach, many of the proposed analyses could have been noticed by the project team instead and the already effective project could have further improved the productivity and efficiency of the project.

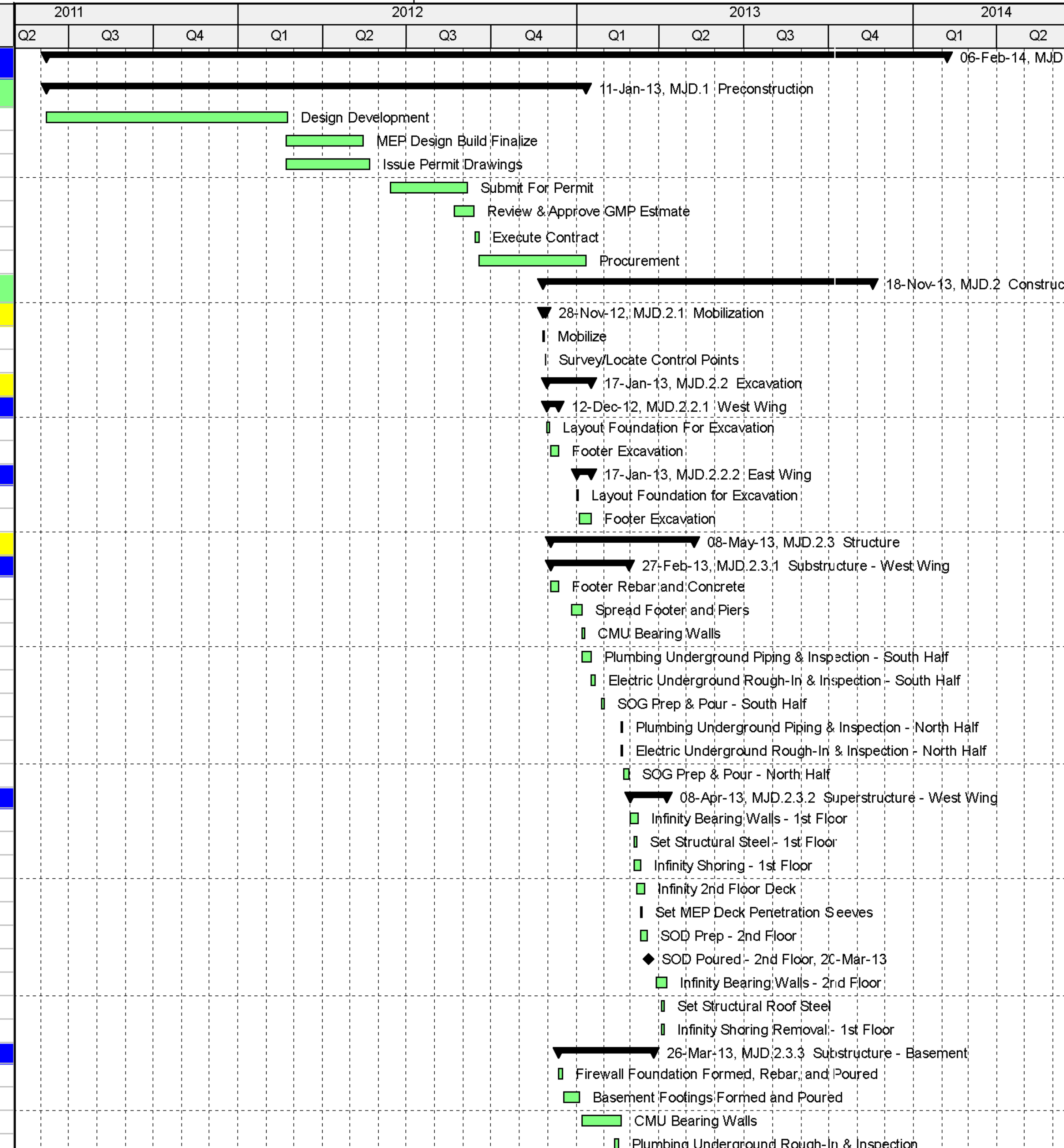
Appendix A: Existing Conditions Plan



RESIDENTIAL HOME
1-2 STORIES
EXISTING COTTAGE
EXISTING NURSING WING
EXISTING MANSION
3 STORIES
EXISTING BARN
2 STORIES
BELMONT AVENUE
RESIDENTIAL HOME
1-2 STORIES
PLAN LEGEND
PROPERTY LINE
EXISTING BUILDING
PART OF BUILDING DEMOLITION
EXISTING NEIGHBORHOOD BUILDINGS
CURRENT ACCESS ROAD
EXISTING GAS LINE
NEW GAS LINE
EXISTING ELECTRIC LINE
NEW ELECTRIC LINE
EXISTING WATER LINE
NEW WATER LINE
NEW TELECOM & CABLE WIRING
EXISTING FIRE HYDRANT
NEW BUILDING FOOTPRINT
N
THE MARY J. DREXEL HOME
ASSISTED LIVING ADDITIONS
238 BELMONT AVENUE
BALA CYNWYD, PA 19004
LOWER MERION TOWNSHIP
MONTGOMERY COUNTY
PENNSYLVANIA
EXISTING CONDITIONS & DEMOLITION

Appendix B: Original Detailed Project Schedule

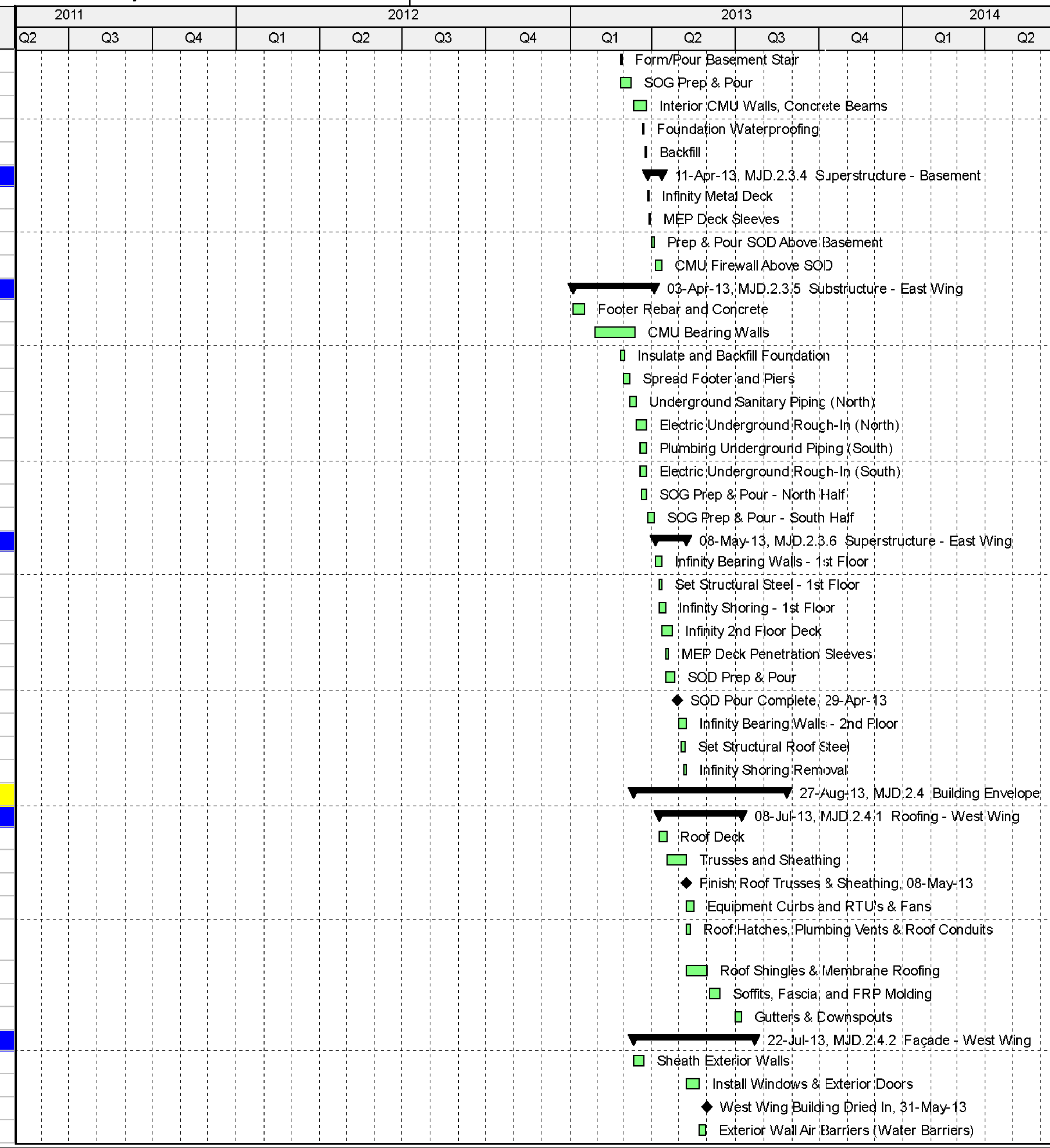
MJD Assisted Living Additions					Classic Schedule Layout	15-Oct-13 21:45
Activity ID	Activity Name	Original Duration	Start	Finish		
MJD	**MJD Assisted Living Additions**	682	07-Jun-11	06-Feb-14		
MJD.1	**Preconstruction**	408	07-Jun-11	11-Jan-13		
A1000	Design Development	182	07-Jun-11	22-Feb-12		
A1010	MEP Design Build Finalize	59	22-Feb-12	14-May-12		
A1020	Issue Permit Drawings	65	22-Feb-12	22-May-12		
A1030	Submit For Permit	57	14-Jun-12	04-Sep-12		
A1040	Review & Approve GMP Estmate	16	21-Aug-12	12-Sep-12		
A1050	Execute Contract	3	13-Sep-12	17-Sep-12		
A1060	Procurement	81	18-Sep-12	11-Jan-13		
MJD.2	**Construction**	251	26-Nov-12	18-Nov-13		
MJD.2.1	**Mobilization**	3	26-Nov-12	28-Nov-12		
A1070	Mobilize	2	26-Nov-12	27-Nov-12		
A1080	Survey/Locate Control Points	1	28-Nov-12	28-Nov-12		
MJD.2.2	**Excavation**	33	30-Nov-12	17-Jan-13		
MJD.2.2.1	**West Wing**	9	30-Nov-12	12-Dec-12		
A1090	Layout Foundation For Excavation	2	30-Nov-12	03-Dec-12		
A1100	Footer Excavation	7	04-Dec-12	12-Dec-12		
MJD.2.2.2	**East Wing**	12	02-Jan-13	17-Jan-13		
A1110	Layout Foundation for Excavation	2	02-Jan-13	03-Jan-13		
A1120	Footer Excavation	10	04-Jan-13	17-Jan-13		
MJD.2.3	**Structure**	110	04-Dec-12	08-May-13		
MJD.2.3.1	**Substructure - West Wing**	60	04-Dec-12	27-Feb-13		
A1130	Footer Rebar and Concrete	7	04-Dec-12	12-Dec-12		
A1140	Spread Footer and Piers	7	27-Dec-12	07-Jan-13		
A1150	CMU Bearing Walls	4	07-Jan-13	10-Jan-13		
A1160	Plumbing Underground Piping & Inspection - South Half	8	07-Jan-13	16-Jan-13		
A1170	Electric Underground Rough-In & Inspection - South Half	3	17-Jan-13	21-Jan-13		
A1180	SOG Prep & Pour - South Half	4	28-Jan-13	31-Jan-13		
A1190	Plumbing Underground Piping & Inspection - North Half	3	18-Feb-13	20-Feb-13		
A1200	Electric Underground Rough-In & Inspection - North Half	3	18-Feb-13	20-Feb-13		
A1210	SOG Prep & Pour - North Half	5	21-Feb-13	27-Feb-13		
MJD.2.3.2	**Superstructure - West Wing**	28	28-Feb-13	08-Apr-13		
A1220	Infinity Bearing Walls - 1st Floor	7	28-Feb-13	08-Mar-13		
A1230	Set Structural Steel - 1st Floor	3	05-Mar-13	07-Mar-13		
A1240	Infinity Shoring - 1st Floor	5	05-Mar-13	11-Mar-13		
A1250	Infinity 2nd Floor Deck	7	07-Mar-13	15-Mar-13		
A1260	Set MEP Deck Penetration Sleeves	3	11-Mar-13	13-Mar-13		
A1270	SOD Prep - 2nd Floor	7	11-Mar-13	19-Mar-13		
A1280	SOD Poured - 2nd Floor	0	20-Mar-13			
A1290	Infinity Bearing Walls - 2nd Floor	7	29-Mar-13	08-Apr-13		
A1300	Set Structural Roof Steel	3	03-Apr-13	05-Apr-13		
A1310	Infinity Shoring Removal - 1st Floor	3	03-Apr-13	05-Apr-13		
MJD.2.3.3	**Substructure - Basement**	72	13-Dec-12	26-Mar-13		
A1320	Firewall Foundation Formed, Rebar, and Poured	3	13-Dec-12	17-Dec-12		
A1330	Basement Footings Formed and Poured	12	18-Dec-12	04-Jan-13		
A1340	CMU Bearing Walls	31	07-Jan-13	18-Feb-13		
A1350	Plumbing Underground Rough-In & Inspection	5	11-Feb-13	15-Feb-13		



Actual Level of Effort	Remaining Work	Milestone	Page 1 of 6	TASK filter: All Activities	
Actual Work	Critical Remaining Work	summary			© Oracle Corporation

MJD Assisted Living Additions | Classic Schedule Layout | 15-Oct-13 21:45

Activity ID	Activity Name	Original Duration	Start	Finish
A1360	Form/Pour Basement Stair	3	25-Feb-13	27-Feb-13
A1370	SOG Prep & Pour	10	25-Feb-13	08-Mar-13
A1380	Interior CMU Walls, Concrete Beams	11	12-Mar-13	26-Mar-13
A1390	Foundation Waterproofing	1	22-Mar-13	22-Mar-13
A1400	Backfill	2	25-Mar-13	26-Mar-13
MJD.2.3.4	**Superstructure - Basement**	**12**	**27-Mar-13**	**11-Apr-13**
A1410	Infinity Metal Deck	2	27-Mar-13	28-Mar-13
A1420	MEP Deck Sleeves	1	29-Mar-13	29-Mar-13
A1430	Prep & Pour SOD Above Basement	3	01-Apr-13	03-Apr-13
A1440	CMU Firewall Above SOD	6	04-Apr-13	11-Apr-13
MJD.2.3.5	**Substructure - East Wing**	**64**	**04-Jan-13**	**03-Apr-13**
A1450	Footer Rebar and Concrete	10	04-Jan-13	17-Jan-13
A1460	CMU Bearing Walls	32	28-Jan-13	12-Mar-13
A1470	Insulate and Backfill Foundation	5	25-Feb-13	01-Mar-13
A1480	Spread Footer and Piers	6	28-Feb-13	07-Mar-13
A1490	Underground Sanitary Piping (North)	5	08-Mar-13	14-Mar-13
A1500	Electric Underground Rough-In (North)	8	14-Mar-13	25-Mar-13
A1510	Plumbing Underground Piping (South)	7	18-Mar-13	26-Mar-13
A1520	Electric Underground Rough-In (South)	6	19-Mar-13	26-Mar-13
A1530	SOG Prep & Pour - North Half	4	20-Mar-13	25-Mar-13
A1540	SOG Prep & Pour - South Half	6	27-Mar-13	03-Apr-13
MJD.2.3.6	**Superstructure - East Wing**	**25**	**04-Apr-13**	**08-May-13**
A1550	Infinity Bearing Walls - 1st Floor	7	04-Apr-13	12-Apr-13
A1560	Set Structural Steel - 1st Floor	3	09-Apr-13	11-Apr-13
A1570	Infinity Shoring - 1st Floor	6	09-Apr-13	16-Apr-13
A1580	Infinity 2nd Floor Deck	7	12-Apr-13	22-Apr-13
A1590	MEP Deck Penetration Sleeves	3	16-Apr-13	18-Apr-13
A1600	SOD Prep & Pour	9	16-Apr-13	26-Apr-13
A1605	SOD Pour Complete	0	29-Apr-13	
A1610	Infinity Bearing Walls - 2nd Floor	7	30-Apr-13	08-May-13
A1620	Set Structural Roof Steel	3	03-May-13	07-May-13
A1630	Infinity Shoring Removal	3	06-May-13	08-May-13
MJD.2.4	**Building Envelope**	**120**	**11-Mar-13**	**27-Aug-13**
MJD.2.4.1	**Roofing - West Wing**	**63**	**09-Apr-13**	**08-Jul-13**
A1640	Roof Deck	7	09-Apr-13	17-Apr-13
A1650	Trusses and Sheathing	15	18-Apr-13	08-May-13
A1655	Finish Roof Trusses & Sheathing	0	08-May-13	
A1660	Equipment Curbs and RTU's & Fans	7	09-May-13	17-May-13
A1670	Roof Hatches, Plumbing Vents & Roof Conduits	3	09-May-13	13-May-13
A1680	Roof Shingles & Membrane Roofing	16	09-May-13	31-May-13
A1690	Soffits, Fascia, and FRP Molding	10	03-Jun-13	14-Jun-13
A1700	Gutters & Downspouts	5	01-Jul-13	08-Jul-13
MJD.2.4.2	**Façade - West Wing**	**94**	**11-Mar-13**	**22-Jul-13**
A1710	Sheath Exterior Walls	10	11-Mar-13	22-Mar-13
A1720	Install Windows & Exterior Doors	10	09-May-13	22-May-13
A1730	West Wing Building Dried In	0	31-May-13	
A1740	Exterior Wall Air Barriers (Water Barriers)	5	23-May-13	30-May-13

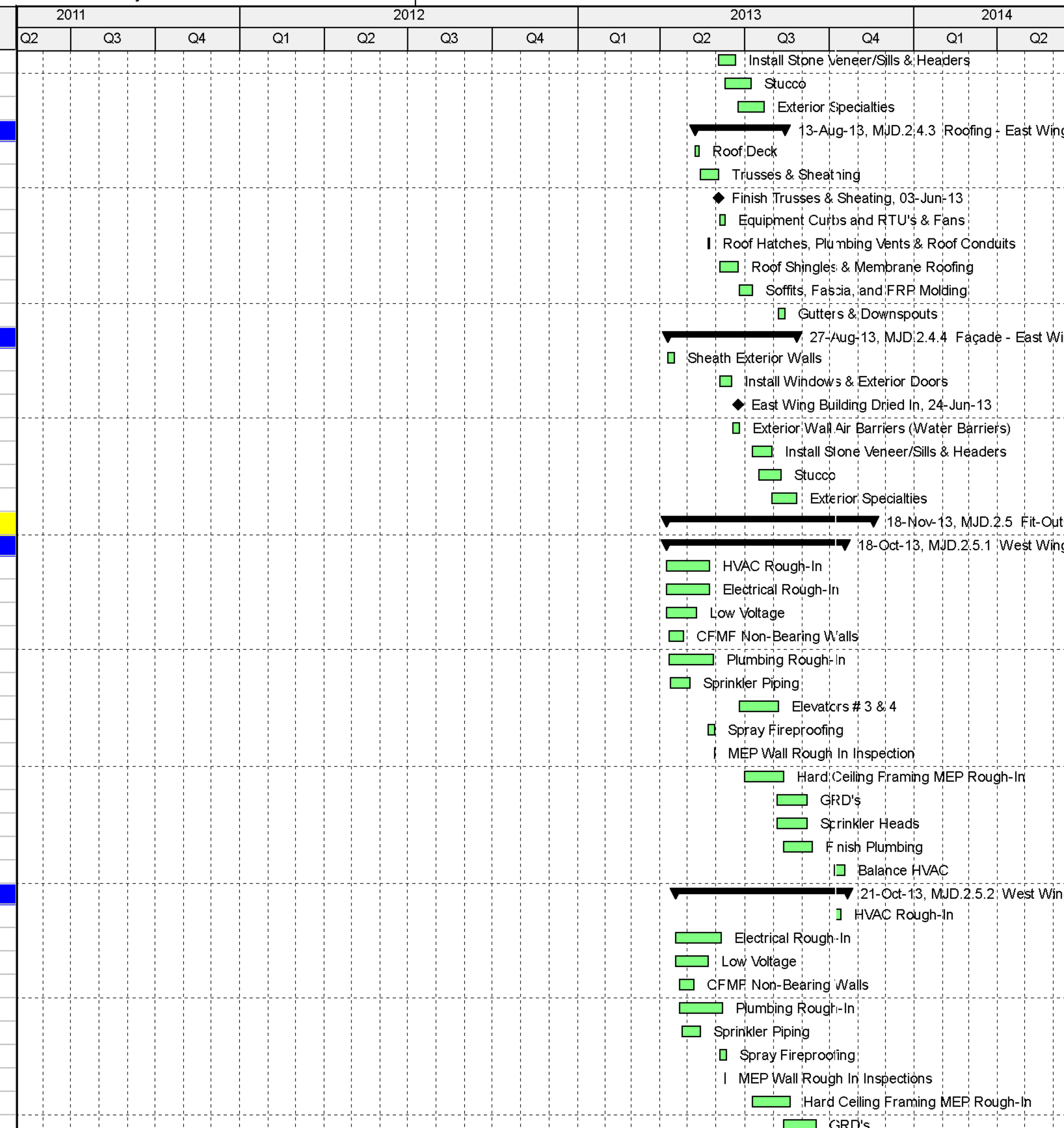


Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

Page 2 of 6

TASK filter: All Activities

MJD Assisted Living Additions				
Classic Schedule Layout				15-Oct-13 21:45
Activity ID	**Activity Name**	**Original Duration**	**Start**	**Finish**
A1750	Install Stone Veneer/Sills & Headers	15	03-Jun-13	21-Jun-13
A1760	Stucco	20	10-Jun-13	08-Jul-13
A1770	Exterior Specialties	20	24-Jun-13	22-Jul-13
MJD.2.4.3 Roofing - East Wing		**67**	**09-May-13**	**13-Aug-13**
A1780	Roof Deck	3	09-May-13	13-May-13
A1790	Trusses & Sheathing	14	14-May-13	03-Jun-13
A1795	Finish Trusses & Sheating	0	03-Jun-13	
A1800	Equipment Curbs and RTU's & Fans	5	04-Jun-13	10-Jun-13
A1810	Roof Hatches, Plumbing Vents & Roof Conduits	3	22-May-13	24-May-13
A1820	Roof Shingles & Membrane Roofing	15	04-Jun-13	24-Jun-13
A1830	Soffits, Fascia, and FRP Molding	10	25-Jun-13	09-Jul-13
A1840	Gutters & Downspouts	5	07-Aug-13	13-Aug-13
MJD.2.4.4 Façade - East Wing		**99**	**09-Apr-13**	**27-Aug-13**
A1850	Sheath Exterior Walls	5	09-Apr-13	15-Apr-13
A1860	Install Windows & Exterior Doors	10	04-Jun-13	17-Jun-13
A1870	East Wing Building Dried In	0	24-Jun-13	
A1880	Exterior Wall Air Barriers (Water Barriers)	6	18-Jun-13	25-Jun-13
A1890	Install Stone Veneer/Sills & Headers	15	10-Jul-13	30-Jul-13
A1900	Stucco	18	17-Jul-13	09-Aug-13
A1910	Exterior Specialties	20	31-Jul-13	27-Aug-13
MJD.2.5 Fit-Outs		**158**	**08-Apr-13**	**18-Nov-13**
MJD.2.5.1 West Wing - 1st Floor		**137**	**08-Apr-13**	**18-Oct-13**
A1920	HVAC Rough-In	35	08-Apr-13	24-May-13
A1930	Electrical Rough-In	35	08-Apr-13	24-May-13
A1940	Low Voltage	25	08-Apr-13	10-May-13
A1950	CFMF Non-Bearing Walls	12	10-Apr-13	25-Apr-13
A1960	Plumbing Rough-In	34	10-Apr-13	28-May-13
A1970	Sprinkler Piping	15	12-Apr-13	02-May-13
A1980	Elevators # 3 & 4	30	25-Jun-13	06-Aug-13
A1990	Spray Fireproofing	5	23-May-13	30-May-13
A2000	MEP Wall Rough In Inspection	1	29-May-13	29-May-13
A2010	Hard Ceiling Framing MEP Rough-In	30	01-Jul-13	12-Aug-13
A2020	GRD's	24	05-Aug-13	06-Sep-13
A2030	Sprinkler Heads	24	05-Aug-13	06-Sep-13
A2040	Finish Plumbing	24	12-Aug-13	13-Sep-13
A2050	Balance HVAC	10	07-Oct-13	18-Oct-13
MJD.2.5.2 West Wing - 2nd Floor		**130**	**18-Apr-13**	**21-Oct-13**
A2060	HVAC Rough-In	5	08-Oct-13	14-Oct-13
A2070	Electrical Rough-In	34	18-Apr-13	05-Jun-13
A2080	Low Voltage	25	18-Apr-13	22-May-13
A2090	CFMF Non-Bearing Walls	12	22-Apr-13	07-May-13
A2100	Plumbing Rough-In	34	22-Apr-13	07-Jun-13
A2110	Sprinkler Piping	15	24-Apr-13	14-May-13
A2120	Spray Fireproofing	6	04-Jun-13	11-Jun-13
A2130	MEP Wall Rough In Inspections	1	10-Jun-13	10-Jun-13
A2140	Hard Ceiling Framing MEP Rough-In	30	10-Jul-13	20-Aug-13
A2150	GRD's	24	13-Aug-13	16-Sep-13



Actual Level of Effort | Remaining Work | Milestone
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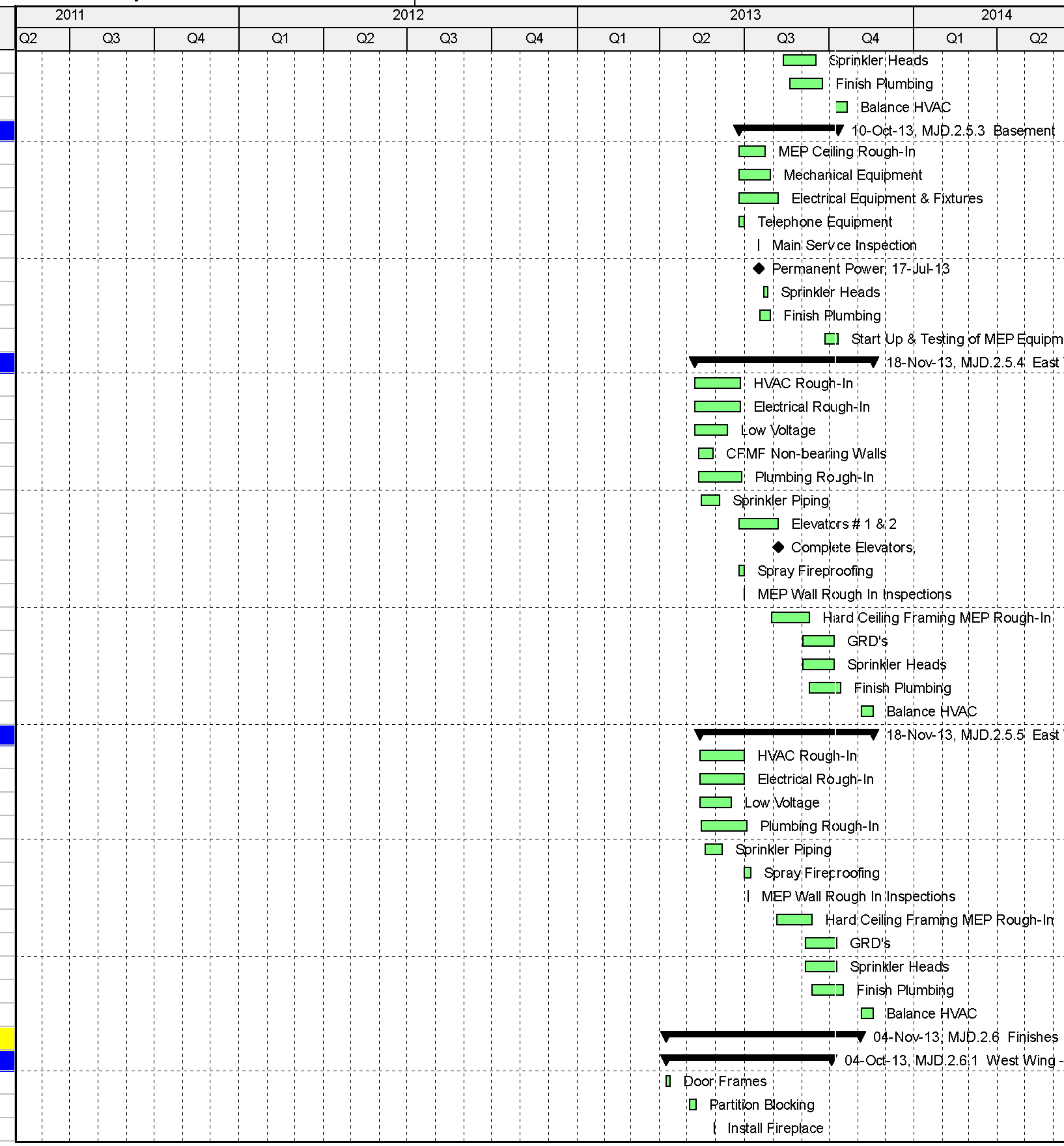
TASK filter: All Activities

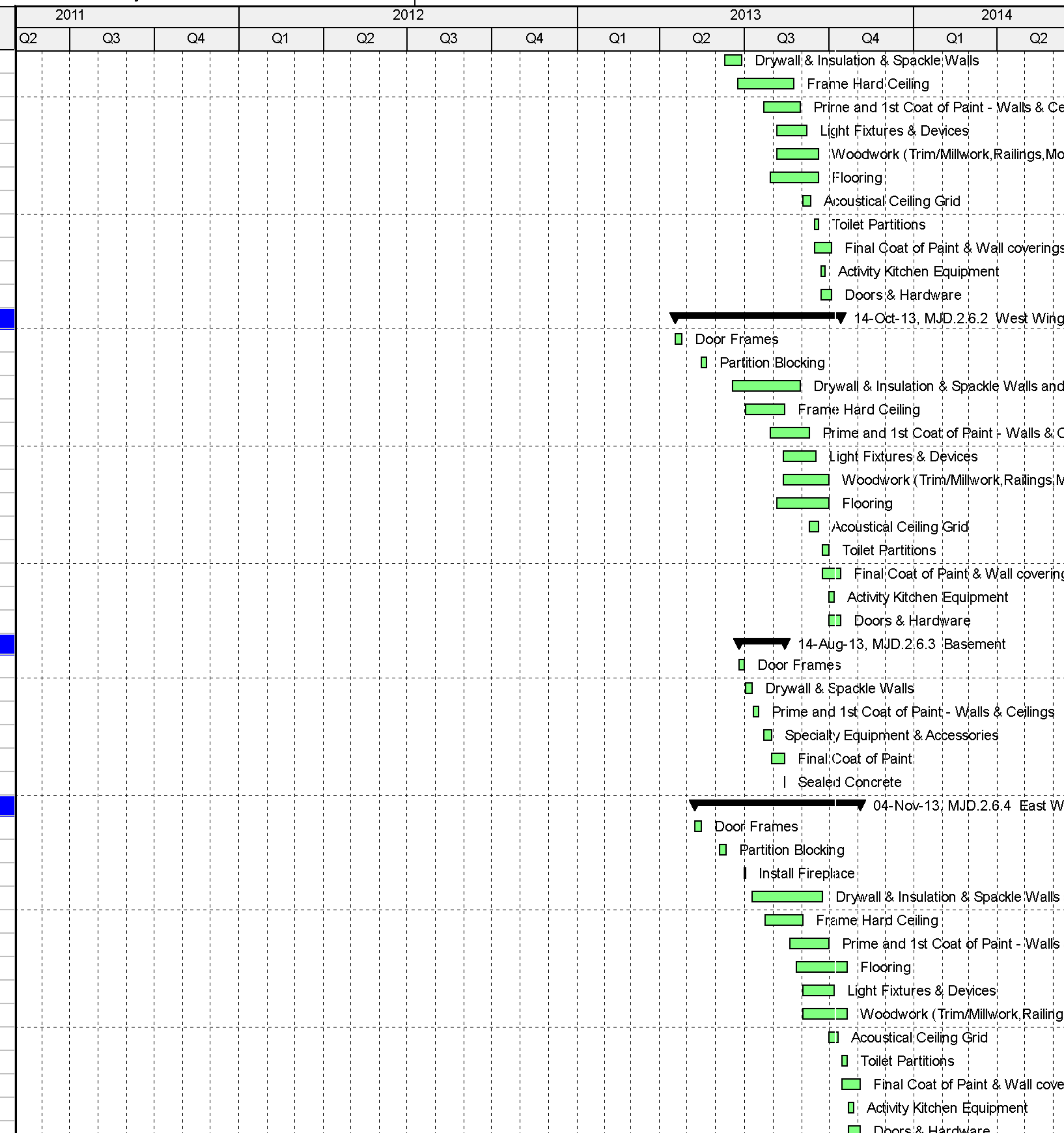
MJD Assisted Living Additions					Classic Schedule Layout	15-Oct-13 21:45
Activity ID	Activity Name	Original Duration	Start	Finish		
A2160	Sprinkler Heads	24	13-Aug-13	16-Sep-13		
A2170	Finish Plumbing	24	20-Aug-13	23-Sep-13		
A2180	Balance HVAC	10	08-Oct-13	21-Oct-13		
MJD.2.5.3	**Basement**	**76**	**25-Jun-13**	**10-Oct-13**		
A2190	MEP Ceiling Rough-In	20	25-Jun-13	23-Jul-13		
A2200	Mechanical Equipment	24	25-Jun-13	29-Jul-13		
A2210	Electrical Equipment & Fixtures	30	25-Jun-13	06-Aug-13		
A2220	Telephone Equipment	5	25-Jun-13	01-Jul-13		
A2230	Main Service Inspection	1	17-Jul-13	17-Jul-13		
A2240	Permanent Power	0	17-Jul-13			
A2250	Sprinkler Heads	5	22-Jul-13	26-Jul-13		
A2260	Finish Plumbing	8	18-Jul-13	29-Jul-13		
A2270	Start Up & Testing of MEP Equipment	10	27-Sep-13	10-Oct-13		
MJD.2.5.4	**East Wing - 1st Floor**	**135**	**09-May-13**	**18-Nov-13**		
A2280	HVAC Rough-In	34	09-May-13	26-Jun-13		
A2290	Electrical Rough-In	34	09-May-13	26-Jun-13		
A2300	Low Voltage	24	09-May-13	12-Jun-13		
A2310	CFMF Non-bearing Walls	11	13-May-13	28-May-13		
A2320	Plumbing Rough-In	34	13-May-13	28-Jun-13		
A2330	Sprinkler Piping	14	15-May-13	04-Jun-13		
A2340	Elevators # 1 & 2	30	25-Jun-13	06-Aug-13		
A2345	Complete Elevators	0		06-Aug-13		
A2350	Spray Fireproofing	5	25-Jun-13	01-Jul-13		
A2360	MEP Wall Rough In Inspections	1	01-Jul-13	01-Jul-13		
A2370	Hard Ceiling Framing MEP Rough-In	29	31-Jul-13	10-Sep-13		
A2380	GRD's	25	03-Sep-13	07-Oct-13		
A2390	Sprinkler Heads	25	03-Sep-13	07-Oct-13		
A2400	Finish Plumbing	25	10-Sep-13	14-Oct-13		
A2410	Balance HVAC	10	05-Nov-13*	18-Nov-13		
MJD.2.5.5	**East Wing - 2nd Floor**	**132**	**14-May-13**	**18-Nov-13**		
A2420	HVAC Rough-In	34	14-May-13	01-Jul-13		
A2430	Electrical Rough-In	34	14-May-13	01-Jul-13		
A2440	Low Voltage	24	14-May-13	17-Jun-13		
A2450	Plumbing Rough-In	34	16-May-13	03-Jul-13		
A2460	Sprinkler Piping	14	20-May-13	07-Jun-13		
A2470	Spray Fireproofing	5	01-Jul-13	08-Jul-13		
A2480	MEP Wall Rough In Inspections	1	05-Jul-13	05-Jul-13		
A2490	Hard Ceiling Framing MEP Rough-In	29	05-Aug-13	13-Sep-13		
A2500	GRD's	25	05-Sep-13	09-Oct-13		
A2510	Sprinkler Heads	25	05-Sep-13	09-Oct-13		
A2520	Finish Plumbing	25	12-Sep-13	16-Oct-13		
A2530	Balance HVAC	10	05-Nov-13*	18-Nov-13		
MJD.2.6	**Finishes**	**148**	**08-Apr-13**	**04-Nov-13**		
MJD.2.6.1	**West Wing - 1st Floor**	**127**	**08-Apr-13**	**04-Oct-13**		
A2540	Door Frames	5	08-Apr-13	12-Apr-13		
A2550	Partition Blocking	5	03-May-13	09-May-13		
A2560	Install Fireplace	2	29-May-13	30-May-13		



Actual Level of Effort	Remaining Work	◆ ◆ Milestone	Page 4 of 6	TASK filter: All Activities	
Actual Work	Critical Remaining Work	summary			© Oracle Corporation

MJD Assisted Living Additions — Classic Schedule Layout — 15-Oct-13 21:45

Activity ID	Activity Name	Original Duration	Start	Finish
A2570	Drywall & Insulation & Spackle Walls	15	10-Jun-13	28-Jun-13
A2580	Frame Hard Ceiling	44	24-Jun-13	23-Aug-13
A2590	Prime and 1st Coat of Paint - Walls & Ceilings	30	22-Jul-13	30-Aug-13
A2600	Light Fixtures & Devices	24	05-Aug-13	06-Sep-13
A2610	Woodwork (Trim/Millwork,Railings,Mouldings)	34	05-Aug-13	20-Sep-13
A2620	Flooring	39	29-Jul-13	20-Sep-13
A2630	Acoustical Ceiling Grid	7	03-Sep-13	11-Sep-13
A2640	Toilet Partitions	5	16-Sep-13	20-Sep-13
A2650	Final Coat of Paint & Wall coverings	15	16-Sep-13	04-Oct-13
A2660	Activity Kitchen Equipment	5	23-Sep-13	27-Sep-13
A2670	Doors & Hardware	10	23-Sep-13	04-Oct-13
MJD.2.6.2	**West Wing - 2nd Floor**	**125**	**18-Apr-13**	**14-Oct-13**
A2680	Door Frames	5	18-Apr-13	24-Apr-13
A2690	Partition Blocking	5	15-May-13	21-May-13
A2700	Drywall & Insulation & Spackle Walls and Ceilings	53	18-Jun-13	30-Aug-13
A2710	Frame Hard Ceiling	30	02-Jul-13	13-Aug-13
A2720	Prime and 1st Coat of Paint - Walls & Ceilings	29	30-Jul-13	09-Sep-13
A2730	Light Fixtures & Devices	24	13-Aug-13	16-Sep-13
A2740	Woodwork (Trim/Millwork,Railings,Mouldings)	34	13-Aug-13	30-Sep-13
A2750	Flooring	39	06-Aug-13	30-Sep-13
A2760	Acoustical Ceiling Grid	8	10-Sep-13	19-Sep-13
A2770	Toilet Partitions	5	24-Sep-13	30-Sep-13
A2780	Final Coat of Paint & Wall coverings	15	24-Sep-13	14-Oct-13
A2790	Activity Kitchen Equipment	5	01-Oct-13	07-Oct-13
A2800	Doors & Hardware	10	01-Oct-13	14-Oct-13
MJD.2.6.3	**Basement**	**36**	**25-Jun-13**	**14-Aug-13**
A2810	Door Frames	5	25-Jun-13	01-Jul-13
A2820	Drywall & Spackle Walls	6	02-Jul-13	10-Jul-13
A2830	Prime and 1st Coat of Paint - Walls & Ceilings	5	11-Jul-13	17-Jul-13
A2840	Specialty Equipment & Accessories	8	22-Jul-13	31-Jul-13
A2850	Final Coat of Paint	10	31-Jul-13	13-Aug-13
A2860	Sealed Concrete	1	14-Aug-13	14-Aug-13
MJD.2.6.4	**East Wing - 1st Floor**	**125**	**09-May-13**	**04-Nov-13**
A2870	Door Frames	5	09-May-13	15-May-13
A2880	Partition Blocking	5	05-Jun-13	11-Jun-13
A2890	Install Fireplace	2	01-Jul-13	02-Jul-13
A2900	Drywall & Insulation & Spackle Walls and Ceilings	53	10-Jul-13	23-Sep-13
A2910	Frame Hard Ceiling	29	24-Jul-13	03-Sep-13
A2920	Prime and 1st Coat of Paint - Walls & Ceilings	29	20-Aug-13	30-Sep-13
A2930	Flooring	39	27-Aug-13	21-Oct-13
A2940	Light Fixtures & Devices	25	03-Sep-13	07-Oct-13
A2950	Woodwork (Trim/Millwork,Railings,Mouldings)	35	03-Sep-13	21-Oct-13
A2960	Acoustical Ceiling Grid	8	01-Oct-13	10-Oct-13
A2970	Toilet Partitions	5	15-Oct-13*	21-Oct-13
A2980	Final Coat of Paint & Wall coverings	15	15-Oct-13*	04-Nov-13
A2990	Activity Kitchen Equipment	5	22-Oct-13*	28-Oct-13
A3000	Doors & Hardware	10	22-Oct-13*	04-Nov-13



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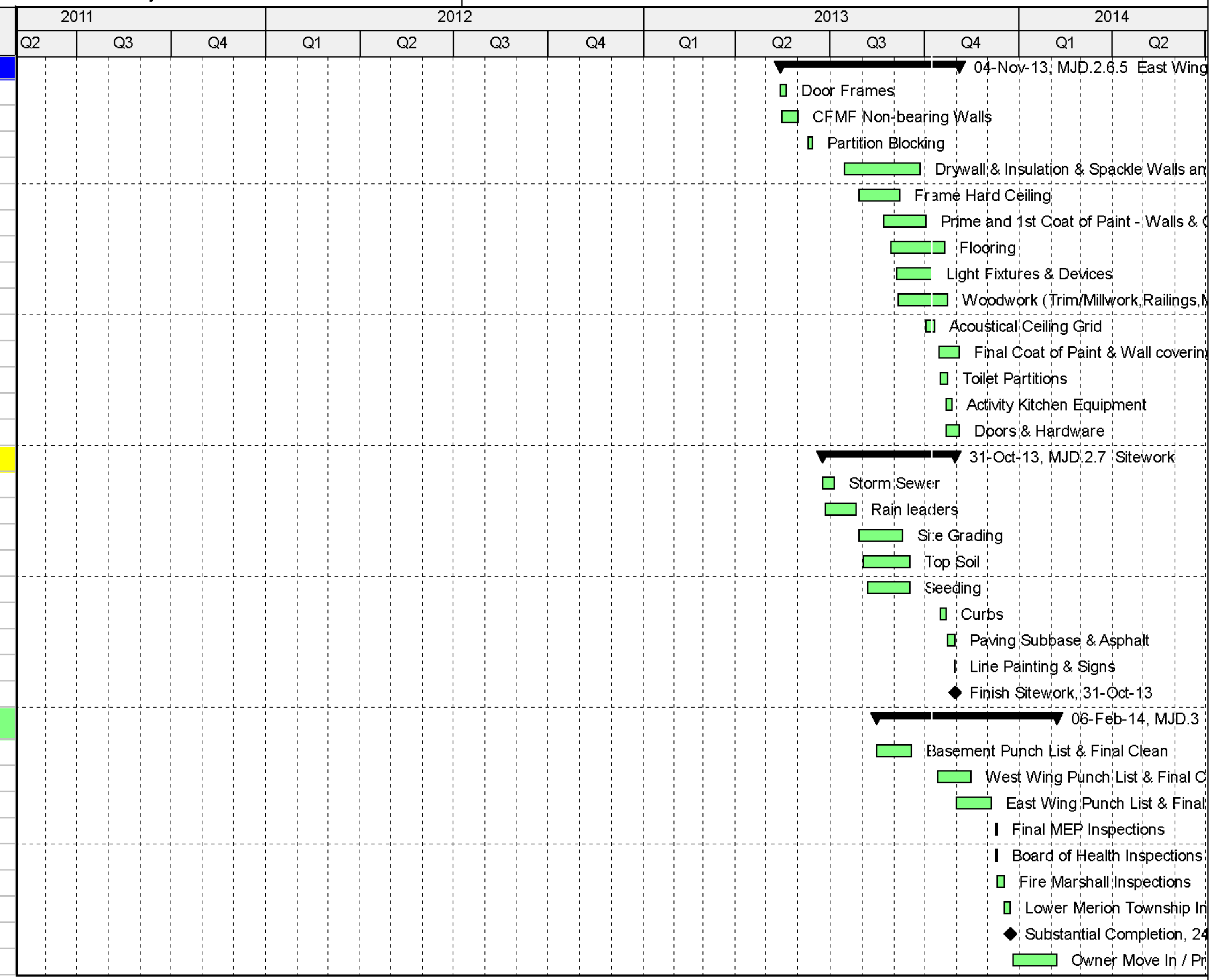
MJD Assisted Living Additions | Classic Schedule Layout | 15-Oct-13 21:45

Activity ID	Activity Name	Original Duration	Start	Finish
MJD.2.6.5	East Wing - 2nd Floor	122	14-May-13	04-Nov-13
A3010	Door Frames	5	14-May-13	20-May-13
A3020	CFMF Non-bearing Walls	11	16-May-13	31-May-13
A3030	Partition Blocking	5	10-Jun-13	14-Jun-13
A3040	Drywall & Insulation & Spackle Walls and Ceilings	53	15-Jul-13	26-Sep-13
A3050	Frame Hard Ceiling	29	29-Jul-13	06-Sep-13
A3060	Prime and 1st Coat of Paint - Walls & Ceilings	29	22-Aug-13	02-Oct-13
A3070	Flooring	37	29-Aug-13	21-Oct-13
A3080	Light Fixtures & Devices	25	04-Sep-13	08-Oct-13
A3090	Woodwork (Trim/Millwork,Railings,Mouldings)	35	05-Sep-13	23-Oct-13
A3100	Acoustical Ceiling Grid	7	03-Oct-13	11-Oct-13
A3110	Final Coat of Paint & Wall coverings	15	15-Oct-13*	04-Nov-13
A3120	Toilet Partitions	5	17-Oct-13*	23-Oct-13
A3130	Activity Kitchen Equipment	5	22-Oct-13*	28-Oct-13
A3140	Doors & Hardware	10	22-Oct-13*	04-Nov-13
MJD.2.7	Sitework	92	24-Jun-13	31-Oct-13
A3150	Storm Sewer	9	24-Jun-13	05-Jul-13
A3160	Rain leaders	21	27-Jun-13	26-Jul-13
A3170	Site Grading	30	30-Jul-13	10-Sep-13
A3180	Top Soil	31	02-Aug-13	16-Sep-13
A3190	Seeding	29	07-Aug-13	17-Sep-13
A3200	Curbs	4	17-Oct-13*	22-Oct-13
A3210	Paving Subbase & Asphalt	6	23-Oct-13*	30-Oct-13
A3220	Line Painting & Signs	1	31-Oct-13*	31-Oct-13
A3320	Finish Sitework	0	31-Oct-13	
MJD.3	Final Inspections & Project Closeout	123	15-Aug-13	06-Feb-14
A3230	Basement Punch List & Final Clean	24	15-Aug-13	18-Sep-13
A3240	West Wing Punch List & Final Clean	25	14-Oct-13*	15-Nov-13
A3250	East Wing Punch List & Final Clean	24	01-Nov-13*	05-Dec-13
A3260	Final MEP Inspections	2	09-Dec-13*	10-Dec-13
A3270	Board of Health Inspections	3	09-Dec-13*	11-Dec-13
A3280	Fire Marshall Inspections	5	11-Dec-13*	17-Dec-13
A3290	Lower Merion Township Inspection	4	18-Dec-13*	23-Dec-13
A3300	Substantial Completion	0	24-Dec-13*	
A3310	Owner Move In / Project Completion	31	26-Dec-13*	06-Feb-14



Actual Level of Effort | Remaining Work | Milestone
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Appendix C: Original General Conditions Estimate

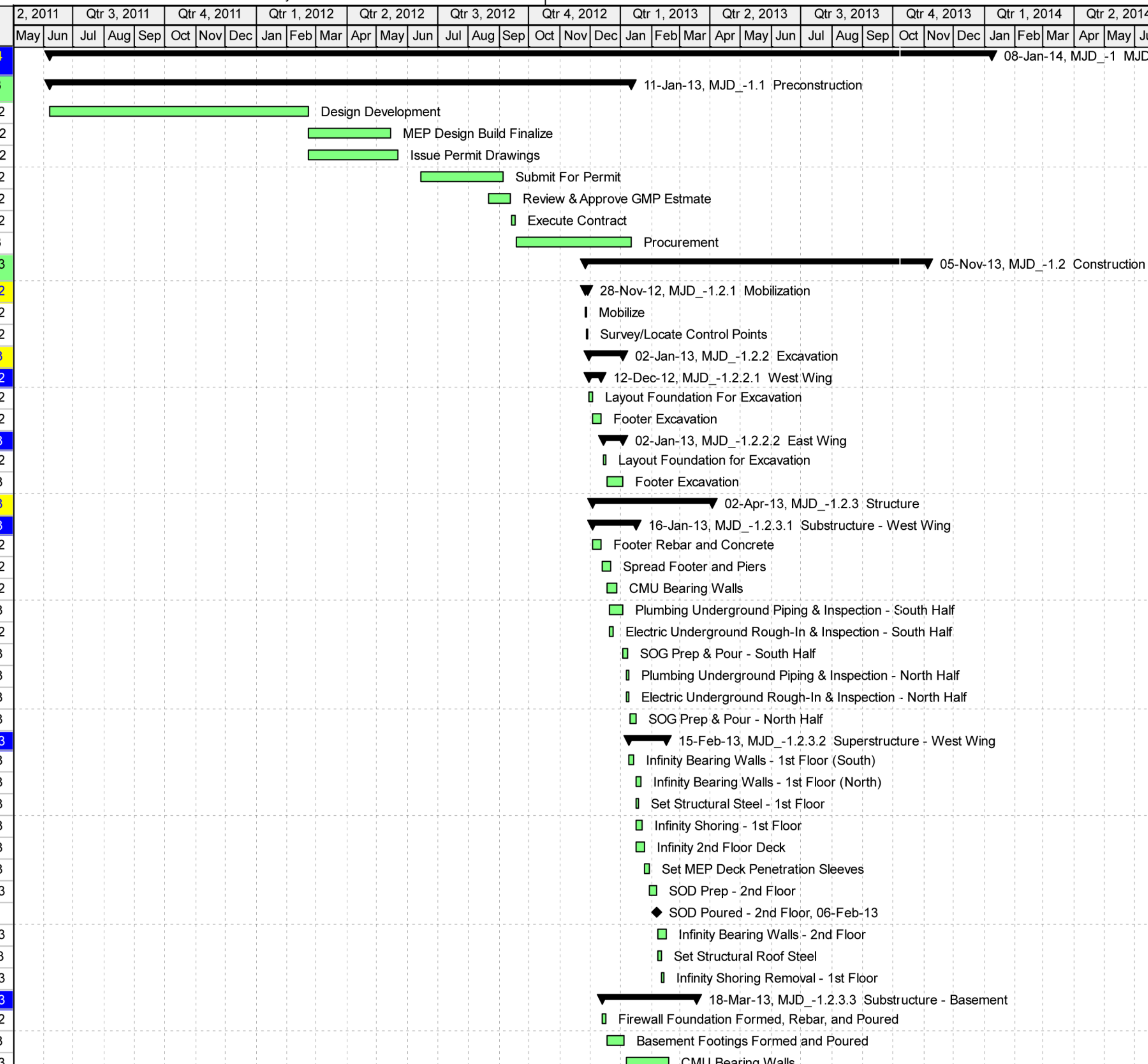
General Conditions Estimate				
	Project Duration - 14 Months - 56 Weeks			
Description	Quantity	Unit	Cost	Amount
Project Management Team				**$776,250**
Project Executive (10%)	14	Mo.	$2,050.00	$28,700
Field Operations Manager (10%)	14	Mo.	$1,700.00	$23,800
Project Manager	14	Mo.	$16,000.00	$224,000
Superintendent	14	Mo.	$15,500.00	$217,000
Project Engineer	14	Mo.	$11,200.00	$156,800
Project Assistant (50%)	14	Mo.	$4,000.00	$56,000
Accountant	250	Hr.	$55.00	$13,750
Contract Administrator	100	Hr.	$80.00	$8,000
Safety Manager	165	Hr.	$80.00	$13,200
Laborer (50%)	14	Mo.	$2,500.00	$35,000
Site Conditions				**$95,455**
Temporary Power	1	LS	$7,500.00	$7,500
Temporary Fence	500	LF	$10.00	$5,000
Temporary Phone	14	Mo.	$750.00	$10,500
Temporary Toilets (4)	14	Mo.	$600.00	$8,400
Drinking Water	14	Mo.	$150.00	$2,100
Temporary Stair & Rails	1500	LF	$10.00	$15,000
Dumpsters (2)	14	Mo.	$2,500.00	$35,000
Signage	100	SF	$26.50	$2,650
Small Tools & Equip	14609579	LS	0.05%	$7,305
Job Photos	4	Set	$500.00	$2,000
Insurance				**$200,151**
Builder's Risk	14609579	($)	0.15%	$21,914
General Liability	14609579	($)	0.75%	$109,572
MEP Liability Insurance (based on GMP)	14609579	($)	0.47%	$68,665
Field Operations				**$86,334**
Field Office/Trailer - use existing facilities	0	Mo.	$0.00	$0
Storage Trailers - use existing facilities	0	Mo.	$0.00	$0
Final Cleaning	76,000	SF	$0.50	$38,000
Computer Equipment	1	LS	$3,500.00	$3,500
Job Office Supplies	14	Mo.	$77.40	$1,084
Drawings & Blueprints	65	Ea.	$150.00	$9,750
Safety Equipment	1	LS	$3,000.00	$3,000
Protect New Work	76,000	SF	$0.25	$19,000
Layout (Own Forces)	3	Wk	$4,000.00	$12,000
Contingency	14609579	($)	3.00%	**$438,287**
			TOTAL	**$1,596,477**

General Conditions Estimate - *Monthly Paid Line Items*				
Project Duration - 14 Months - 56 Weeks				
Description	Quantity	Unit	Cost	Amount
Project Management Team				**$741,300**
Project Executive (10%)	14	Mo.	$2,050.00	$28,700
Field Operations Manager (10%)	14	Mo.	$1,700.00	$23,800
Project Manager	14	Mo.	$16,000.00	$224,000
Superintendent	14	Mo.	$15,500.00	$217,000
Project Engineer	14	Mo.	$11,200.00	$156,800
Project Assistant (50%)	14	Mo.	$4,000.00	$56,000
Laborer (50%)	14	Mo.	$2,500.00	$35,000
Site Conditions				**$56,000**
Temporary Phone	14	Mo.	$750.00	$10,500
Temporary Toilets (4)	14	Mo.	$600.00	$8,400
Drinking Water	14	Mo.	$150.00	$2,100
Dumpsters (2)	14	Mo.	$2,500.00	$35,000
Field Operations				**$1,084**
Field Office/Trailer - use existing facilities	0	Mo.	$0.00	$0
Storage Trailers - use existing facilities	0	Mo.	$0.00	$0
Job Office Supplies	14	Mo.	$77.40	$1,084
			TOTAL	**$798,384**

Appendix D: Revised Detailed Project Schedule

MJD Assisted Living Additions -REVISED | Classic Schedule Layout | Feb-14

Activity ID	Activity Name	Original Duration	Start	Finish
MJD_-1	MJD Assisted Living Additions -REVISI	661	07-Jun-11	08-Jan-14
MJD_-1.1	Preconstruction	408	07-Jun-11	11-Jan-13
A1000	Design Development	182	07-Jun-11	22-Feb-12
A1010	MEP Design Build Finalize	59	22-Feb-12	14-May-12
A1020	Issue Permit Drawings	65	22-Feb-12	22-May-12
A1030	Submit For Permit	57	14-Jun-12	04-Sep-12
A1040	Review & Approve GMP Estmate	16	21-Aug-12	12-Sep-12
A1050	Execute Contract	3	13-Sep-12	17-Sep-12
A1060	Procurement	81	18-Sep-12	11-Jan-13
MJD_-1.2	Construction	242	26-Nov-12	05-Nov-13
MJD_-1.2.1	Mobilization	3	26-Nov-12	28-Nov-12
A1070	Mobilize	2	26-Nov-12	27-Nov-12
A1080	Survey/Locate Control Points	1	28-Nov-12	28-Nov-12
MJD_-1.2.2	Excavation	22	30-Nov-12	02-Jan-13
MJD_-1.2.2.1	West Wing	9	30-Nov-12	12-Dec-12
A1090	Layout Foundation For Excavation	2	30-Nov-12	03-Dec-12
A1100	Footer Excavation	7	04-Dec-12	12-Dec-12
MJD_-1.2.2.2	East Wing	12	14-Dec-12	02-Jan-13
A1110	Layout Foundation for Excavation	2	14-Dec-12	17-Dec-12
A1120	Footer Excavation	10	18-Dec-12	02-Jan-13
MJD_-1.2.3	Structure	84	04-Dec-12	02-Apr-13
MJD_-1.2.3.1	Substructure - West Wing	30	04-Dec-12	16-Jan-13
A1130	Footer Rebar and Concrete	7	04-Dec-12	12-Dec-12
A1140	Spread Footer and Piers	7	13-Dec-12	21-Dec-12
A1150	CMU Bearing Walls	7	18-Dec-12	27-Dec-12
A1160	Plumbing Underground Piping & Inspection - South Ha	8	20-Dec-12	02-Jan-13
A1170	Electric Underground Rough-In & Inspection - South H	3	20-Dec-12	24-Dec-12
A1180	SOG Prep & Pour - South Half	4	03-Jan-13	08-Jan-13
A1190	Plumbing Underground Piping & Inspection - North Ha	3	07-Jan-13	09-Jan-13
A1200	Electric Underground Rough-In & Inspection - North H.	3	07-Jan-13	09-Jan-13
A1210	SOG Prep & Pour - North Half	5	10-Jan-13	16-Jan-13
MJD_-1.2.3.2	Superstructure - West Wing	28	09-Jan-13	15-Feb-13
A1220	Infinity Bearing Walls - 1st Floor (South)	4	09-Jan-13	14-Jan-13
A1225	Infinity Bearing Walls - 1st Floor (North)	4	16-Jan-13	21-Jan-13
A1230	Set Structural Steel - 1st Floor	3	16-Jan-13	18-Jan-13
A1240	Infinity Shoring - 1st Floor	5	16-Jan-13	22-Jan-13
A1250	Infinity 2nd Floor Deck	7	16-Jan-13	24-Jan-13
A1260	Set MEP Deck Penetration Sleeves	3	25-Jan-13	29-Jan-13
A1270	SOD Prep - 2nd Floor	7	29-Jan-13	06-Feb-13
A1280	SOD Poured - 2nd Floor	0	06-Feb-13	
A1290	Infinity Bearing Walls - 2nd Floor	7	07-Feb-13	15-Feb-13
A1300	Set Structural Roof Steel	3	07-Feb-13	11-Feb-13
A1310	Infinity Shoring Removal - 1st Floor	3	11-Feb-13	13-Feb-13
MJD_-1.2.3.3	Substructure - Basement	66	13-Dec-12	18-Mar-13
A1320	Firewall Foundation Formed, Rebar, and Poured	3	13-Dec-12	17-Dec-12
A1330	Basement Footings Formed and Poured	12	18-Dec-12	04-Jan-13
A1340	CMU Bearing Walls	31	07-Jan-13	18-Feb-13



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MJD Assisted Living Additions -REVISED

Classic Schedule Layout

Feb-14

Activity ID	Activity Name	Original Duration	Start	Finish
A1350	Plumbing Underground Rough-In & Inspection	5	11-Feb-13	15-Feb-13
A1360	Form/Pour Basement Stair	3	18-Feb-13	20-Feb-13
A1370	SOG Prep & Pour	10	18-Feb-13	01-Mar-13
A1380	Interior CMU Walls, Concrete Beams	11	04-Mar-13	18-Mar-13
A1390	Foundation Waterproofing	1	14-Mar-13	14-Mar-13
A1400	Backfill	2	15-Mar-13	18-Mar-13
MJD_-1.2.3.4	Superstructure - Basement	12	18-Mar-13	02-Apr-13
A1410	Infinity Metal Deck	2	18-Mar-13	19-Mar-13
A1420	MEP Deck Sleeves	1	19-Mar-13	19-Mar-13
A1430	Prep & Pour SOD Above Basement	3	22-Mar-13	26-Mar-13
A1440	CMU Firewall Above SOD	6	26-Mar-13	02-Apr-13
MJD_-1.2.3.5	Substructure - East Wing	32	26-Dec-12	08-Feb-13
A1450	Footer Rebar and Concrete	10	26-Dec-12	09-Jan-13
A1460	CMU Bearing Walls	14	26-Dec-12*	15-Jan-13
A1480	Spread Footer and Piers	7	14-Jan-13	22-Jan-13
A1490	Underground Sanitary Piping (North)	5	14-Jan-13	18-Jan-13
A1500	Electric Underground Rough-In (North)	8	14-Jan-13	23-Jan-13
A1510	Plumbing Underground Piping (South)	7	24-Jan-13	01-Feb-13
A1520	Electric Underground Rough-In (South)	6	24-Jan-13	31-Jan-13
A1530	SOG Prep & Pour - North Half	4	25-Jan-13	30-Jan-13
A1540	SOG Prep & Pour - South Half	6	01-Feb-13	08-Feb-13
MJD_-1.2.3.6	Superstructure - East Wing	32	30-Jan-13	14-Mar-13
A1550	Infinity Bearing Walls - 1st Floor (North)	4	30-Jan-13	04-Feb-13
A1555	Infinity Bearing Walls - 1st Floor (South)	4	11-Feb-13	14-Feb-13
A1560	Set Structural Steel - 1st Floor	3	11-Feb-13	13-Feb-13
A1570	Infinity Shoring - 1st Floor	6	11-Feb-13	18-Feb-13
A1580	Infinity 2nd Floor Deck	7	11-Feb-13	19-Feb-13
A1590	MEP Deck Penetration Sleeves	3	19-Feb-13	21-Feb-13
A1600	SOD Prep & Pour	9	21-Feb-13	05-Mar-13
A1605	SOD Pour Complete	0	05-Mar-13	
A1610	Infinity Bearing Walls - 2nd Floor	7	06-Mar-13	14-Mar-13
A1620	Set Structural Roof Steel	3	06-Mar-13	08-Mar-13
A1630	Infinity Shoring Removal	3	08-Mar-13	12-Mar-13
MJD_-1.2.4	Building Envelope	92	19-Feb-13	27-Jun-13
MJD_-1.2.4.1	Roofing - West Wing	60	19-Feb-13	13-May-13
A1640	Roof Deck	7	19-Feb-13	27-Feb-13
A1650	Trusses and Sheathing	15	19-Feb-13	11-Mar-13
A1655	Finish Roof Trusses & Sheathing	0	11-Mar-13	
A1660	Equipment Curbs and RTU's & Fans	7	11-Mar-13	19-Mar-13
A1670	Roof Hatches, Plumbing Vents & Roof Conduits	3	11-Mar-13	13-Mar-13
A1680	Roof Shingles & Membrane Roofing	16	11-Mar-13	01-Apr-13
A1690	Soffits, Fascia, and FRP Molding	10	02-Apr-13	15-Apr-13
A1700	Gutters & Downspouts	5	07-May-13	13-May-13
MJD_-1.2.4.2	Façade - West Wing	75	19-Feb-13	04-Jun-13
A1710	Sheath Exterior Walls	10	19-Feb-13	04-Mar-13
A1720	Install Windows & Exterior Doors	10	12-Mar-13	25-Mar-13
A1730	West Wing Building Dried In	0	25-Mar-13	

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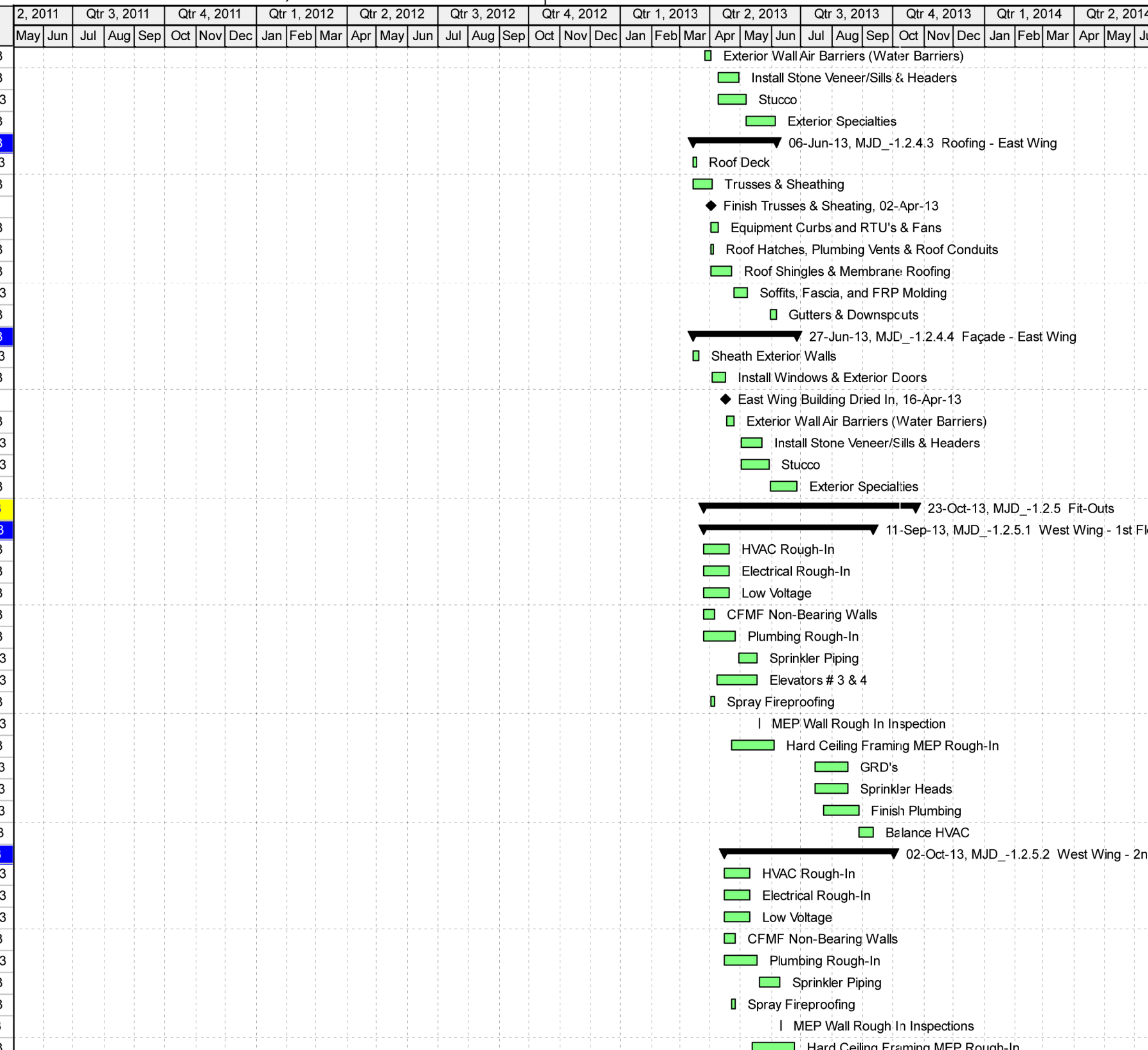
Activity ID	Activity Name	Original Duration	Start	Finish
A1740	Exterior Wall Air Barriers (Water Barriers)	5	26-Mar-13	01-Apr-13
A1750	Install Stone Veneer/Sills & Headers	15	09-Apr-13	29-Apr-13
A1760	Stucco	20	09-Apr-13	06-May-13
A1770	Exterior Specialties	20	07-May-13	04-Jun-13
MJD_-1.2.4.3	**Roofing - East Wing**	**60**	**14-Mar-13**	**06-Jun-13**
A1780	Roof Deck	3	14-Mar-13	18-Mar-13
A1790	Trusses & Sheathing	14	14-Mar-13	02-Apr-13
A1795	Finish Trusses & Sheating	0	02-Apr-13	
A1800	Equipment Curbs and RTU's & Fans	5	02-Apr-13	08-Apr-13
A1810	Roof Hatches, Plumbing Vents & Roof Conduits	3	02-Apr-13	04-Apr-13
A1820	Roof Shingles & Membrane Roofing	15	02-Apr-13	22-Apr-13
A1830	Soffits, Fascia, and FRP Molding	10	25-Apr-13	08-May-13
A1840	Gutters & Downspouts	5	31-May-13	06-Jun-13
MJD_-1.2.4.4	**Façade - East Wing**	**75**	**14-Mar-13**	**27-Jun-13**
A1850	Sheath Exterior Walls	5	14-Mar-13	20-Mar-13
A1860	Install Windows & Exterior Doors	10	03-Apr-13	16-Apr-13
A1870	East Wing Building Dried In	0	16-Apr-13	
A1880	Exterior Wall Air Barriers (Water Barriers)	6	17-Apr-13	24-Apr-13
A1890	Install Stone Veneer/Sills & Headers	15	02-May-13	22-May-13
A1900	Stucco	20	02-May-13	30-May-13
A1910	Exterior Specialties	20	31-May-13	27-Jun-13
MJD_-1.2.5	**Fit-Outs**	**150**	**25-Mar-13**	**23-Oct-13**
MJD_-1.2.5.1	**West Wing - 1st Floor**	**120**	**25-Mar-13**	**11-Sep-13**
A1920	HVAC Rough-In	20	25-Mar-13	19-Apr-13
A1930	Electrical Rough-In	20	25-Mar-13	19-Apr-13
A1940	Low Voltage	20	25-Mar-13	19-Apr-13
A1950	CFMF Non-Bearing Walls	10	25-Mar-13	05-Apr-13
A1960	Plumbing Rough-In	25	25-Mar-13	26-Apr-13
A1970	Sprinkler Piping	15	29-Apr-13	17-May-13
A1980	Elevators # 3 & 4	30	08-Apr-13	17-May-13
A1990	Spray Fireproofing	5	01-Apr-13	05-Apr-13
A2000	MEP Wall Rough In Inspection	1	20-May-13	20-May-13
A2010	Hard Ceiling Framing MEP Rough-In	30	22-Apr-13	03-Jun-13
A2020	GRD's	25	15-Jul-13	16-Aug-13
A2030	Sprinkler Heads	25	15-Jul-13	16-Aug-13
A2040	Finish Plumbing	25	24-Jul-13	27-Aug-13
A2050	Balance HVAC	10	28-Aug-13	11-Sep-13
MJD_-1.2.5.2	**West Wing - 2nd Floor**	**120**	**15-Apr-13**	**02-Oct-13**
A2060	HVAC Rough-In	20	15-Apr-13	10-May-13
A2070	Electrical Rough-In	20	15-Apr-13	10-May-13
A2080	Low Voltage	20	15-Apr-13	10-May-13
A2090	CFMF Non-Bearing Walls	10	15-Apr-13	26-Apr-13
A2100	Plumbing Rough-In	25	15-Apr-13	17-May-13
A2110	Sprinkler Piping	15	20-May-13	10-Jun-13
A2120	Spray Fireproofing	5	22-Apr-13	26-Apr-13
A2130	MEP Wall Rough In Inspections	1	11-Jun-13	11-Jun-13
A2140	Hard Ceiling Framing MEP Rough-In	30	13-May-13	24-Jun-13



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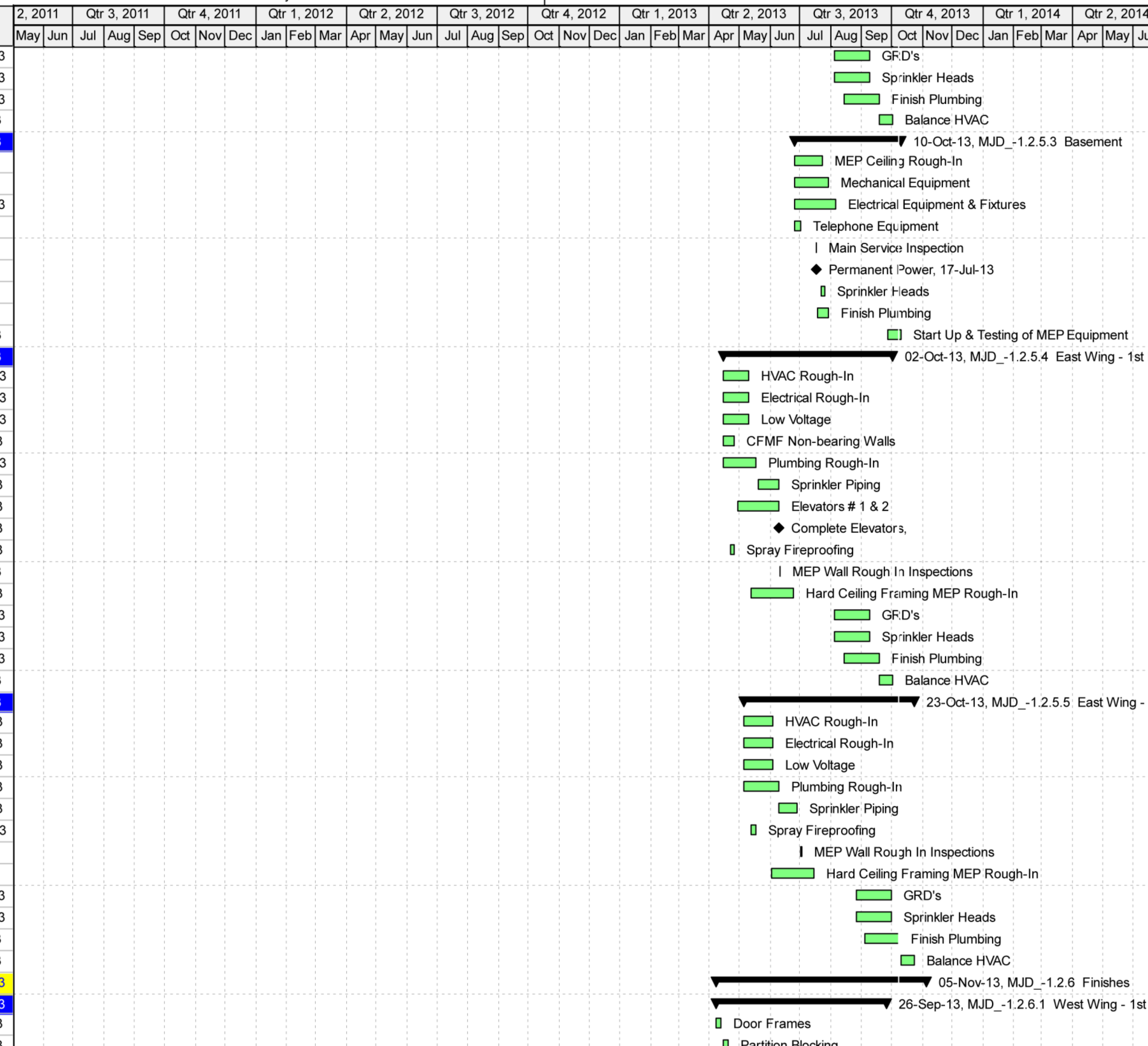
Activity ID	Activity Name	Original Duration	Start	Finish
A2150	GRD's	25	05-Aug-13	09-Sep-13
A2160	Sprinkler Heads	25	05-Aug-13	09-Sep-13
A2170	Finish Plumbing	25	14-Aug-13	18-Sep-13
A2180	Balance HVAC	10	19-Sep-13	02-Oct-13
MJD_-1.2.5.3 Basement		**76**	**25-Jun-13**	**10-Oct-13**
A2190	MEP Ceiling Rough-In	20	25-Jun-13	23-Jul-13
A2200	Mechanical Equipment	24	25-Jun-13	29-Jul-13
A2210	Electrical Equipment & Fixtures	30	25-Jun-13	06-Aug-13
A2220	Telephone Equipment	5	25-Jun-13	01-Jul-13
A2230	Main Service Inspection	1	17-Jul-13	17-Jul-13
A2240	Permanent Power	0	17-Jul-13	
A2250	Sprinkler Heads	5	22-Jul-13	26-Jul-13
A2260	Finish Plumbing	8	18-Jul-13	29-Jul-13
A2270	Start Up & Testing of MEP Equipment	10	27-Sep-13	10-Oct-13
MJD_-1.2.5.4 East Wing - 1st Floor		**120**	**15-Apr-13**	**02-Oct-13**
A2280	HVAC Rough-In	20	15-Apr-13	10-May-13
A2290	Electrical Rough-In	20	15-Apr-13	10-May-13
A2300	Low Voltage	20	15-Apr-13	10-May-13
A2310	CFMF Non-bearing Walls	10	15-Apr-13	26-Apr-13
A2320	Plumbing Rough-In	25	15-Apr-13	17-May-13
A2330	Sprinkler Piping	15	20-May-13	10-Jun-13
A2340	Elevators # 1 & 2	30	29-Apr-13	10-Jun-13
A2345	Complete Elevators	0		10-Jun-13
A2350	Spray Fireproofing	5	22-Apr-13	26-Apr-13
A2360	MEP Wall Rough In Inspections	1	11-Jun-13	11-Jun-13
A2370	Hard Ceiling Framing MEP Rough-In	30	13-May-13	24-Jun-13
A2380	GRD's	25	05-Aug-13	09-Sep-13
A2390	Sprinkler Heads	25	05-Aug-13	09-Sep-13
A2400	Finish Plumbing	25	14-Aug-13	18-Sep-13
A2410	Balance HVAC	10	19-Sep-13*	02-Oct-13
MJD_-1.2.5.5 East Wing - 2nd Floor		**120**	**06-May-13**	**23-Oct-13**
A2420	HVAC Rough-In	20	06-May-13	03-Jun-13
A2430	Electrical Rough-In	20	06-May-13	03-Jun-13
A2440	Low Voltage	20	06-May-13	03-Jun-13
A2450	Plumbing Rough-In	25	06-May-13	10-Jun-13
A2460	Sprinkler Piping	15	10-Jun-13	28-Jun-13
A2470	Spray Fireproofing	5	13-May-13	17-May-13
A2480	MEP Wall Rough In Inspections	1	02-Jul-13	02-Jul-13
A2490	Hard Ceiling Framing MEP Rough-In	30	03-Jun-13	15-Jul-13
A2500	GRD's	25	26-Aug-13	30-Sep-13
A2510	Sprinkler Heads	25	26-Aug-13	30-Sep-13
A2520	Finish Plumbing	25	04-Sep-13	08-Oct-13
A2530	Balance HVAC	10	10-Oct-13*	23-Oct-13
MJD_-1.2.6 Finishes		**149**	**08-Apr-13**	**05-Nov-13**
MJD_-1.2.6.1 West Wing - 1st Floor		**121**	**08-Apr-13**	**26-Sep-13**
A2540	Door Frames	5	08-Apr-13	12-Apr-13
A2550	Partition Blocking	5	15-Apr-13	19-Apr-13



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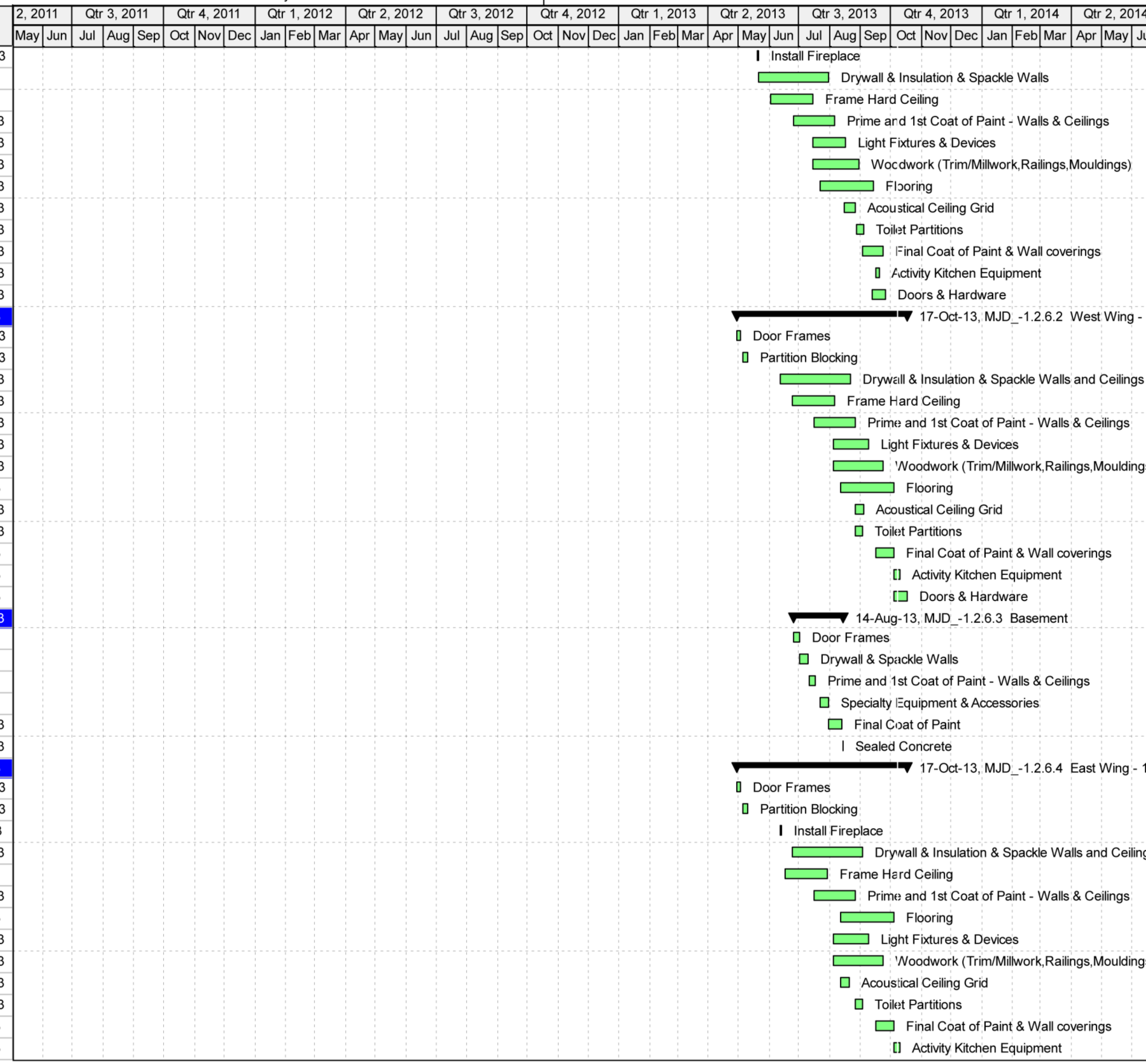
MJD Assisted Living Additions -REVISED | Classic Schedule Layout | Feb-14

Activity ID	Activity Name	Original Duration	Start	Finish
A2560	Install Fireplace	2	20-May-13	21-May-13
A2570	Drywall & Insulation & Spackle Walls	50	21-May-13	31-Jul-13
A2580	Frame Hard Ceiling	30	03-Jun-13	15-Jul-13
A2590	Prime and 1st Coat of Paint - Walls & Ceilings	30	25-Jun-13	06-Aug-13
A2600	Light Fixtures & Devices	25	15-Jul-13	16-Aug-13
A2610	Woodwork (Trim/Millwork,Railings,Mouldings)	35	15-Jul-13	30-Aug-13
A2620	Flooring	39	22-Jul-13	13-Sep-13
A2630	Acoustical Ceiling Grid	7	16-Aug-13	26-Aug-13
A2640	Toilet Partitions	5	28-Aug-13	04-Sep-13
A2650	Final Coat of Paint & Wall coverings	15	03-Sep-13	23-Sep-13
A2660	Activity Kitchen Equipment	5	16-Sep-13	20-Sep-13
A2670	Doors & Hardware	10	13-Sep-13	26-Sep-13
MJD_-1.2.6.2 West Wing - 2nd Floor		**121**	**29-Apr-13**	**17-Oct-13**
A2680	Door Frames	5	29-Apr-13	03-May-13
A2690	Partition Blocking	5	06-May-13	10-May-13
A2700	Drywall & Insulation & Spackle Walls and Ceilings	50	12-Jun-13	21-Aug-13
A2710	Frame Hard Ceiling	30	24-Jun-13	05-Aug-13
A2720	Prime and 1st Coat of Paint - Walls & Ceilings	30	16-Jul-13	26-Aug-13
A2730	Light Fixtures & Devices	25	05-Aug-13	09-Sep-13
A2740	Woodwork (Trim/Millwork,Railings,Mouldings)	35	05-Aug-13	23-Sep-13
A2750	Flooring	39	12-Aug-13	04-Oct-13
A2760	Acoustical Ceiling Grid	7	26-Aug-13	04-Sep-13
A2770	Toilet Partitions	5	27-Aug-13	03-Sep-13
A2780	Final Coat of Paint & Wall coverings	15	16-Sep-13	04-Oct-13
A2790	Activity Kitchen Equipment	5	04-Oct-13	10-Oct-13
A2800	Doors & Hardware	10	04-Oct-13	17-Oct-13
MJD_-1.2.6.3 Basement		**36**	**25-Jun-13**	**14-Aug-13**
A2810	Door Frames	5	25-Jun-13	01-Jul-13
A2820	Drywall & Spackle Walls	6	02-Jul-13	10-Jul-13
A2830	Prime and 1st Coat of Paint - Walls & Ceilings	5	11-Jul-13	17-Jul-13
A2840	Specialty Equipment & Accessories	8	22-Jul-13	31-Jul-13
A2850	Final Coat of Paint	10	31-Jul-13	13-Aug-13
A2860	Sealed Concrete	1	14-Aug-13	14-Aug-13
MJD_-1.2.6.4 East Wing - 1st Floor		**121**	**29-Apr-13**	**17-Oct-13**
A2870	Door Frames	5	29-Apr-13	03-May-13
A2880	Partition Blocking	5	06-May-13	10-May-13
A2890	Install Fireplace	2	12-Jun-13	13-Jun-13
A2900	Drywall & Insulation & Spackle Walls and Ceilings	50	24-Jun-13	03-Sep-13
A2910	Frame Hard Ceiling	30	17-Jun-13	29-Jul-13
A2920	Prime and 1st Coat of Paint - Walls & Ceilings	30	16-Jul-13	26-Aug-13
A2930	Flooring	39	12-Aug-13	04-Oct-13
A2940	Light Fixtures & Devices	25	05-Aug-13	09-Sep-13
A2950	Woodwork (Trim/Millwork,Railings,Mouldings)	35	05-Aug-13	23-Sep-13
A2960	Acoustical Ceiling Grid	7	12-Aug-13	20-Aug-13
A2970	Toilet Partitions	5	27-Aug-13*	03-Sep-13
A2980	Final Coat of Paint & Wall coverings	15	16-Sep-13*	04-Oct-13
A2990	Activity Kitchen Equipment	5	04-Oct-13*	10-Oct-13



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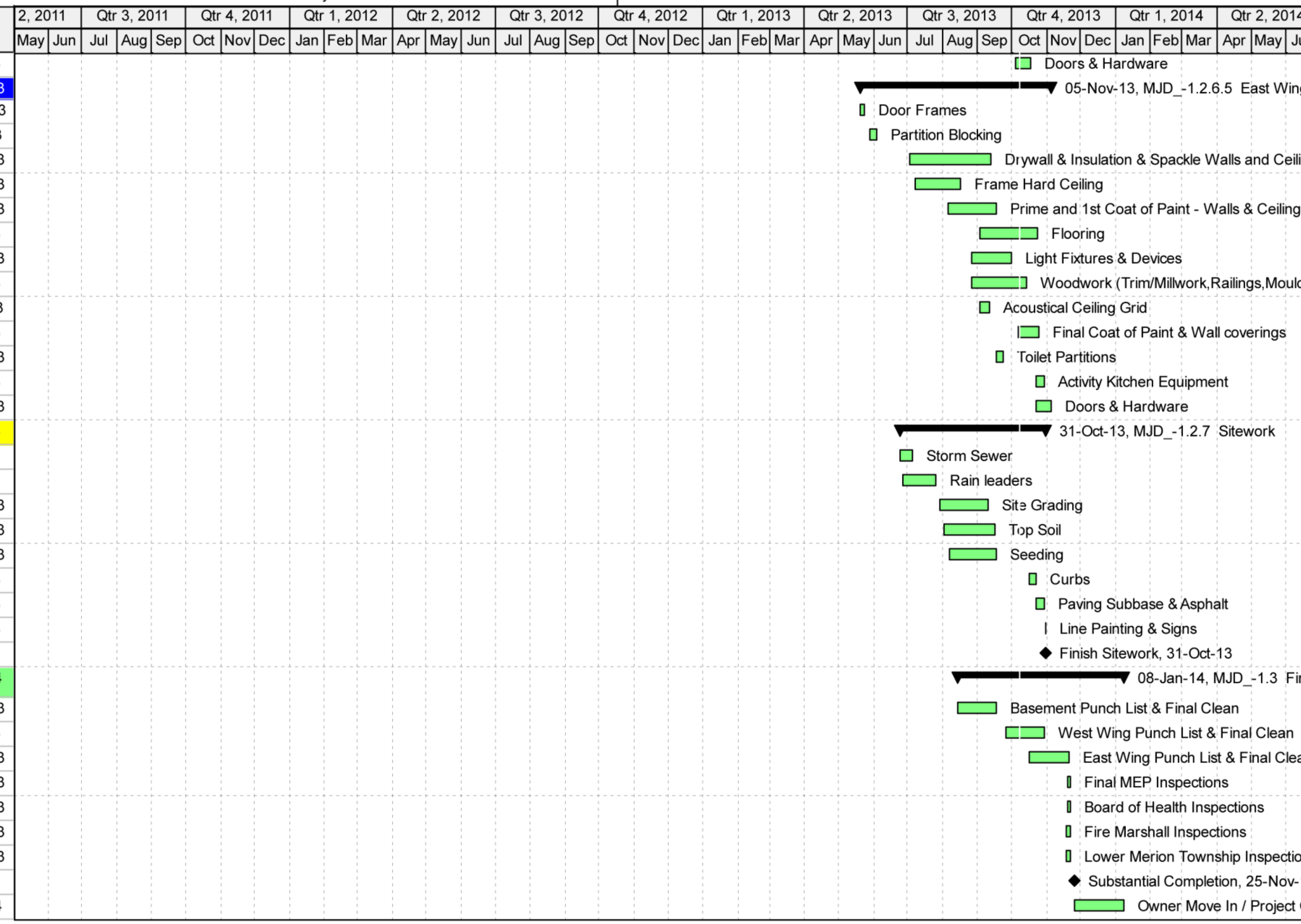
Activity ID	Activity Name	Original Duration	Start	Finish
A3000	Doors & Hardware	10	04-Oct-13*	17-Oct-13
MJD_-1.2.6.5	**East Wing - 2nd Floor**	119	20-May-13	05-Nov-13
A3010	Door Frames	5	20-May-13	24-May-13
A3030	Partition Blocking	5	28-May-13	03-Jun-13
A3040	Drywall & Insulation & Spackle Walls and Ceilings	50	03-Jul-13	12-Sep-13
A3050	Frame Hard Ceiling	30	08-Jul-13	16-Aug-13
A3060	Prime and 1st Coat of Paint - Walls & Ceilings	30	06-Aug-13	17-Sep-13
A3070	Flooring	37	03-Sep-13	23-Oct-13
A3080	Light Fixtures & Devices	25	26-Aug-13	30-Sep-13
A3090	Woodwork (Trim/Millwork,Railings,Mouldings)	35	26-Aug-13	14-Oct-13
A3100	Acoustical Ceiling Grid	7	03-Sep-13	11-Sep-13
A3110	Final Coat of Paint & Wall coverings	15	07-Oct-13*	25-Oct-13
A3120	Toilet Partitions	5	17-Sep-13*	23-Sep-13
A3130	Activity Kitchen Equipment	5	23-Oct-13*	29-Oct-13
A3140	Doors & Hardware	10	23-Oct-13*	05-Nov-13
MJD_-1.2.7	**Sitework**	92	24-Jun-13	31-Oct-13
A3150	Storm Sewer	9	24-Jun-13	05-Jul-13
A3160	Rain leaders	21	27-Jun-13	26-Jul-13
A3170	Site Grading	30	30-Jul-13	10-Sep-13
A3180	Top Soil	31	02-Aug-13	16-Sep-13
A3190	Seeding	29	07-Aug-13	17-Sep-13
A3200	Curbs	4	17-Oct-13*	22-Oct-13
A3210	Paving Subbase & Asphalt	6	23-Oct-13*	30-Oct-13
A3220	Line Painting & Signs	1	31-Oct-13*	31-Oct-13
A3320	Finish Sitework	0	31-Oct-13	
MJD_-1.3	**Final Inspections & Project Closeout**	103	14-Aug-13	08-Jan-14
A3230	Basement Punch List & Final Clean	24	14-Aug-13	17-Sep-13
A3240	West Wing Punch List & Final Clean	25	26-Sep-13*	30-Oct-13
A3250	East Wing Punch List & Final Clean	25	17-Oct-13*	20-Nov-13
A3260	Final MEP Inspections	2	20-Nov-13*	21-Nov-13
A3270	Board of Health Inspections	3	20-Nov-13*	22-Nov-13
A3280	Fire Marshall Inspections	5	18-Nov-13*	22-Nov-13
A3290	Lower Merion Township Inspection	4	18-Nov-13*	21-Nov-13
A3300	Substantial Completion	0	25-Nov-13*	
A3310	Owner Move In / Project Completion	31	25-Nov-13*	08-Jan-14



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Appendix E: Structural Analysis Design Criteria

Design Criteria
Structural Drawing S2.0 General Notes - SFCS, Inc.

2. DESIGN CRITERIA

A. BUILDING DESIGNED IN ACCORDANCE WITH THE 2009 INTERNATIONAL BUILDING CODE WITH PA UNIFORM CONSTRUCTION CODE AMENDMENTS
STEEL DESIGN - AISC 13TH EDITION
CONCRETE DESIGN - ACI 318-08
NDS - 2005
ACI - 530-05

B. FLOOR LOADS:
LIVE 80 PSF (REDUCIBLE)
SUPERIMPOSED DEAD 15 PSF
RESIDENTIAL UNITS 40 PSF
PUBLIC AREAS AND CORRIDORS 100 PSF

C. ROOF LIVE LOAD = 20PSF

D. ROOF SNOW LOAD
1. GROUND SNOW LOAD P_g = 30.0 PSF
2. FLAT-ROOF SNOW LOAD P_f = 23.1 PSF
3. SNOW EXPOSURE FACTOR C_e = 1.0
4. THERMAL FACTOR C_t = 1.0
5. SNOW LOAD IMPORTANCE FACTOR I_s = 1.1

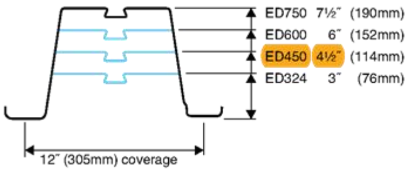
E. WIND LOADS DESIGNED IN ACCORDANCE WITH THE 2009 INTERNATIONAL BUILDING CODE AND ANSI/ASCE 7-05
1. BASIC WIND SPEED (3-SECOND GUST) = 90 MPH
2. WIND IMPORTANCE FACTOR I_w = 1.15
3. WIND EXPOSURE B
4. WIND BASE SHEAR
EAST ADDITION V_x = 35.0 k , V_y = 112.0 k
WEST ADDITION V_x = 31.0 k , V_y = 48.0 k
5. INTERNAL PRESSURE COEFFICIENT GC_{pi} = ±.18
6. COMPONENTS AND CLADDING SHALL BE DESIGNED FOR THE WIND PRESSURE TABULATED BELOW. DEFLECTION CALCULATIONS MAY USE 70% OF TABULATED VALUES

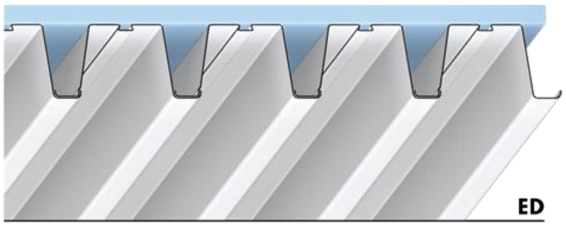
ZONE PER FIG. 6-3	EFFECTIVE WIND AREA	POSITIVE PRESSURE PSF	NEGATIVE PRESSURE PSF
1	50	+10.0	-15.8
2	50	+10.0	-21.2
3	50	+10.0	-25.4
4	10	+16.8	-18.2
4	20	+16.0	-17.4
4	50	+15.0	-16.4
4	100	+14.3	-15.6
5	10	+16.8	-22.4
5	20	+16.0	-20.9
5	50	+15.0	-19.0
5	100	+14.3	-17.4

F. EARTHQUAKE DESIGN DATA
1. OCCUPANCY CATEGORY III
2. SPECTRAL RESPONSE COEFFICIENTS: S_{DS} = .220 S_{D1} = .069
3. SITE CLASS C
4. BASIC SEISMIC-FORCE-RESISTING SYSTEM:
LIGHT FRAMED WALL SYSTEM USING FLAT STRAP BRACING
5. SEISMIC BASE SHEAR:
EAST ADDITION V = 108 k
WEST ADDITION V = 103 k
6. ANALYSIS PROCEDURE: EQUIVALENT LATERAL FORCE
7. R = 4, OMEGA = 2, Cd = 3 1/2
8. SEISMIC PERFORMANCE CATEGORY - B
9. SEISMIC IMPORTANCE FACTOR I_E =1.25

G. MECHANICAL ANCHORAGE I_p=1.5

30 WIDECK® ED TECHNICAL TABLES





ED Section Properties (per foot of width)

Deck Type	Gage	Weight (psf)	I_D (in.^{4})	S_P (in.^{3})	S_N (in.^{3})	Allowable Support Reaction (PLF) End*	Allowable Support Reaction (PLF) Int.*
ED324	20	2.77	1.18	0.60	0.60	592	1114
	18	3.70	1.64	0.92	0.88	987	1841
	16	4.63	2.16	1.19	1.18	1512	2803
	14	5.80	2.70	1.51	1.51	2243	4145
ED450	20	3.14	2.84	0.98	0.99	572	1138
	18	4.20	3.95	1.51	1.45	963	1882
	16	5.25	5.21	1.96	1.91	1486	2868
	14	6.57	6.50	2.48	2.49	2218	4243
ED600	18	4.70	7.46	2.17	2.07	925	1889
	16	5.87	9.85	2.82	2.76	1437	2882
	14	7.36	12.29	3.58	3.59	2158	4266
ED750	18	5.20	12.36	2.88	2.64	889	1889
	16	6.50	16.28	3.77	3.67	1391	2882
	14	8.11	20.34	4.80	4.80	2099	4269

*Minimum end and interior support bearing lengths (see Note 5 below):
End = 4"
Interior = 6"

Wideck ED & EDA EpiGrip® Hanger Safe Load Hanging Capacities

1. EpiGrip Hangers carry 100 pounds safe load hanging capacities.
2. Deck shall be designed to carry these additional hanging loads.
3. Do not place hangers closer together than 5' on center along the same deck rib.
4. Contact EPIC for installation instructions.

WARNING: Failure to adhere to the above notes may cause hangers to pull from deck rib.

AE 404 used LRFD Design (refer to similar roof deck for LRFD loads) [Deep-Dek 4.5]

ED Load Table — Uniform Total Load (Dead and Live) in Pounds Per Square Foot

No. Spans	Deck Type	Gage	Span Length Center to Center of Supports (ft.) 10	12	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	30	32
1	ED324	20	96/77	67/45	49/28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		18	147/108	102/62	75/39	65/32	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		16	190/142	132/82	97/52	85/42	[illegible]	66/29	—	—	—	—	—	—	—	—	—	—	—	—	—
		14	242/177	168/103	123/65	107/53	94/43	84/36	75/30	67/26	—	—	—	—	—	—	—	—	—	—	—
2	ED324	20	89/187	67/108	49/68	43/55	38/46	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		18	141/259	98/150	72/94	[illegible]	55/63	49/53	43/44	39/38	35/32	32/27	—	—	—	—	—	—	—	—	—
		16	189/341	131/198	96/124	[illegible]	74/83	65/69	58/59	52/50	47/43	43/35	39/29	—	—	—	—	—	—	—	—
		14	242/427	168/247	123/156	[illegible]	94/104	84/87	75/73	67/62	60/53	55/44	50/36	46/31	42/26	—	—	—	—	—	—
1	ED450	20	114/186	108/95	80/68	[illegible]	61/46	54/38	48/32	43/27	—	—	—	—	—	—	—	—	—	—	—
		18	193/259	161/150	123/95	107/77	94/63	84/53	75/44	67/38	60/32	55/27	—	—	—	—	—	—	—	—	—
		16	297/342	218/198	[illegible]	139/101	123/84	109/70	97/59	87/50	78/43	71/35	65/29	—	—	—	—	—	—	—	—
		14	397/427	276/247	[illegible]	176/126	155/104	137/87	122/73	110/62	99/53	90/44	82/36	75/31	69/26	—	—	—	—	—	—
2	ED450	20	91/449	76/260	[illegible]	61/133	57/110	54/91	49/77	44/65	40/56	36/46	33/38	30/32	—	—	—	—	—	—	—
		18	151/500	125/361	[illegible]	100/185	91/152	80/127	72/107	64/91	58/78	53/64	48/53	44/45	40/38	37/32	34/27	—	—	—	—
		16	229/500	191/477	156/300	136/244	119/201	106/168	94/141	85/120	76/103	69/85	63/70	58/59	53/50	49/42	45/36	42/31	39/27	—	—
		14	339/500	[illegible]	203/374	177/304	156/251	138/209	123/176	110/150	100/128	90/106	82/88	75/73	69/62	64/53	59/45	55/39	51/33	44/25	—
1	ED600	18	185/490	[illegible]	132/179	123/145	116/120	109/100	103/84	96/71	87/61	79/50	72/42	66/35	60/30	56/25	—	—	—	—	—
		16	287/500	[illegible]	205/236	192/192	176/158	156/132	139/111	125/94	113/81	102/67	93/55	85/46	78/39	72/33	67/28	—	—	—	—
		14	432/500	[illegible]	292/294	255/239	224/197	198/164	177/138	159/118	143/101	130/83	118/69	108/58	99/49	92/41	85/35	79/30	73/26	—	—
1	ED750	18	[illegible]	148/470	127/296	119/240	111/198	105/165	99/139	94/118	89/101	85/83	81/69	77/58	74/49	71/42	68/36	66/31	64/26	—	—
		16	[illegible]	[illegible]	199/390	185/317	174/261	164/218	155/183	146/156	139/134	132/110	125/91	114/76	105/64	97/55	89/47	83/40	77/35	67/26	—
		14	[illegible]	350/500	300/487	280/396	262/326	247/272	233/229	213/195	192/167	174/137	159/114	145/95	133/81	123/68	114/58	105/50	98/43	85/33	75/25

If higher loads or longer spans are required, contact EPIC Metals Corporation.

NOTES: 1. Loads are based on ASD Design.
2. Uniform load values listed on the left side of the box, 100/75, are governed by stress and the values listed on the right side, 100/75, are governed by deflection.
3. The deflection criteria used for generating the tables above were L/240 or 1" maximum. The Engineer of Record shall calculate the allowable uniform load if a different deflection criteria is required.
4. Stress governed values assume a maximum allowable stress of 24 ksi.
5. Minimum end support bearing lengths are shown above. If shorter bearing lengths are used, check safe reaction table on page 36.

EPIC METALS CORPORATION

Metal Dek Group®
a unit of CSi®

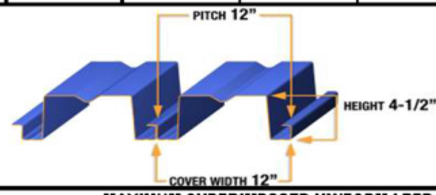
DEEP-DEK® 4.5 ROOF (LRFD)

4-1/2" high x 12" pitch x 12" wide

SECTION PROPERTIES fy = 40 ksi

GAGE	Wd	I_D (DEFLECTION)	Sp	Sn	Rbe 4"	Rbe 5"	Rbe 6"	Rbi 5"	Rbi [illegible]	Va
20	3.14	2.962	1.099	1.181	900	977	1046	1628	1732	2847
18	4.15	3.954	1.560	1.611	1515	1639	1752	2700	2864	6429
16	5.23	4.982	2.005	2.030	2322	2506	2673	4100	4339	10233
14	6.53	6.215	2.531	2.531	3487	3753	3994	6118	6458	14726

similar data to ED450



LRFD Loads used to perform analysis of existing ED450 deck

MAXIMUM SUPERIMPOSED UNIFORM LRFD LOADS, psf

LRFD DESIGN		SINGLE SPAN				DOUBLE SPAN				TRIPLE SPAN			
Span	Load Combinations	20	18	16	14	20	18	16	14	20	18	16	14
11'-0"	λ_DD+λ_LL (Strength)	160*	270*	400	400	122*	203*	309*	400*	139*	232*	352*	400*
	D+L (Deflection)	140	190	241	300	122	203	309	400	139	232	352	400
	L (Deflection)	96	130	164	204	122	203	309	400	139	232	309	385
12'-0"	λ_DD+λ_LL (Strength)	146*	247*	347	400	112*	186*	283*	400*	127*	212*	322*	400*
	D+L (Deflection)	107	146	184	230	112	186	283	400	127	212	322	400
	L (Deflection)	74	100	126	157	112	186	283	379	127	189	238	297
13'-0"	λ_DD+λ_LL (Strength)	135*	228*	294	372	103*	171*	261*	364*	117*	195*	297*	400*
	D+L (Deflection)	84	114	144	179	103	171	261	364	117	195	275	343
	L (Deflection)	58	79	99	124	103	171	239	298	111	148	187	233
14'-0"	λ_DD+λ_LL (Strength)	125*	197	253	319	95*	159*	242*	313*	109*	181*	275*	390*
	D+L (Deflection)	67	90	114	142	95	159	242	313	109	174	219	274
	L (Deflection)	46	63	79	99	95	152	191	239	89	119	150	187
15'-0"	λ_DD+λ_LL (Strength)	116*	171	220	277	89*	148*	217*	273*	101*	169*	257*	340*
	D+L (Deflection)	54	73	92	114	89	148	217	273	101	141	177	221
	L (Deflection)	38	51	65	81	89	123	156	194	72	97	122	152
16'-0"	λ_DD+λ_LL (Strength)	105	149	192	243	83*	138*	191*	239*	95*	158*	238*	299*
	D+L (Deflection)	44	59	75	93	83	138	187	233	86	115	145	181
	L (Deflection)	31	42	53	66	76	102	128	160	60	80	100	125
17'-0"	λ_DD+λ_LL (Strength)	93	132	170	214	78*	130*	169*	211*				
	D+L (Deflection)	36	49	61	77	78	123	155	193				
	L (Deflection)	26	35	44	55	64	85	107	133				
18'-0"	λ_DD+λ_LL (Strength)	82	117	151	190	73*	118*	150*	188*				
	D+L (Deflection)	30	40	51	63	73	103	130	162				
	L (Deflection)	22	30	37	47	54	71	90	112				
19'-0"	λ_DD+λ_LL (Strength)	73	104	134	170	66*	106*	134*	168*				
	D+L (Deflection)	25	34	42	53	65	87	110	137				
	L (Deflection)	19	25	32	40	46	61	77	95				
20'-0"	λ_DD+λ_LL (Strength)	66	94	121	152	60*	95*	121*	151*				
	D+L (Deflection)	21	28	36	44	55	74	93	116				
	L (Deflection)	16	22	27	34	39	52	66	82				
21'-0"	λ_DD+λ_LL (Strength)	59	85	109	138	54*	86*	109*	136*				
	D+L (Deflection)	17	22	28	35	45	60	76	94				
	L (Deflection)	14	19	24	29	34	45	57	71				
22'-0"	λ_DD+λ_LL (Strength)	54	77	99	125	48*	78*	99*	124*				
	D+L (Deflection)	13	18	23	28	37	49	62	77				
	L (Deflection)	12	16	20	26	29	39	49	62				
23'-0"	λ_DD+λ_LL (Strength)	49	70	90	113	44*	71*	90*	113*				
	D+L (Deflection)	11	14	18	23	30	41	51	64				
	L (Deflection)	10	14	18	22	26	34	43	54				
24'-0"	λ_DD+λ_LL (Strength)	45	64	82	103	40*	65*	82*	103*				
	D+L (Deflection)	8	11	14	18	25	34	42	53				
	L (Deflection)	8	11	14	18	23	30	38	47				

Span	Load Combinations	Value	
11'-0"	λ_DD+λ_LL (Strength)	160*	Max. superimposed factored LRFD dead + live load (psf) (governed by strength limitation
	D+L (Deflection)	140	Max. superimposed unfactored LRFD dead + live load (psf) (governed by deflection limitation)
	L (Deflection)	96	Max. superimposed unfactored LRFD live load (psf) (governed by deflection limitation

Vertical load span (center to center spacing)

- **Wd** Weight of deck (uncoated), psf
- **I_D** Moment of inertia for deflection per foot of deck width (in⁴)/ft
- **Sp** Section modulus for positive bending per foot of deck width, (in³)/ft
- **Sn** Section modulus for negative bending per foot of deck width, (in³)/ft
- **λ_D, λ_L** Load factors for D & L loads to be applied by Engineer in accordance with Building Codes.
- **Rbe** Allowable exterior web crippling value per foot of deck, pl
- **Rbi** Allowable interior web crippling value per foot of deck, plf
- **Va** Allowable shear value per foot of deck width, plf
- **D** Uniform dead load, psf
- **L** Uniform live load, psf

Notes:
1. Bending strength based on flexural stress limit of 38 ksi.
2. Loads marked with asterisk (*) are governed by moment & shear, interior (6" bearing) and exterior (4" bearing) reactions (web crippling) or moment & reactions.
3. Deflection based on maximum dead + live load deflection of L/240 or 1 in. and on maximum live load deflection of L/360 or 1 in.
4. An upper limit of 400 psf has been applied to the loads.
5. Deck length over 45'-0" require inquiry and special accommodations. Please contact the Metal-Dek Group® for further information.

The section properties table is based on 2001 AISI's North American Specification for the Design of Cold-Formed Steel Structural Members (2004 Supplement).

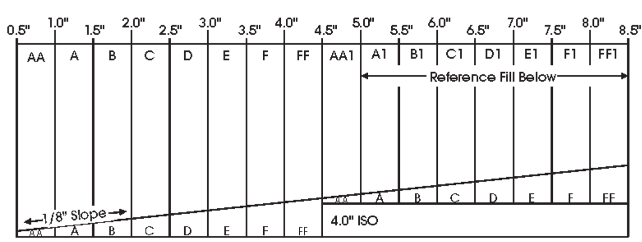
Acoustical profile is also available.

VERSICO ROOFING SYSTEMS

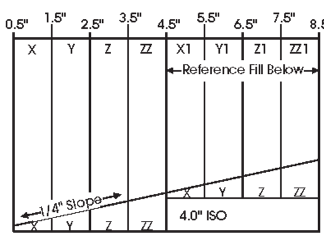
Tapered Loading Chart

TAPERED PANELS — 48" x 48"

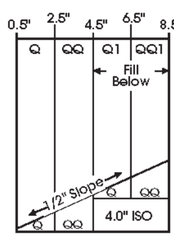
1/8" Slope



1/4" Slope



1/2" Slope



* Tapered panels are available for Versico's MP-H and SecurShield polyiso insulations.

SLOPE	BOARD STYLE	DIMENSIONS IN INCHES	BD FEET PER PANEL	PCS PER BUNDLE	SQ FT PER BUNDLE	WEIGHT PER SQ FT
1/8"	AA	.5" - 1"	12	64	1024	0.227
1/8"	A	1" - 1.5"	20	38	608	0.308
1/8"	B	1.5" - 2"	28	26	416	0.389
1/8"	C	2" - 2.5"	36	20	320	0.471
1/8"	D	2.5" - 3"	44	16	256	0.552
1/8"	E	3" - 3.5"	52	14	224	0.633
1/8"	F	3.5" - 4"	60	12	192	0.714
1/8"	FF	4" - 4.5"	68	10	160	0.747
1/4"	X	.5" - 1.5"	16	48	768	0.259
1/4"	Y	1.5" - 2.5"	32	24	384	0.422
1/4"	Z	2.5" - 3.5"	48	16	256	0.[illegible]84
1/4"	ZZ	3.5" - 4.5"	64	10	160	0.747
1/4"	G	1" - 2"	24	32	512	0.341
1/4"	H	2" - 3"	40	18	288	0.503
1/4"	I	3[illegible]	[illegible]	[illegible]	[illegible]	0.666
1/2"	Q	.5"[illegible]	[illegible]	[illegible]	[illegible]	0.341
1/2"	QQ	2.5[illegible]	[illegible]	[illegible]	[illegible]	0.666
1/2"	XX	1" - 3"	32	22	352	0.422
3/16"	JJ	.5" - 1.25"	14	50	800	0.243
3/16"	KK	1.25" - 2"	26	26	416	0.357
3/16"	LL	2" - 2.75"	38	18	288	0.487
3/16"	MM	2.75" - 3.5"	50	14	224	0.601
3/16"	J	1" - 1.75"	22	32	512	0.324
3/16"	K	1.75" - 2.5"	34	20	320	0.438
3/16"	L	2.5" - 3.25"	46	16	256	0.568
3/16"	M	3.25" - 4"	58	12	192	0.682
3/8"	SS	.5" - 2"	20	36	576	0.308
3/8"	TT	2" - 3.5"	44	16	256	0.552
3/8"	S	1" - 2.5"	28	24	384	0.389
1/16"	1	.5" - .75"	10	72	1152	0.195
1/16"	2	.75" - 1"	14	52	832	0.243
1/16"	3	1" - 1.25"	18	40	640	0.276
1/16"	4	1.25" - 1.5"	22	32	512	0.324
1/16"	5	1.5" - 1.75"	26	28	448	0.357
1/16"	6	1.75" - 2"	30	24	384	0.405
1/16"	7	2" - 2.25"	34	20	320	0.438
1/16"	8	2.25" - 2.5"	38	18	288	0.487

Used 0.500 in calculations
(10" = 5 psf)

VERSICO ROOFING SYSTEMS

A SINGLE SOURCE FOR SINGLE-PLY ROOFING

Versico, PO Box 1289, Carlisle, PA 17013
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HYDROTECH

GARDEN TRAY GT15® PRODUCT DATA SHEET

GENERAL DESCRIPTION

Garden Tray GT15 is made from recycled polyethylene molded into a three-dimensional tray. The unique design of the floor of the tray provides retention cups on the top side, drainage channels on top and bottom, and holes in the tops of the “domes” for ventilation and evaporation. Systemfilter™ filter fabric is laid in the bottom and the tray filled with growing media and plants.

BASIC USE

Garden Tray GT15 is specifically designed for use in a Hydrotech extensive Garden Roof® Assembly, but may be installed over other roof assemblies.

TECHNICAL DATA

DIMENSIONS:		18 in. X 22 in. (457 mm X 559 mm)
COVERAGE:		2.75 sq.ft. (0.3 sq.m.)
HEIGHT/DEPTH:		4 in. (101 mm)
WEIGHT:	empty	0.4 lb./sq.ft (2 kg./sq.m.)
	filled, wet	approx. 29 lb./sq.ft. (107 kg./sq.m.); approx 80 lb./tray

INSTALLATION

- Garden Tray GT15 is typically loose laid over IRMA Stone Filter Fabric laid over STYROFOAM® insulation. Contact Hydrotech for additional applications.
- Adjacent trays are typically butt together and may be mechanically fastened or clipped together if required.
- Garden Tray GT15 is delivered with the Systemfilter® and LiteTop® growing media in place.
- The vegetation for Garden Tray GT15 will be the InstaGreen® sedum carpet. The sedum carpet will be delivered separately and will have to be placed into each tray by the installing contractor. The InstaGreen sedum carpet is pre-cut to the size of the Garden Tray GT15.

American Hydrotech, Inc.
303 East Ohio Street, Chicago, IL 60611 * (312) 337-4998 * (312) 661-0731 fax * 01/12
www.hydrotechusa.com

SECTION 1605
LOAD COMBINATIONS

1605.1 General. Buildings and other structures and portions thereof shall be designed to resist:

1. The load combinations specified in Section 1605.2, 1605.3.1 or 1605.3.2,
2. The load combinations specified in Chapters 18 through 23, and
3. The load combinations with overstrength factor specified in Section 12.4.3.2 of ASCE 7 where required by Section 12.2.5.2, 12.3.3.3 or 12.10.2.1 of ASCE 7. With the simplified procedure of ASCE 7 Section 12.14, the load combinations with overstrength factor of Section 12.14.3.2 or ASCE 7 shall be used.

Applicable loads shall be considered, including both earthquake and wind, in accordance with the specified load combinations. Each load combination shall also be investigated with one or more of the variable loads set to zero.

Where the load combinations with overstrength factor in Section 12.4.3.2 of ASCE 7 apply, they shall be used as follows:

1. The basic combinations for strength design with overstrength factor in lieu of Equations 16-5 and 16-7 in Section 1605.2.1.
2. The basic combinations for *allowable stress design* with overstrength factor in lieu of Equations 16-12, 16-13 and 16-15 in Section 1605.3.1.
3. The basic combinations for *allowable stress design* with overstrength factor in lieu of Equations 16-20 and 16-21 in Section 1605.3.2.

1605.1.1 Stability. Regardless of which load combinations are used to design for strength, where overall structure stability (such as stability against overturning, sliding, or buoyancy) is being verified, use of the load combinations specified in Section 1605.2 or 1605.3 shall be permitted. Where the load combinations specified in Section 1605.2 are used, strength reduction factors applicable to soil resistance shall be provided by a *registered design professional*. The stability of retaining walls shall be verified in accordance with Section 1807.2.3.

1605.2 Load combinations using strength design or load and resistance factor design.

1605.2.1 Basic load combinations. Where strength design or *load and resistance factor design* is used, structures and portions thereof shall resist the most critical effects from the following combinations of factored loads:

$1.4(D+F)$ **(Equation 16-1)**

$1.2(D+F+T)+1.6(L+H)+0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-2)**

$1.2D+1.6(L_r \text{ or } S \text{ or } R)+(f_1L \text{ or } 0.8W)$ **(Equation 16-3)**

$1.2D+1.6W+f_1L+0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-4)**

$1.2D+1.0E+f_1L+f_2S$ **(Equation 16-5)**

$0.9D+1.6W+1.6H$ **(Equation 16-6)**

$0.9D+1.0E+1.6H$ **(Equation 16-7)**

where:

f_1 = 1 for floors in places of public assembly, for live loads in excess of 100 pounds per square foot (4.79 kN/m^2), and for parking garage live load, and

= 0.5 for other live loads.

f_2 = 0.7 for roof configurations (such as saw tooth) that do not shed snow off the structure, and

= 0.2 for other roof configurations.

Exception: Where other factored load combinations are specifically required by the provisions of this code, such combinations shall take precedence.

1605.2.2 Flood loads. Where flood loads, *Fa*' are to be considered in the design, the load combinations of Section 2.3.3 of ASCE 7 shall be used. I

1605.3 Load combinations using allowable stress design.

1605.3.1 Basic load combinations. Where *allowable stress design* (working stress design), as permitted by this code, is used, structures and portions thereof shall resist the most critical effects resulting from the following combinations of loads:

$D+F$ **(Equation 16-8)**

$D+H+F+L+T$ **(Equation 16-9)**

$D+H+F+(L_r \text{ or } S \text{ or } R)$ **(Equation 16-10)**

$D+H+F+0.75(L+T)+0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-11)**

$D+H+F+(W \text{ or } 0.7E)$ **(Equation 16-12)**

$D+H+F+0.75(W \text{ or } 0.7E)+0.75L+0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-13)**

$0.6D+W+H$ **(Equation 16-14)**

$0.6D+0.7E+H$ **(Equation 16-15)**

Exceptions:

1. Crane hook loads need not be combined with roof live load or with more than three-fourths of the snow load or one-half of the wind load.
2. Flat roof snow loads of 30 psf (1.44 kN/m^2) or less and roof live loads of 30 psf or less need not be combined with seismic loads. Where flat roof snow loads exceed 30 psf (1.44 kN/m^2), 20 percent shall be combined with seismic loads.

1605.3.1.1 Stress increases. Increases in allowable stresses specified in the appropriate material chapter or the referenced standards shall not be used with the load combinations of Section 1605.3.1, except that increases shall be permitted in accordance with Chapter 23.

1605.3.1.2 Flood loads. Where flood loads, *Fa*' are to be considered in design, the load combinations of Section 2.4.2 of ASCE 7 shall be used.

Appendix F: Metal Stud Allowable Load Tables

Interior Panels

ALLOWABLE COMBINED AXIAL & LATERAL LOADS (Kips/Stud)

Wind = 5psf			S162 (1-5/8" Flange)					S200 (2" Flange)					S250 (2-1/2" Flange)			
	Stud length (ft)	Spacing (in) o.c.	-33 (20ga) 33ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi	-33 (20ga) 33ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi
6" Stud		12	2.42 a	3.39 a	5.61 a	7.45 a	11.40 a	2.86 a	4.31 a	7.46 a	9.97 a	15.65 a	4.65 a	7.64 a	11.05 a	18.28 a
	8	16	2.37 a	3.35 a	5.57 a	7.41 a	11.36 a	2.81 a	4.26 a	7.41 a	9.92 a	15.60 a	4.60 a	7.59 a	11.00 a	18.22 a
		24	2.28 a	3.27 a	5.49 a	7.33 a	11.29 a	2.72 a	4.16 a	7.31 a	9.83 a	15.51 a	4.50 a	7.50 a	10.90 a	18.12 a
		12	2.38 a	3.36 a	5.57 a	7.41 a	11.36 a	2.80 a	4.23 a	7.31 a	9.79 a	15.39 a	4.57 a	7.51 a	10.85 a	17.92 a
	9	16	2.32 a	3.30 a	5.52 a	7.36 a	11.31 a	2.74 a	4.16 a	7.25 a	9.73 a	15.33 a	4.50 a	7.44 a	10.78 a	17.85 a
		24	2.20 a	3.19 a	5.42 a	7.26 a	11.22 a	2.62 a	4.03 a	7.12 a	9.61 a	15.20 a	4.37 a	7.32 a	10.64 a	17.72 a
		12	2.33 a	3.31 a	5.53 a	7.37 a	11.32 a	2.73 a	4.13 a	7.14 a	9.58 a	15.07 a	4.47 a	7.35 a	10.60 a	17.49 a
	10	16	2.25 a	3.24 a	5.46 a	7.30 a	11.26 a	2.65 a	4.05 a	7.05 a	9.50 a	14.99 a	4.39 a	7.27 a	10.52 a	17.41 a
	11	24	2.10 a	3.11 a	5.33 a	7.17 a	11.13 a	2.50 a	3.88 a	6.89 a	9.34 a	14.83 a	4.23 a	7.11 a	10.35 a	17.23 a
		12	2.17 a	3.15 a	5.35 a	7.25 a	11.20 a	2.55 a	3.88 a	6.67 a	9.00 a	14.21 a	4.24 a	6.94 a	10.00 a	16.41 a
	12	16	2.06 a	3.05 a	5.25 a	7.15 a	11.10 a	2.44 a	3.76 a	6.55 a	8.89 a	14.09 a	4.11 a	6.82 a	9.87 a	16.28 a
		24	1.85 a	2.85 a	5.05 a	6.95 a	10.89 a	2.22 a	3.52 a	6.31 a	8.66 a	13.85 a	3.88 a	6.59 a	9.62 a	16.02 a
		12	1.95 a	2.91 a	4.93 a	6.77 a	10.96 a	2.32 a	3.56 a	6.07 a	8.26 a	13.08 a	3.94 a	6.46 a	9.26 a	15.07 a
	14	16	1.81 a	2.78 a	4.80 a	6.63 a	10.80 a	2.17 a	3.40 a	5.91 a	8.10 a	12.91 a	3.77 a	6.29 a	9.08 a	14.88 a
		24	1.54 a	2.51 a	4.53 a	6.35 a	10.49 a	1.89 a	3.09 a	5.59 a	7.79 a	12.58 a	3.45 a	5.98 a	8.73 a	14.52 a
		12	1.71 a	2.62 a	4.41 a	6.10 a	9.89 a	2.05 a	3.18 a	5.38 a	7.38 a	11.74 a	3.59 a	5.96 a	8.44 a	13.53 a
	16	16	1.53 a	2.45 a	4.24 a	5.91 a	9.68 a	1.87 a	2.98 a	5.18 a	7.17 a	11.52 a	3.38 a	5.75 a	8.21 a	13.29 a
		24	1.20 b	2.12 a	3.91 a	5.57 a	9.28 a	1.52 a	2.61 a	4.79 a	6.79 a	11.09 a	2.98 a	5.34 a	7.76 a	12.82 a
8" Stud		12	2.39 a*	3.35 a	5.43 a	7.25 a	11.26 a	2.97 a*	4.47 a	7.74 a	10.29 a	15.98 a	4.89 a	8.17 a	11.80 a	19.77 a
	8	16	2.36 a*	3.32 a	5.40 a	7.22 a	11.24 a	2.93 a*	4.44 a	7.71 a	10.25 a	15.95 a	4.86 a	8.14 a	11.76 a	19.73 a
		24	2.29 a*	3.26 a	5.35 a	7.16 a	11.18 a	2.86 a*	4.36 a	7.64 a	10.19 a	15.89 a	4.78 a	8.06 a	11.69 a	19.66 a
		12	2.37 a*	3.33 a	5.41 a	7.22 a	11.24 a	2.94 a*	4.44 a	7.71 a	10.26 a	15.95 a	4.85 a	8.10 a	11.72 a	19.65 a
	9	16	2.32 a*	3.29 a	5.37 a	7.19 a	11.21 a	2.89 a*	4.39 a	7.67 a	10.21 a	15.91 a	4.80 a	8.06 a	11.68 a	19.60 a
		24	2.24 a*	3.21 a	5.30 a	7.12 a	11.14 a	2.80 a*	4.30 a	7.57 a	10.13 a	15.83 a	4.70 a	7.97 a	11.58 a	19.51 a
		12	2.33 a*	3.30 a	5.38 a	7.20 a	11.21 a	2.90 a*	4.41 a	7.68 a	10.22 a	15.92 a	4.79 a	8.02 a	11.63 a	19.51 a
	10	16	2.28 a*	3.25 a	5.34 a	7.15 a	11.17 a	2.85 a*	4.35 a	7.62 a	10.17 a	15.87 a	4.73 a	7.97 a	11.57 a	19.45 a
		24	2.18 a*	3.15 a	5.24 a	7.06 a	11.08 a	2.73 a*	4.23 a	7.50 a	10.06 a	15.77 a	4.61 a	7.85 a	11.45 a	19.33 a
		12	2.26 a*	3.22 a	5.31 a	7.13 a	11.15 a	2.82 a*	4.32 a	7.59 a	10.14 a	15.84 a	4.66 a	7.81 a	11.39 a	19.12 a
	12	16	2.18 a*	3.15 a	5.24 a	7.06 a	11.08 a	2.74 a*	4.23 a	7.50 a	10.06 a	15.76 a	4.57 a	7.73 a	11.29 a	19.03 a
		24	2.03 a*	3.00 a	5.11 a	6.93 a	10.95 a	2.57 a*	4.06 a	7.32 a	9.90 a	15.61 a	4.39 a	7.56 a	11.11 a	18.84 a
		12	2.17 a*	3.13 a	5.22 a	7.04 a	11.06 a	2.69 a*	4.16 a	7.36 a	9.96 a	15.73 a	4.48 a	7.52 a	10.99 a	18.47 a
	14	16	2.06 a*	3.03 a	5.13 a	6.95 a	10.96 a	2.58 a*	4.04 a	7.24 a	9.84 a	15.61 a	4.36 a	7.40 a	10.86 a	18.34 a
		24	1.85 a*	2.83 a	4.94 a	6.76 a	10.77 a	2.35 a*	3.80 a	6.99 a	9.61 a	15.38 a	4.12 a	7.17 a	10.60 a	18.08 a
		12	2.05 a*	3.02 a	5.11 a	6.93 a	10.94 a	2.52 a*	3.93 a	6.95 a	9.46 a	15.15 a	4.26 a	7.15 a	10.42 a	17.50 a
	16	16	1.92 a*	2.89 a	4.98 a	6.80 a	10.81 a	2.37 a*	3.77 a	6.78 a	9.30 a	15.00 a	4.10 a	6.99 a	10.25 a	17.32 a
		24	1.64 a*	2.62 a	4.72 a	6.54 a	10.54 a	2.09 a*	3.46 a	6.46 a	9.00 a	14.68 a	3.78 a	6.69 a	9.92 a	16.97 a

See page 26 for clarification of code developed wind pressures prior to using this table.

Notes:

1 For additional general notes, see page 40.
2 Allowable axial loads determined in accordance with section C5 of AISI S100-07, with section D4 used for treatment of punchouts, and assuming that all axial loads pass through centroid of effective section.
3 Allowable axial loads listed in kips (1 kip=1000 pounds).
4 Listed tables are based on simple (single)-span.
5 Studs are assumed to be adequately braced at a maximum spacing of Lu to develop full allowable moment, Ma.
6 Cells marked with an "a," "b," "c," "d," "e," or "f" meet L/720, L/600, L/480, L/360, L/240, or L/120 respectively. Blank cells do not meet L/120.
7 For deflection calculations, lateral loads are multiplied by 0.7 per the AISI S211-07 Standard for Cold-Formed Steel Framing—Wall Stud Design except for 5psf load which is considered interior wall load.
8 Cells marked with an " * " have h/t > 200, and thus require bearing stiffeners. Cells are left blank when h/t > 260.

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The technical content of this literature is effective 11/1/12 and supersedes all previous information.

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Exterior Panels

ALLOWABLE COMBINED AXIAL & LATERAL LOADS (Kips/Stud)

Wind = 25psf			S162 (1-5/8" Flange)					S200 (2" Flange)					S250 (2-1/2" Flange)			
	Stud length (ft)	Spacing (in) o.c.	-33 (20ga) 33ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi	-33 (20ga) 33ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi	-43 (18ga) 33ksi	-54 (16ga) 50ksi	-68 (14ga) 50ksi	-97 (12ga) 50ksi
6" Stud	8	12	1.87 a	2.89 a	5.14 a	6.99 a	10.95 a	2.29 a	3.71 a	6.86 a	9.41 a	15.09 a	4.04 a	7.06 a	10.43 a	17.65 a
		16	1.64 a	2.69 a	4.94 a	6.80 a	10.77 a	2.06 a	3.46 a	6.61 a	9.18 a	14.86 a	3.79 a	6.82 a	10.17 a	17.39 a
		24	1.21 a	2.28 a	4.56 a	6.43 a	10.40 a	1.60 a	2.98 a	6.12 a	8.72 a	14.40 a	3.29 a	6.35 a	9.65 a	16.88 a
	9	12	1.68 a	2.71 a	4.96 a	6.82 a	10.78 a	2.08 a	3.46 a	6.54 a	9.07 a	14.66 a	3.79 a	6.76 a	10.04 a	17.11 a
		16	1.40 a	2.45 a	4.71 a	6.57 a	10.54 a	1.79 a	3.15 a	6.23 a	8.78 a	14.36 a	3.47 a	6.46 a	9.71 a	16.78 a
		24	0.86 a	1.95 a	4.22 a	6.09 a	10.06 a	1.23 a	2.55 a	5.62 a	8.19 a	13.77 a	2.85 a	5.87 a	9.06 a	16.12 a
	10	12	1.46 a	2.51 a	4.75 a	6.61 a	10.57 a	1.84 a	3.18 a	6.17 a	8.67 a	14.14 a	3.51 a	6.42 a	9.59 a	16.47 a
		16	1.13 a	2.19 a	4.44 a	6.30 a	10.26 a	1.49 a	2.81 a	5.79 a	8.30 a	13.77 a	3.12 a	6.05 a	9.18 a	16.05 a
	11	24	0.48 a	1.58 a	3.84 a	5.71 a	9.66 a	0.82 a	2.08 a	5.05 a	7.59 a	13.03 a	2.38 a	5.32 a	8.39 a	15.24 a
	12	12	0.97 a	2.01 a	4.20 a	6.09 a	10.02 a	1.31 a	2.55 a	5.30 a	7.68 a	12.83 a	2.87 a	5.61 a	8.53 a	14.89 a
		16	0.53 b	1.58 a	3.77 a	5.64 a	9.55 a	0.85 a	2.04 a	4.78 a	7.17 a	12.29 a	2.34 a	5.09 a	7.95 a	14.29 a
		24	—	0.76 b	2.94 a	4.79 a	8.66 a	—	1.10 b	3.79 a	6.20 a	11.25 a	1.36 a	4.11 a	6.86 a	13.15 a
	14	12	0.45 c	1.44 a	3.44 a	5.21 a	9.22 a	0.76 b	1.86 a	4.31 a	6.51 a	11.20 a	2.16 a	4.69 a	7.30 a	13.00 a
		16	—	0.91 c	2.90 b	4.65 a	8.58 a	0.21 c	1.25 b	3.67 a	5.87 a	10.50 a	1.51 a	4.05 a	6.57 a	12.23 a
		24	—	—	1.92 d	3.60 c	7.39 a	—	0.15 d	2.52 c	4.70 b	9.21 a	0.34 c	2.86 b	5.24 a	10.80 a
	16	12	—	0.87 c	2.64 b	4.22 a	7.74 a	0.23 d	1.18 c	3.31 a	5.29 a	9.42 a	1.44 b	3.78 a	6.02 a	10.97 a
		16	—	0.29 d	2.04 d	3.57 c	6.99 a	—	0.50 d	2.61 c	4.57 b	8.61 a	0.71 c	3.03 b	5.18 a	10.08 a
		24	—	—	0.98 e	2.42 d	5.67 c	—	—	1.37 d	3.28 d	7.16 b	—	1.70 d	3.70 c	8.47 b
8" Stud	8	12	2.00 a*	2.98 a	5.09 a	6.92 a	10.94 a	2.55 a*	4.03 a	7.31 a	9.89 a	15.61 a	4.44 a	7.74 a	11.34 a	19.32 a
		16	1.84 a*	2.82 a	4.95 a	6.78 a	10.81 a	2.37 a*	3.85 a	7.14 a	9.73 a	15.45 a	4.25 a	7.56 a	11.15 a	19.14 a
		24	1.52 a*	2.52 a	4.67 a	6.51 a	10.54 a	2.03 a*	3.49 a	6.78 a	9.41 a	15.14 a	3.88 a	7.21 a	10.78 a	18.77 a
	9	12	1.87 a*	2.85 a	4.97 a	6.80 a	10.82 a	2.40 a*	3.88 a	7.16 a	9.75 a	15.47 a	4.27 a	7.55 a	11.14 a	19.08 a
		16	1.66 a*	2.65 a	4.79 a	6.62 a	10.65 a	2.18 a*	3.65 a	6.93 a	9.54 a	15.27 a	4.03 a	7.33 a	10.90 a	18.84 a
		24	1.26 a*	2.26 a	4.44 a	6.28 a	10.31 a	1.75 a*	3.20 a	6.48 a	9.13 a	14.87 a	3.56 a	6.87 a	10.41 a	18.36 a
	10	12	1.72 a*	2.70 a	4.84 a	6.67 a	10.69 a	2.24 a*	3.71 a	6.98 a	9.59 a	15.31 a	4.08 a	7.34 a	10.90 a	18.78 a
		16	1.47 a*	2.46 a	4.61 a	6.45 a	10.47 a	1.97 a*	3.42 a	6.70 a	9.33 a	15.06 a	3.78 a	7.05 a	10.59 a	18.48 a
		24	0.97 a*	1.98 a	4.17 a	6.01 a	10.04 a	1.43 a*	2.86 a	6.13 a	8.81 a	14.56 a	3.20 a	6.50 a	9.99 a	17.89 a
	12	12	1.37 a*	2.36 a	4.51 a	6.34 a	10.36 a	1.86 a*	3.30 a	6.55 a	9.19 a	14.91 a	3.62 a	6.81 a	10.30 a	18.03 a
		16	1.02 a*	2.01 a	4.18 a	6.02 a	10.04 a	1.48 a*	2.89 a	6.13 a	8.80 a	14.53 a	3.20 a	6.40 a	9.86 a	17.58 a
		24	0.33 a*	1.34 a	3.55 a	5.39 a	9.40 a	0.73 a*	2.10 a	5.32 a	8.04 a	13.78 a	2.39 a	5.61 a	8.99 a	16.70 a
	14	12	0.97 a*	1.96 a	4.11 a	5.93 a	9.94 a	1.40 a*	2.78 a	5.93 a	8.61 a	14.38 a	3.08 a	6.15 a	9.48 a	16.94 a
		16	0.51 a*	1.49 a	3.66 a	5.49 a	9.48 a	0.91 a*	2.24 a	5.37 a	8.08 a	13.84 a	2.53 a	5.61 a	8.89 a	16.32 a
		24	—	0.62 a	2.82 a	4.64 a	8.60 a	—	1.22 a	4.30 a	7.05 a	12.79 a	1.47 a	4.57 a	7.74 a	15.13 a
	16	12	0.53 a*	1.50 a	3.63 a	5.44 a	9.40 a	0.91 a*	2.18 a	5.12 a	7.71 a	13.34 a	2.47 a	5.39 a	8.48 a	15.48 a
		16	—	0.93 a	3.07 a	4.87 a	8.80 a	0.31 b*	1.53 a	4.44 a	7.04 a	12.64 a	1.79 a	4.71 a	7.73 a	14.69 a
		24	—	—	2.01 b	3.78 a	7.66 a	—	0.32 c	3.15 a	5.77 a	11.30 a	0.53 b	3.45 a	6.32 a	13.19 a

See page 26 for clarification of code developed wind pressures prior to using this table.

Notes:

1. For additional general notes, see page 40.
2. Allowable axial loads determined in accordance with section C5 of AISI S100-07, with section D4 used for treatment of punchouts, and assuming that all axial loads pass through centroid of effective section.
3. Allowable axial loads listed in kips (1 kip=1000 pounds).
4. Listed tables are based on simple (single)-span.
5. Studs are assumed to be adequately braced at a maximum spacing of Lu to develop full allowable moment, Ma.
6. Cells marked with an "a," "b," "c," "d," "e," or "f" meet L/720, L/600, L/480, L/360, L/240, or L/120 respectively. Blank cells do not meet L/120.
7. For deflection calculations, lateral loads are multiplied by 0.7 per the AISI S211-07 Standard for Cold-Formed Steel Framing—Wall Stud Design except for 5psf load which is considered interior wall load.
8. Cells marked with an " * " have h/t > 200, and thus require bearing stiffeners. Cells are left blank when h/t > 260.

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The technical content of this literature is effective 11/1/12 and supersedes all previous information.

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Appendix G: Acoustical Analysis Calculations & Reference Data

Grant, Elizabeth. "A Decision-Making Framework for Vegetated Roofing System Selection." Diss. Doctor of Philosophy in Architecture and Design Research, 2007. Web.

5.4.1.5. Excluded Parameters Affecting Category B

While the significant weight of intensive green roof systems obviously contributes to the thermal mass of the roof assembly, this parameter is not addressed separately. While it is intuitively clear, and has been demonstrated in several in-situ green roof tests, that deep growing medium has sufficient heat capacity to create a time lag effect reducing undesired temperature swings due to heat flow through the roof assembly, there is not currently a simple or convenient way to assign different value to green roof systems based on their thermal mass. Similarly, the conductive properties of green roof assemblies have been found by most researchers to be far less significant than the effects of evapotranspiration and solar shading, which are effectively accounted for using the "equivalent albedo" in the DOE Cool Roof Calculator.

It would also be ideal to include a measure of the embodied energy and environmental impact of different vegetated roof system types within the broad category of "Energy". However, such an analysis is beyond the scope of this investigation due to the great variability in origin, composition, and combination of green roof systems' constituent components. Lesser quantifiable still are their downstream effects, many of which are as yet unknown due to the relative newness of this technology, especially in North America. A placeholder for this future parameter is represented in the final influence diagram with the notation "B2 Embodied energy and environmental impact".

5.5. Category C: Acoustics

5.5.1. Parameter C1: Approximate Sound Transmission Class

5.5.1.1. Included Attributes and Design Variables

Roof system type

Sound transmission properties of roof structure.

5.5.1.2. Value Functions and Derivations

Since data determining the approximate sound transmission class (STC) of green roofs are nearly nonexistent, a proxy scale based loosely on the "mass law" (described in Section 3.3) is adopted. Because the mass law itself is theoretical, STC ratings are a useful tool for determining a rough estimate of sound transmission through a barrier. Stein and Reynolds (1992) define STC as follows,

> To avoid the shortcomings of averages [of sound transmission loss at a range of frequencies] and yet to benefit from the indisputable convenience of single-number

systems, a system of standard contours was developed, called sound transmission class (STC) contours. Actual test results for a given construction, measured in a series of sixteen 1/3 octave bands, are compared to the standard STC contours according to a fixed procedure, and the STC number for that barrier is derived.

STC ratings have not been developed for green roof systems. Virtually the only published findings on green roof acoustical performance are found in *Häuser Mit Grünem Pelz: Ein Handbuch Zur Hausbegrünung* by Minke and Witter (1983). They claimed that typically it is the sound absorptive capacity of the plant substrate and not of the plants themselves that determines sound absorption on green roofs. When sound waves strike the roof perpendicularly, only minor absorption of high-frequency sound by the plant layer occurs, while the soil layer reduces noise by about 40 dB when it is 4.8 inches (120 mm) thick and 46 dB when it is 8 inches (200 mm) thick. In the absence of more substantial data, it is useful to employ a proxy material to estimate the average sound attenuation achievable by vegetated roofs of various thicknesses. "Surface mass" is the relevant factor used to predict the acoustical behavior of building materials according to the mass law, defined by Stein and Reynolds for walls as "the weight of the wall per square foot of surface area" (1992, p. 1383).

Actual growing media density and other variables such as the nature of the vegetation and the characteristics of the filter, drainage and protective layers obviously have an effect on the surface mass of a green roof system taken as a whole. Since the growing medium is typically the heaviest component of green roof systems, the density of the system is, for the sake of simplicity, defined here as its weight divided by the thickness of the growing medium layer. To compare green roof systems of various thickness, the weight of green roof systems in pounds per square foot (kilograms per square meter) must be divided by their thickness to yield density in pounds per cubic foot (kilograms per cubic meter). Two materials with the same density and the same thickness will have the same mass for a given surface area.

Stein and Reynolds (1992) give STC values for lightweight hollow masonry block walls which align well along a logarithmic scale with the small number of acoustic values reported by Minke and Witter. Lightweight concrete block also has a similar "surface mass" to green roof media, based on the reported wet densities of the six case study projects investigated. These are shown in Table 5.3. Since the operation of the mass law is based on the "surface mass" of materials, a comparison of the density of green roof systems and of lightweight concrete blocks

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determines whether or not the STC ratings for lightweight concrete masonry units may be used as a proxy for the expected STC ratings of green roof systems.

Table 5.3 - Density of green roof media from case study green roof systems

Case Study Project	Saturated Weight of Green Roof System (psf)		Media Depth		Density	
	psf	kg/m^2	inches	mm	pcf	kg/m^3
Montgomery Park Business Center	18 (MDE, 2004b)	88	2.0 to 3.0[6]	50 to 75	108 to 72	1730 to 1200
Life Expression Chiropractic Center	28 (Miller, 2002)	140	5.0 (Miller, 2002)	130	67.2	1080
Chicago City Hall	30 to 90 (per project specifications)	150 to 440	3.0 to 18[7]	75 to 450	120 to 60	1900 to 960
Ford Dearborn Truck Assembly Plant	11 (Russell, 2004)	54	2.5 to 3.0 (Russell, 2004)	63 to 75	52.8 to 44	846 to 700
Mountain Equipment Cooperative (MEC)	38 (Johnson, 2003)	190	5.0 (Johnson, 2003)	130	91.2	1460
Jordan N. Carlos Middle School Art Building	35[5]	170	6.5[8]	160	64.6	1030

The densities in pounds per cubic foot for lightweight concrete masonry units (CMU) of various thickness are calculated from the weight of these blocks divided by their dimensions, as shown in Table 5.4. Weight data is taken from the Concrete and Masonry Databook (Beall & Jaffe, 2003, p.1.37). The actual, as opposed to nominal, outside dimensions of the blocks are used without subtracting the core spaces.

[6] (Stewart Comstock, personal communication, April 12, 2004)

[7] (Kevin Laberge, personal communication, July 16, 2004)

[8] (R. Alfred Vick, personal communication, September 23, 2004)

National Concrete Masonry Association, "Sound Transmission Class Ratings For Concrete Masonry Walls.". National Concrete Masonry Association, 2008. Web. 3 Mar 2014. <http://www.ncma.org/etek/Pages/Manualviewer.aspx?filename=TEK 13-01B.pdf>.

TRENWYTH

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SOUND TRANSMISSION CLASS RATINGS FOR CONCRETE MASONRY WALLS

TEK 13-1B
Sound (2008)

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INTRODUCTION

Unwanted noise can be a major distraction, whether in the school, work or home environment. Concrete masonry walls are often used for their ability to isolate and dissipate noise. Concrete masonry offers excellent noise control in two ways. First, masonry walls effectively block airborne sound transmission over a wide range of frequencies. Second, concrete masonry effectively absorbs noise, thereby diminishing noise intensity. Because of these abilities, concrete masonry has been used successfully in applications ranging from party walls to hotel separation walls, and even highway sound barriers.

Sound is caused by vibrations transmitted through air or other mediums, and is characterized by its frequency and intensity. Frequency is a measure of the number of vibrations or cycles per second. One cycle per second is defined as a hertz (Hz). Intensity is measured in decibels (dB), a relative logarithmic intensity scale. For each 20 dB increase in sound there is a corresponding tenfold increase in pressure.

This logarithmic scale is particularly appropriate for sound because the perception of sound by the human ear is also logarithmic. For example, a 10 dB sound level increase is perceived by the ear as a doubling of the loudness. The human ear can perceive sounds as low as 16 Hz to as high as 20,000 Hz, although it is most sensitive to sounds between 500 and 5,000 Hz. Human voices speaking in conversational tones have a frequency of approximately 500 Hz.

The speed of sound through a particular medium, such as a party wall, depends on both the density and stiffness of the medium. All solid materials have a natural frequency of vibration. If the natural frequency of a solid is at or near the frequency of the sound which strikes it, the solid will vibrate in sympathy with the sound, which will be regenerated on the opposite side. The effect is especially noticeable in walls or partitions that are light, thin or flexible. Conversely, the vibration is effectively stopped if the partition is heavy and rigid, as is the case with concrete masonry walls. In this case, the natural frequency of vibration is relatively low, so only sounds of low frequency will cause sympathetic vibration. Because of its mass (and resulting inertia) and rigidity, concrete masonry is especially effective at reducing the transmission of unwanted sound.

SOUND TRANSMISSION CLASS

Sound transmission class (STC) provides an estimate of the acoustic performance of a wall in certain common airborne sound insulation applications.

The STC of a wall is determined by comparing sound transmission loss (STL) values at various frequencies to a standard contour. STL is the decrease or attenuation in sound energy, in dB, of airborne sound as it passes through a wall. In general, the STL of a concrete masonry wall increases with increasing frequency of the sound.

To determine STC, a standard curve is superimposed over a plot of STL values obtained by test (Figure 1) and shifted upward or downward relative to the test curve until some of the measured transmission loss values fall below the standard STC contour and the following conditions are fulfilled:

1. the sum of the deficiencies (deviations below the standard contour) does not exceed 32 dB, and
2. the maximum deficiency at any single test point is not greater than 8 dB.

When the contour is adjusted to the highest value that meets the above criteria, the sound transmission class is taken as the transmission loss value read from the standard contour at the 500 Hz frequency line. For example, the STC for the data plotted in Figure 1 is 25.

Note that the STC rating was developed to be representative of STL at the frequency content of speech, which is important because at these frequencies, higher mass systems tend to perform better than lighter ones.

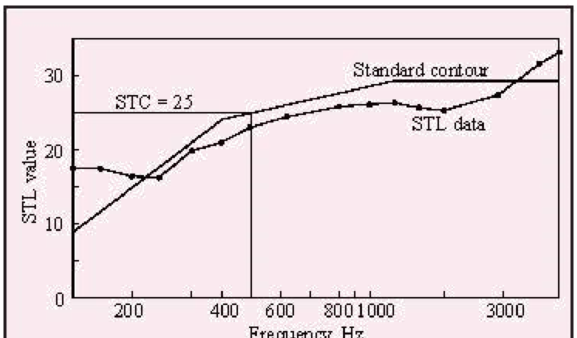

Figure 1—Determining STC: Standard Contour Fitted to Transmission Loss Data

Although STC is a convenient index of transmission loss, it may be necessary in some cases to study the sound transmission loss data at specific frequencies, such as when the main noise source is of one known frequency. In this case, the STL value at the frequency of interest is checked to ensure there is not a "hole," or low STL value, at that particular frequency.

DETERMINING STC FOR CONCRETE MASONRY

Many sound transmission loss tests have been performed on various concrete masonry walls. These tests have indicated a direct relationship between wall weight and the resulting sound transmission class—heavier concrete masonry walls have higher STC ratings. A wide variety of STC ratings is available with concrete masonry construction, depending on wall weight, wall construction and finishes.

In the absence of test data, standard calculation methods exist, although these tend to be conservative. *Standard Method for Determining the Sound Transmission Class Rating for Masonry Walls*, TMS 0302 (ref. 1), contains procedures for determining STC values of concrete masonry walls. According to the standard, STC can be determined by field or laboratory testing in accordance with standard test methods or by calculation. The calculation in TMS 0302 is based on a best-fit relationship between concrete masonry wall weight and STC based on a wide range of test results, as follows:

$$STC = 21.5W^{0.223} \quad \text{Eqn. 1}$$

$$[\text{SI: } STC = 15.1W^{0.223}]$$

where W = the average wall weight based on the weight of the masonry units; the weight of mortar, grout and loose fill material in voids within the wall; and the weight of surface treatments (excluding drywall) and other components of the wall, psf (kg/m^2)

Equation 1 is applicable to uncoated fine- or medium-textured concrete masonry and to coated coarse-textured concrete masonry. Because coarse-textured units may allow airborne sound to enter the wall, they require a surface treatment to seal at least one side of the wall. At least one coat of acrylic latex, alkyd or cement-based paint, or plaster are specifically called out in TMS 0302, although other coatings that effectively seal the surface are also acceptable. One example is a layer of drywall with sealed penetrations, as shown in Figure 4. Note that architectural concrete masonry units are also considered to be sealed for the purposes of using Equation 1.

Equation 1 also assumes the following:

1. walls have a thickness of 3 in. (76 mm) or greater,
2. hollow units are laid with face shell mortar bedding, with mortar joints the full thickness of the face shell,
3. solid units are fully mortar bedded, and
4. all holes, cracks and voids in the masonry that are intended to be filled with mortar are solidly filled with mortar.

Calculated values of STC based on Equation 1 are listed in Table 1.

Because the best-fit equation is based solely on wall weight, the calculation tends to underestimate the STC of masonry walls that incorporate dead air spaces, which contribute to sound attenuation. Figure 2 illustrates some examples and compares calculated STC ratings with those determined by test.

For multi-wythe walls where both wythes are concrete masonry, the weight of both wythes is used in Equation 1 to determine STC. For multi-wythe walls having both concrete masonry and clay brick wythes, however, a different procedure must be used, because concrete and clay masonry have different acoustical properties. In this case, Equation 2, representing a best-fit

Table 1—Calculated STC Ratings for Concrete Masonry Walls (ref. 1)

Nominal unit thickness, in. (mm)[b]	Density, pcf (kg/m^3)	STC[a] Hollow unit	Grout-filled unit	Sand-filled unit	Solid unit
4 (100)	85 (1,362)	43	46[c]	45	45
	95 (1,522)	44	46[c]	45	45
	105 (1,682)	44	46[c]	46	46
	115 (1,842)	44	47[c]	46	46
	125 (2,002)	45	47[c]	46	47
	135 (2,162)	45	47[c]	47	47
6 (150)	85 (1,362)	44	49	47	47
	95 (1,522)	44	50	48	48
	105 (1,682)	45	50	48	49
	115 (1,842)	45	51	49	50
	125 (2,002)	46	51	49	51
	135 (2,162)	46	52	50	51
8 (200)	85 (1,362)	45	53	50	50
	95 (1,522)	46	53	51	51
	105 (1,682)	46	54	51	52
	115 (1,842)	47	55	52	53
	125 (2,002)	47	55	52	54
	135 (2,162)	48	56	53	55
10 (250)	85 (1,362)	46	56	53	53
	95 (1,522)	47	57	53	54
	105 (1,682)	48	58	54	55
	115 (1,842)	48	58	55	57
	125 (2,002)	49	59	56	58
	135 (2,162)	50	60	56	59
12 (300)	85 (1,362)	47	60	55	55
	95 (1,522)	48	61	56	57
	105 (1,682)	49	62	57	59
	115 (1,842)	49	62	58	60
	125 (2,002)	50	63	59	62
	135 (2,162)	51	64	59	63

[a] Based on: grout density of 140 lb/ft^3 (2,243 kg/m^3); sand density of 90 lb/ft^3 (1,442 kg/m^3); unit percentage solid from mold manufacturer's literature for typical units (4-in. (100-mm) 73.8% solid, 6-in. (150-mm) 55.0% solid, 8-in. (200-mm) 53.0% solid, 10-in. (250-mm) 51.7% solid, 12-in. (300-mm) 48.7% solid). STC values for grout-filled and sand-filled units assume the fill materials completely occupy all voids in and around the units. STC values for solid units are based on all mortar joints solidly filled with mortar.

[b] Metric dimensions reflect equivalent metric unit sizes as opposed to direct SI conversions. Therefore, STC ratings of these hard metric units may be slightly different from the ratings listed here.

[c] Because of small core size and the resulting difficulty consolidating grout, these units are rarely grouted.

EPDM Roof		
Frequency (Hz)	TL (dB)	τ
125	25	0.00316
160	28	0.00158
200	31	0.00079
250	34	0.00040
315	37	0.00020
400	40	0.00010
500	41	0.00008
630	42	0.00006
800	43	0.00005
1000	44	0.00004
1250	45	0.00003
1600	45	0.00003
2000	45	0.00003
2500	45	0.00003
3150	45	0.00003
4000	45	0.00003
STC =	41	

Green Roof		
Frequency (Hz)	TL (dB)	τ
125	32	0.00063
160	32	0.00032
200	38	0.00016
250	41	0.00008
315	44	0.00004
400	47	0.00002
500	48	0.00001
630	49	0.00001
800	50	0.00001
1000	51	0.00001
1250	52	0.00001
1600	52	0.00001
2000	52	0.00001
2500	52	0.00001
3150	52	0.00001
4000	52	0.00001
STC =	48	

Complete Roof System				
Frequency (Hz)	EPMD τ	Green Roof τ	τ_{eff}	TL
125	0.00316	0.00063	0.00175	28
160	0.00158	0.00032	0.00088	31
200	0.00079	0.00016	0.00044	34
250	0.00040	0.00008	0.00022	37
315	0.00020	0.00004	0.00011	40
400	0.00010	0.00002	0.00006	43
500	0.00008	0.00002	0.00004	44
630	0.00006	0.00001	0.00003	45
800	0.00005	0.00001	0.00003	46
1000	0.00004	0.00001	0.00002	47
1250	0.00003	0.00001	0.00002	48
1600	0.00003	0.00001	0.00002	48
2000	0.00003	0.00001	0.00002	48
2500	0.00003	0.00001	0.00002	48
3150	0.00003	0.00001	0.00002	48
4000	0.00003	0.00001	0.00002	48

STC = 44

EPDM Area = 7500 SF | Green Roof Area = 9500 SF | Total = 17000 SF