The Sterling & Francine Clark Art Institute

Williamstown, MA.

Senior Thesis Final Report
Penn State AE Senior Capstone Project

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Dr. Rob Leicht
April 4, 2012

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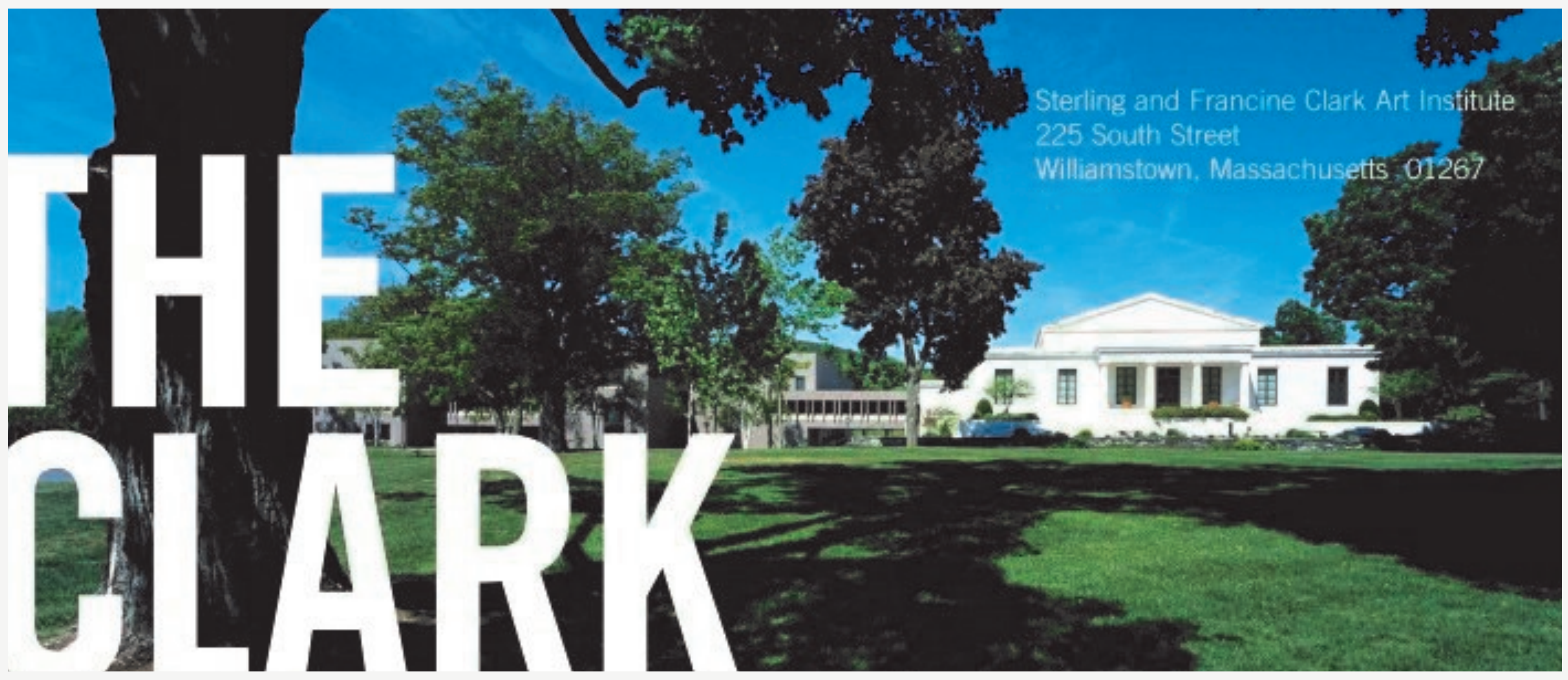

General Building Data

- Building name: Plant Sterling & Francine Clark Art Institute
- Location: Williamstown, MA
- Building Occupant Name: The Clark
- Occupancy: C-1, C-2 Art Museum
- Size: 78,800 feet squared
- Number of stories: First floor & Basement
- Construction Dates: June 2010 – October 2011
- Deliver Method and Cost information: GMP, Confidential

Architecture

The First floor of the Clark's new addition would be an open area with glass walls all over to allow light to enter the building except the south side which would be a concrete cast-in-place reinforced walls which would also extend to be the southern wall of the tunnel connecting the museum to the existing building. The stairs in the center of the first floor leads to the basement. The north extension of the building will hold the utilities such as the electrical room and mechanical rooms.

Structure

- Foundation: 2 way reinforced cast in place (CIP) flat slab, mat slab, and concrete CIP walls.
- Columns: 18" x 18" concrete cast in place.
- Curtain Wall: glazed aluminum wall (low-e coated, triple insulating laminate glass). Preformed intumescent fireproofing will be used, and fluid applied membrane air barrier will be placed in between the concrete and rigid insulation..

Electrical

- Distributed as 3 Phase 480Y/277V via dry type 2000kVA transformer.
- Emergency generator: 1500KW/1875 KVA.
- Luminaires Used: 120 V for CFL and T4's —- 277V for T8, MH, LED lighting and Par 38.

Mechanical

- 2 main Hot Water Boilers supplying heat @ 150 HP to supply a NET MBH of 5021 per boiler.
- 6 heat exchanger units.
- 2 main chillers: Capacity: 290 Tons, 696 GPM

Sustainable

- The Sterling and Francine Clark Art Institute is committed to build a sustainable building to line up with the surrounding environment. It is built with recycled, regional, and even some renewable materials.
- The Building is aiming a LEED® SILVER Certification.

CPEP Web Address:
http://www.engr.psu.edu/ae/thesis/portfolios/2012/MSA5097/index.html

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1.0 Executive Summary

Senior Thesis Final Report is to discuss and provide a comprehensive background and four solutions or enhancements to construction issues about the Sterling and Francine Clark Art Institute through analyzing of schedules, different types of estimates, investigations, and evaluations. The project is adding a new extension to accommodate the new needs. The new addition serves as an exhibition, conference and visitor center, and a new plant where the new addition's equipment such as Heating/Ventilation/Air-Conditioning (HVAC) and electrical units will be placed and to accommodate some of the existing museum mechanical needs.

Analysis 1: Implementation of MEP Prefabrication

The Mechanical/Electrical/Plumbing (MEP) systems that are embedded in the 2 ½' thick mat slab is the main construction issue. Many conflicts were spotted before construction which called the need to build a 3D model to better coordinate the embedded system. The analysis was performed on the plumbing system utilizing the 3D model and achieved the following findings: 3.5 days saved from the project's critical path, and a net savings of $57,771.

Analysis 2: Building Information Modeling – Virtual Mockup

The successful use of building information modeling (BIM) in 3D Coordination on the project is a proof of how BIM is beneficial to construction projects. The project team at the Sterling and Francine Clark Art Institute has efficiently utilized only 3D coordination BIM use. The goal of this analysis is to explore and suggest more applicable BIM uses as they are project specific. The virtual mockup analysis presents different benefits and limitations of the application from different standpoints. The analysis resulted in increasing the efficiency of the project as well as aiding future modifications to the building. It will cost $240 to build the model built for this analysis after labor hours' savings.

Analysis 3: Precast Roof Planks

With the irregularity in the shape of the Sterling and Francine Clark Art Institute, pouring concrete in corners can be tedious and challenging. The precast units can ease the construction process by having the ultimate unite size with exception of corner units to reduce joints and onsite resizing. The goal of using the precast units is to increase productivity and constructability of the building. With the great advantages the analysis will represent, such as 18 days of savings of the project critical path and $47,601 of net savings, it is not recommended to go with this analysis due to the building nature and location. The analysis will study the structural impact (structural breadth) by the new system.

Analysis 4: Solar Photovoltaic (PV) Panels

Being a green building is not implicitly means obtaining LEED certifications or having lower carbon footprint. It can also mean more energy cost savings with reasonable payback and less dependency on electric generators. The PV panels are to assist in electricity generation to power the high energy consumption of the art institute. The analysis will study the electrical production (electrical breadth) by the new system. The system cost is $227,646 after incentives and rebates and the payback period calculated to be six years. However, in the course of 25 years, the owner will end up saving $544,520.

2.0 Acknowledgements

In this chapter of the report, I would like to thank every individual who aided me, directly and indirectly, with all different means to accomplish this report and the entire five academic years at Penn State.

H. H. Sheikh Zayed Bin Sultan Al Nahyan & H. H. Sheikh Khalifa Bin Zayed Al Nahyan and The Scholarships Office for the generous full scholarship and all other facilitations provided.

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- Prof. Moses Ling
- Dr. Kevin Parfitt
- Dr. Robert Leicht
- Prof. Robert Holland
- Dr. David Riley
- Prof. Paul Bowers

Turner Construction – Robert Stewart, LEED AP
Joseph Rossetti, LEED AP

The Sterling & Francine Clark Art Institute

Last but not least, my beloved family and dear friends.

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3.0 Project Overview

3.1 Introduction

The Sterling and Francine Clark Art Institute project schedule is very straightforward as it can be seen in Appendix A. The construction process is broken down into phases following a specific sequence of construction with each representing a specific area of the new building being constructed. Initially, the Construction Drawings were published on 01/04/2011 were it was approved on 04/04/2011. After which the following steps were Approvals, Coordination, Fabrication and delivery until Excavation began on 09/27/2011. The building is intended to be completed by 09/03/2013 which is very close to a period of construction of 2 years.

3.2 Building Location

The Sterling and Francine Clark Art Institute new project is located in 225 South Street, Williamstown, MA 01267. The new addition is located near two existing buildings, the Manton and the Museum. More details about the building location and adjacent buildings will be discussed later in the report.

Figure 3-1: Aerial View of the Building
Image courtesy of Bing Maps

3.2.1 Existing Conditions

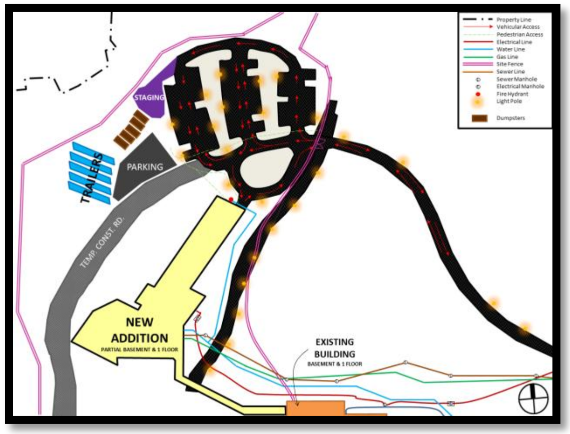


Figure 3-2: Existing Conditions Plan

Since this project is adding a new extension to accommodate the owner new needs, it will use some of the existing utilities and will have new ones as well. The existing buildings have to remain fully functional during all construction phases, including demolition, because of the museum nature that holds several galleries year around. Temporary parking will be made for construction. Also, there are roads that are either located nearby or on existing utility lines that require extra care not to affect them due to construction heavy loads. Otherwise, the site is not very congested and has a fair amount of space.

3.2.3 Site Layout Planning

As mentioned earlier, the site has a decent amount of space. There is new temporary parking beside the trailers. Dumpsters were placed near the northern side of the temporary parking and to the eastern side of the trailers whereas the staging area for the project is located at the eastern side of the dumpsters. The location of both dumpsters and the staging are chosen based on the ease of accessing them from the eastern side of the staging area where there is a vehicular access to them. A temporary construction was paved to facilitate access to trailers and different areas of the new building construction. Since the staging area is located inconveniently somewhat far, there will be a multiple smaller staging areas around the site as needed and the space permits that. That might be a little bit of waste of time and money due to moving material more than once. Overall, the site is well planned logistically.

Refer to Appendix C for 11x17 site plans.

3.3 Client Information

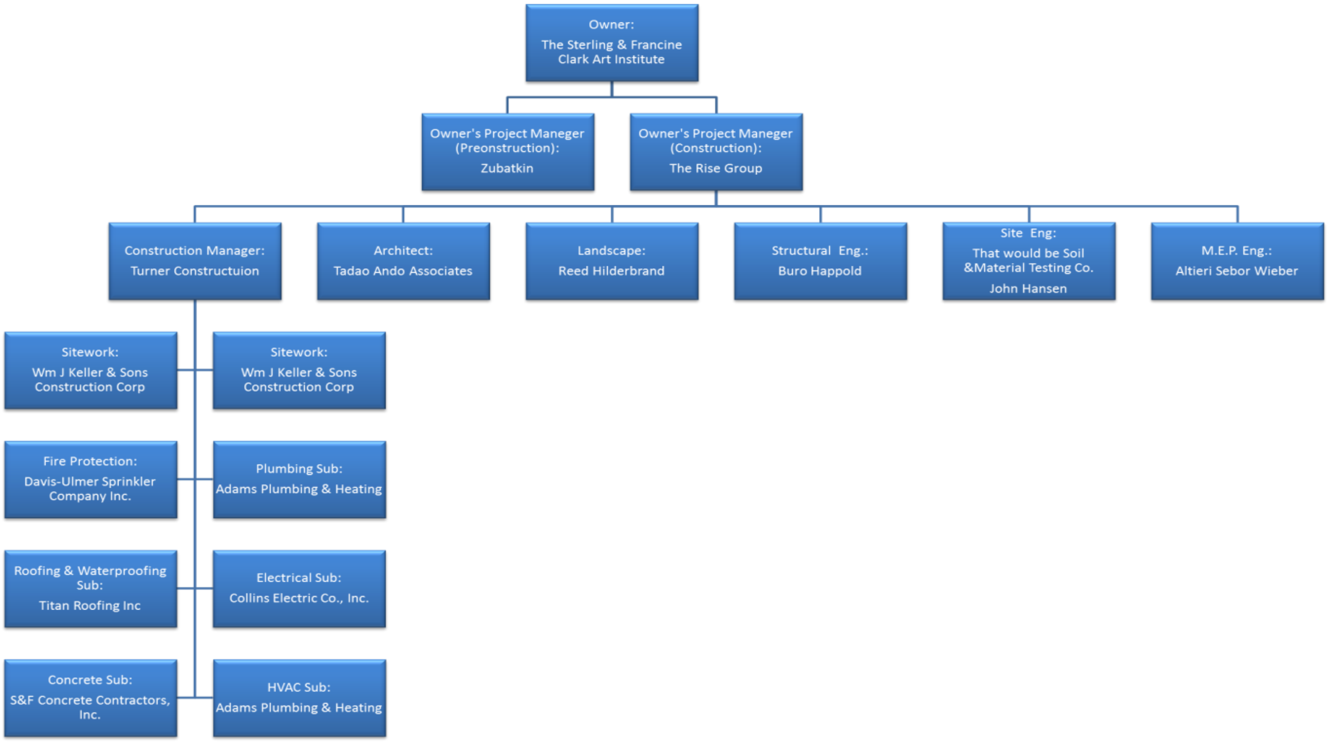
Sterling and his spouse, Francine, shared a passion of collecting art work. They founded the "Sterling and Francine Clark Art Institute which is an art museum and a center for research and higher education, dedicated to advancing and extending the public understanding of art."[(1)] The major reason was to protect their valuable art work such as paintings, sculpture, porcelain, drawings, and prints, they collected through the years. With time, the institute needed another extension for doing research work. A building was built on the 1970's. Nowadays, with current advancements in sciences and arts, a new building is essential. The new addition will mainly have an exhibition, conference, visitor center, and a new plant.

The new addition will reinforce the Clark's unique standing as one of the only major art museums in the world located in a dramatic rural setting. Also, the new galleries will present the special exhibitions programs highlighting the Clark's collection as well as works representing periods and cultures not currently shown. One of the new galleries is a space for American art and decorative arts. The improved visitor amenities, including a new shop and restaurant in the Exhibition, Visitor, and Conference Center, will support the institute's role as a public art museum. More space will be included for the library and its special collection of works on paper and public reading room. Moreover, expanded visitor amenities, including a full-service restaurant, café, museum shop, and family activity room will be accommodated. Last but not least, an auditorium and conference center will also be available to accommodate a wide range of museum and academic programs.

The Clark logo is courtesy of the Sterling and Francine Clark Art Institute website.

[(1)] "The Clark - Mission." *Sterling and Francine Clark Art Institute*. Web. 20 Sept. 2011. <http://www.clarkart.edu/about/content.cfm?ID=37>.

3.4 Project Delivery Method

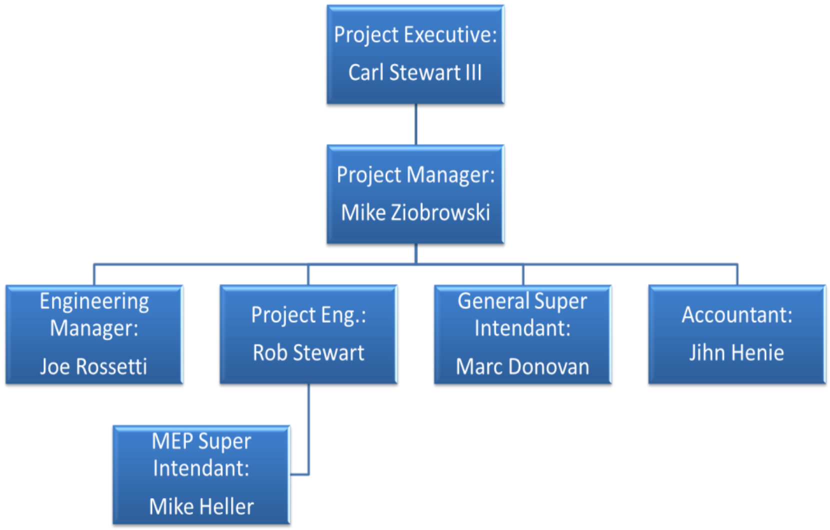


The project will be delivered through a Guaranteed Maximum price (GMP) where Turner construction would be the construction Manager at Risk for the project. Since the project involves world renowned architects where quality is a major concern, a lump sum would not have been a good idea and the only other economical best option would be a GMP.

The Sterling and Francine Clark Art Institute holds contracts with around 7 parties including Turner Construction Company. First and foremost is the famous Architect Tadao Ando who has designed this state of the art museum; and so, the most important factor to take into consideration is delivering a high quality facility. Hence, when it came to choose a General Contractor to deliver the project and bring the Architecture into reality, the requirements for a GC changed. Many companies came to bid for the project and Turner won the Bid for many reason including but is not limited to the fact that it is a worldwide trusted company that has delivered thousands of projects all over the world which speak for the architects that designed them and Turner company.

As for the other contractors and subcontractors, the bids are usually given to the best bid package which would still be under the supervision of Turner even though they have separate direct contracts with the Clark Art Institute. Turner's subcontractors are chosen in a similar way where Turner would create scopes of work in which eventually both Turner and the Sterling and Francine Clark Art Institute have to agree on the subcontractors that were chosen.

3.5 Staffing Plan



The Sterling and Francine Clark Art Institute project is managed by the order of major role players shown in the above chart. The project executive Carl Stewart III overseas the whole project, while the project manager Mike Ziobrowski handles the overall project tasks. The general superintendant Marc Donovman manages the day to day on site operations generally. There are also four main people in the team that supports solving the daily job problems such as the project engineer Rob Stewart.

4.0 Design and Construction Overview

4.1 Local Conditions

4.1.1 Preferred Methods

Williamstown, Massachusetts is a city of just 4,592 people, according to 2007 census, in Berkshire County north east of Massachusetts. Due to the temperate climate and very low seismic loads, the commonly preferred methods of construction in Williamstown, MA are reinforced concrete, which is the case in The Sterling and Francine Clark Institute, and steel.

4.1.2 Construction Parking, Waste, and Tipping Fees

The construction of the new addition will be adjacent to the north side of the current two buildings. The current parking lot will be temporary construction parking.

The building is achieving a Silver LEED certificate. With being said, many of the waste will be recycled. For instance, a removed on site marble will be used as a recycled crushed stone.

Dumpster, Tipping, and Recycling expenses are confidential.

4.1.3 Foundation Sequence

The foundation sequence began by installing 800 Feet Sheeting at a rate of 27 feet per day; After which, excavation of the 22,000 CY began 2 weeks after sheeting process started at a rate of 1500 CY per day to finish on 10/25/2011. Before the excavation process would be completed, the process of forming, reinforcing and placing of the concrete foundation walls would begin along with the rest of the foundation area. Installing Stone cladding, curing and waterproofing would follow to complete the foundation phase.

4.1.4 Structural Sequence

As soon as the foundation is installed completely, the process of installing the concrete structural walls begins with each phase/area starting depending on when its foundation was completed. Since the structure of the building is a cast in place concrete, the same process as the foundation would be taking place which is the FRP process, curing and waterproofing. Installation of the curtain wall, depending on the area if there was, would be done after installing the exterior walls and before installing the roof.

4.1.5 Finishing Sequence

The final stage after installing the structural roof would be the finishing phase. In this final phase Interior fit-out would begin by installing the overhead HVAC piping, Electrical, Sprinkler and finishes in that order. This sequence is the same in other areas of the building except of minor differences such as Rough-In Overhead Drainage, Mechanical/Electrical/Plumbing (MEP) piping, Ductwork, Electric, and then Sprinkler mains. Installing ceiling framing would follow with the MEP drops which would be following by closing ceiling and walls. Following that, Acoustic Plaster would be placed, walls ceiling would be painted following by the wood Flooring finishes.

4.2 Building Systems Summary

4.2.1 Demolition

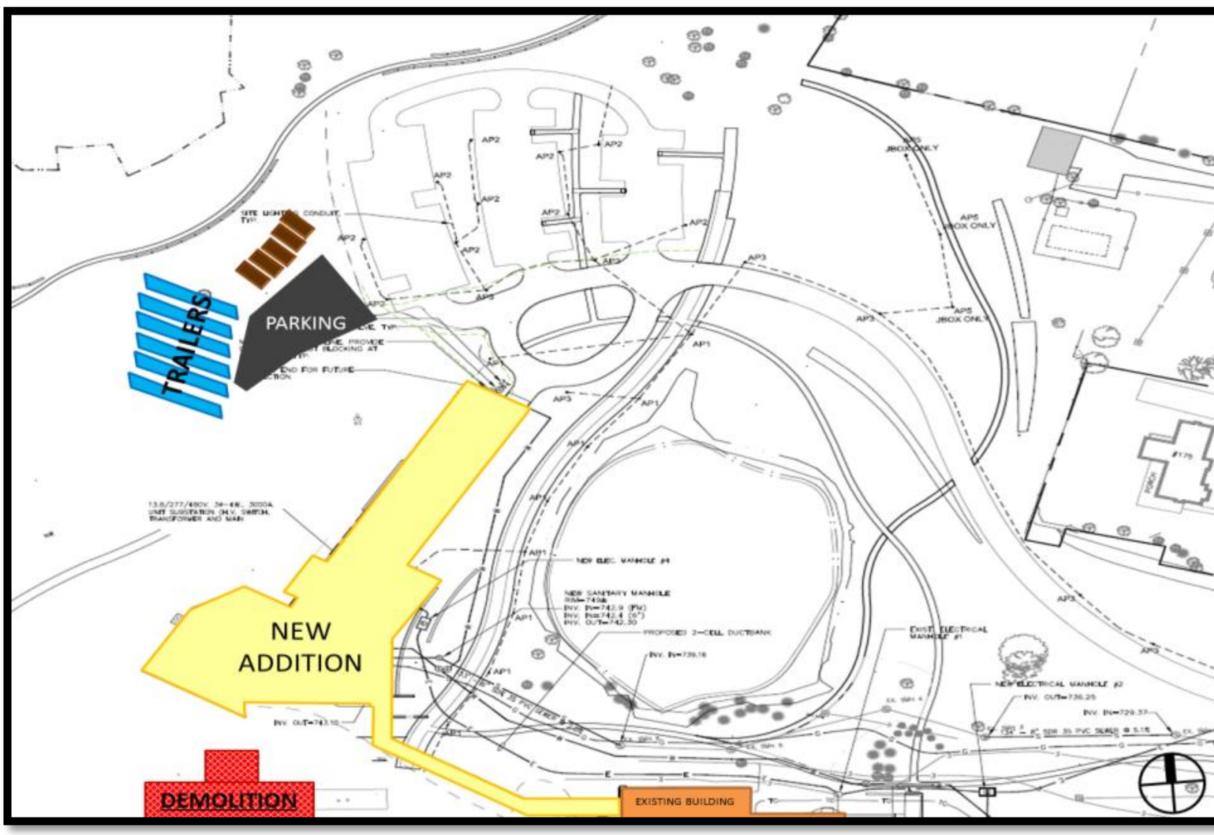


Figure 4-1: Demolition Plan

At the beginning of construction, there is some demolition. As shown in the figure 1, the are shaded in orange is a 2 story office building where the red shaded area is the existing plant which was demolished in order to make room for the new addition excavation and sheeting.

4.2.2 Structural System, Cast in Place Concrete

The foundation would be a 2 way reinforced cast in place flat slab with continuous mat slab which is top and bottom reinforcement. In addition, 18" x 18" concrete columns are all over the cast in place slab on grade (SOG) foundation which is holding the first floor. The first floor itself is also a 2 way reinforced slob on grade with concrete columns placed uniformly across the first floor. Concrete columns heights range from 57 feet to 12 feet depending on the location although most columns have a height of 17 feet. The SOG has thickness ranging from 2.5", which would be placed on a galvanized composite metal deck, up to 16" which is a two way slab. Strength of concrete SOG in this building should be 5000psi with the exception of the 2.5" SOG which would be 3000 psi. Concrete will mostly be pumped using a pump truck although some areas may require a standard crane and bucket method.

4.2.3 Mechanical System

The Mechanical system is located in the basement in the north side of the. The HVAC system will be using a fuel supply pump to operate the boiler and the generator. There are two main hot water boilers that supply heat to the Sterling and Francine Clark Art Institute each running at 150 HP to supply a NET MBH of 5021 per boiler. In addition, there will be 6 heat exchanger units, 3 located in the chiller room and the other 3 will be in the boiler room. As for the chilled water system, there will be 3 chillers; The 2 main chillers will have a capacity of 290 tons with a GPM of 696 supplying the Museum and the Manton (the existing building next to the new addition). The generator will be placed in the generator room in the plant part of the new addition on a concrete pad with a thickness of 24". There are a total of 8 sound attenuators for the mechanical equipment located in the Mechanical room.

4.2.4 Electrical System

The electrical room is also located in the basement in the north side along with the mechanical room. There are a large range of lighting fixtures that will be used throughout the museum. The voltages are 120 V for CFL and T4's while the voltage would be 277V for T8, MH, LED lighting and Par 38. The Sterling and Francine Clark Art Institute will be running on a 15KV feeder that branches of the main utility line. A dry type 2000kVA transformer will transform the electricity to produce a 3 phase (4 wire) 480/277V circuit. There is an emergency generator that can generate 1500KW/1875KVA

4.2.5 Curtain Wall

The Building is held up using CMU walls all around the southern wall all the way through until the Museum in addition to the concrete columns used throughout the floor. Hence, the northern part would use a curtain wall system through the use a glazed aluminum wall which would be composed of low-e coated, triple insulating laminate glass. Pre-formed intumescent fireproofing will be used, and fluid applied membrane air barrier will be placed in between the concrete and rigid insulation.

4.2.6 Support of Excavation

Shoring system is usually used until backfill is installed. This would support the excavation and keep it in place until the foundation phase begins, after which the shoring can be removed when the basement cast in place walls can support themselves towards the end of the project.

4.2.7 LEED Features and Certification

The Sterling and Francine Clark Art Institute is committed to build a sustainable building to line up with the surrounding environment. It is built with recycled, regional, and even some renewable materials. Also, low emitting materials was kept in mind while building this institute. What's more, The Clark made the construction waste management a priority in their plans. There are many efforts made to make the building as much sustainable as possible. For example, the materials were used in this building. For instance, marble claddings, at least 20% of the materials are post-consumer recycled content, regional materials, rapidly renewable materials such as bamboo, wool, cotton insulation, cork, etc. Regarding the low emitting materials, the adhesives, sealants and sealant primers that were used are in comply with the South Coast Air Quality Management District (SCAQMD) Rule #1168. Also, the aerosol adhesives comply with the Green Seal Standard for Commercial Adhesives GS-36.

With all the efforts made on the building, it is aiming to achieve LEED® Silver Certification.

4.3 Project Cost Evaluation

4.3.1 Project Cost

The following tables demonstrate different types of estimates and how they differ from the actual costs. A summary of cost estimate relative to square footage and major building systems costs will be demonstrated in the following two tables.

Table 4-1 : Gross Building Area by Floor	
Basement	37,525 SF
1st Floor	30,628 SF
TOTAL	68,153 SF

Table 4-2 : Cost Estimate		
Type of Cost	**Estimate**	
	Cost ($)	Cost/SF ($/SF)
Construction Cost (CC)	Confidential	Confidential
Total Cost (TC)	$28,000,000	$410

The total cost known is $28,000,000. The total calculated areas of the basement and the first floor are 68,153 ft^2. The construction cost was estimated based on the general range of 5-15% construction fees and 15% is what was considered. This is due to the confidentiality of the cost information per to the owner representative. The total cost is the only reported cost and was reported at the end of Spring 2011 semester and the Cost/SF was dertemind based on that.

4.3.2 Estimates

The estimates were calculated and developed using the online RS Means square foot estimate and assembly estimate tools. The estimates were built on the values as of the third quarter of 2011 RS Means release. Due to the unavailability of the exact matching of the Sterling and Francine Clark Art Institute, a vocational school was the best match to be chosen to develop the estimates. Also, adding a precise square footage for the basement in the online RS Means tools was not possible. So, the only left option was to include the basement and to add the basement square footage with the first floor to complete the calculation of the estimate. Finally, neither Williamstown, MA nor Berkshire County were available in the RS Means online tools. So, Pittsfield, which is the closest location to the project, was chosen.

Table 4-3: Estimate Summary

Stories	1 Floor, Basement
Perimeter	20319 LF
Story Height	1st Floor: 14'-8" FT, Basement: 22'-2 ½" FT
Floor Area	68,153 SF
Cost/SF	$192.75
Construction Cost	$13,136,500

Table 4-4 shows an assembly estimate of the Mechanical, Electrical, and Plumbing (MEP) systems in the building. The estimate was developed using the online RS Means tools as mentioned earlier. The estimates reflect only the major components of the mentioned building systems.

Table 4-4: MEP Assembly Estimate Summary

Mechanical	$2,213,575
Electrical	$1,358,474
Plumbing	$124,406
Total	$3,696,455

Table 4-5 is a comparison between the cost estimate developed using the online RS Means tools and the actual costs for the total construction cost (CC) and CC/SF.

Table 4-5: Estimate Summary vs. Actual

Estimate Type	RS Mean SF Estimate	Actual
Cost/SF	$192.75	Confidential
Construction Cost	$13,136,500	Confidential

Table 4-6 is a comparison between the cost estimate developed using the online RS Means tools and the actual costs for the Mechanical, Electrical, and Plumbing systems in the building.

Table 4-6: RS Means MEP Assembly Estimate vs. Actual

	Assembly Estimate	Actual
Mechanical	$2,213,575	Confidential
Electrical & Telecommunication	$1,358,474	Confidential
Plumbing	$124,406	Confidential
Total	$3,696,455	Confidential

The estimates produced thought the RS Means Square foot estimate and the RS Means Assembly estimate of the MEP system allows us to have an idea about what the cost of the a similar building or the cost of a specific system, as is in the case of the assembly estimate. But at the end of the day, they are just estimates that can never give us the exact cost but provide us with a close estimate.

In this case, the Actual cost was $28 million where the RS means Square Foot estimate was $13,136,500. It can be seen that the price from the RS mean is considerably lower than the actual and there are many reasons. First, the RSMeans does not include any special features of the building that may be costly, especially that the Sterling and Francine Clark Art Institute is a state of the art museum in addition to it being LEED certified. In addition, the RS mean does not account for the specific systems that would be used in the building (which is the purpose of the Assembly Estimate). Those 2 issues by themselves could cause a huge difference between the actual and the estimate cost. Finally, the RS means Square foot estimate is performed by selecting the characteristics of the building through a list which may or may not in many cases have the required characteristics in the list. In that sense, many assumptions have been made while estimating; for example, a museum was not listed as one of the options for the type of building being estimated. The closest to such museum was a school since it has many rooms and features where the closest building that would have all of the features would be a school.

As for the Assembly cost, it provided a closer estimate than the Square footage estimate and that is because it asks for more details about the system being estimated. However, the same obstacles showed up where the system being using the Sterling and Francine Clark Art Institute could not be found in the RS Mean Assembly book, and so, the closest system to what is actually being used was chosen to create estimate.

So even though the estimates did not provide an exact close answer, it did provide us with an idea about what the cost of such facility or system would be.

Refer to Appendix E for detailed estimates.

4.4 Detailed Project Schedule

The Sterling and Francine Clark Art Institute project schedule is very straightforward as it can be seen in Appendix D. The construction process is basically broken down into phases following a specific sequence of construction with each representing a specific area of the new building being constructed. Initially, the GMP documents were published on 01/04/2011 were it was approved on 04/04/2011. After which the following steps were Approvals, Coordination, Fabrication and delivery until Excavation began on 09/27/2011. The building is intended to be completed by 09/03/2013 which is very close to a period of construction of 2 years.

The construction schedule is broken down into two main sections initially: Preconstruction and Construction. The preconstruction phase includes procurement, shop drawings, MEP coordination, budget development, fabrication and delivery. The Construction process in the detailed project schedule is broken down by trade which is also broken down further by Area; this arrangement helps view the total sequential tasks that will take place within a specific area in the project. After the structural enclosure is completed, Interior fit out process takes place to install the rest of the systems such as HVAC, Mechanical Piping, Electrical and Fire protection.

Further, the order in which the tasks are performed within a specific area are constant throughout the project as it can be seen in Appendix D. The project is actually broken down into smaller section by area where each phase takes places in at least 4 parts and they are such in the following sequence: East Lower Lobby, MEP/ Reservoir, Display and East MER. Furthermore, the East MER area is broken down into a central section, East and West. The structure section includes the 4 main areas while the rest of the trades would have the East MER broken down into central, east and west since it does more time and is based on a set of tasks that would have their own detailed broken down sequence.

Refer to Appendix D for the detailed project schedules.

4.5 Detailed Structural System Estimate

The structural system for the new addition of the institute is mainly cast in place concrete. The foundation is a two-way reinforced cast in place flat slab with continuous mat top and bottom reinforcement. In this section of the report, a detailed structural system estimate using the RSMeams CostWorks online tool and the structural drawings provided is developed. The structural drawings were utilized to extract as much detailed information regarding the structural system of the project as possible. The RSMeams CostWorks online tool was used to create a detailed Unit Price Estimate of the system. Unfortunately, there are no actual cost data from the owner as they are classified.

The takeoff of the structural system was done by hand. That included total cubic yards of concrete, calculating total rebar poundage, formwork, etc. Table 4-7 will show a summary of the estimated costs for the concrete structural system of the building.

Table 4-7: summary of estimated costs for structural system

Sub System Type	Mat. O&P	Labor O&P	Equip. O&P	Total O&P
Concrete	$1,808,065	$552,008	$78,787	**$2,438,860**
Rebar	$408,093	$451,392	$0	**$859,485**
Forms & Shoring	$305,150	$857,625	$0	**$1,162,776**
Total	**$2,521,308**	**$1,861,025**	**$78,787**	**$4,461,120**

Due to the irregular shaped building, it was difficult to find a perfect typical bay for the project. As a result, the best match of a typical bay was selected for basement and first floor (Figure 4-2) structures and another bay for the roof structure.

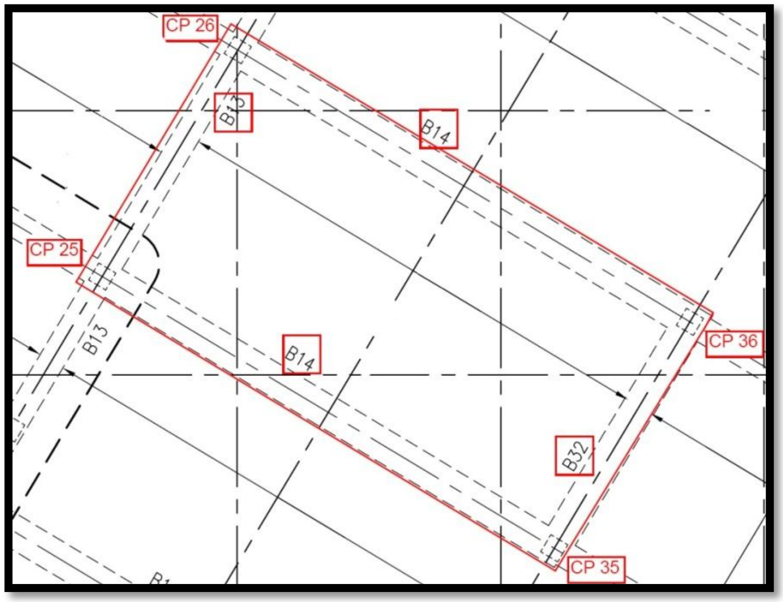


Figure 4-2: Typical bay used in developing the estimate

The following assumptions were made during calculating the detailed estimate:

1. Roof bay reinforcement sizes were accounted similar to the ones on the typical bay since they fall in the same rebar size estimation category. The RSMeans tool will group rebars from #3-#7 to calculate the estimate which will make no difference in final cost.
2. Wall heights were averaged due to the slight differences.
3. For the irregularity of the building shape:
    a. Square root of mat slab area was taken as if it is a regular square shaped building to make the rebar calculation of mat slab feasible (length of rebars and how it would be placed).
    b. The same concept of the previous point was applied in foundation wall rebar calculation.
    c. The average rebar length in beams and columns was taken to calculate total rebar weight for each since RSMeans tool will group rebars as mentioned earlier.

Refer to Appendix E for the detailed RSMeans CostWorks estimates.

4.6 General Conditions Estimate

The General Conditions (GC) estimate was broken into two categories. The first category is the Primary Personnel consists of Project Executive, Project Engineer, Project Manager, Superintendent, MEP Coordinator, and Project Accountant. The other category which is the Field Office Expense & Temporary Facilities which includes office trailers expenses, electric and water consumption expenses, monthly telephone expenses, furniture, office supplies and equipment, porta-johns, temporary storage trailers, tools, etc.

Table 4-8 summarizes the Project's GC based on the mentioned two categories above. Note that the cost of the GC developed doesn't reflect the actual dollar amount in the original contracts.

Table 4-8: General Conditions Summary

Item	Cost
Primary Personnel	$2,242,290
Field Office Expense & Temporary Facilities	$1,399,006
TOTAL GC COST	**$3,641,296**

From the Table 4-8, the Primary Personnel costs are about 61% of the total GC costs whereas the Field Office Expense & Temporary Facilities costs are about 38% of the total GC costs.

The total GC cost is about 13% of the total project cost of $28 million. This number was reached based on the best estimate could be made without information provided by the owner representative.

Refer to Appendix F for the detailed GC estimates tables.

4.7 LEED Evaluation

The Sterling and Francine Clark Art Institute is trying to build the new addition environmental friendly. So, they decided to get a LEED certification, and they are aiming for a Silver rating. The building has met all the requirements' prerequisites defined by the U.S. Green Building Council (USGBC) for the LEED certification. This analysis is to show what has been achieved or in the progress of achieving in terms of LEED requirements. The building has achieved the minimum Silver rating requirements according to the draft LEED-NC v2.2 Scorecard provided by the owner representative. However, it is still under the goal it is aiming for by nine points according to the most recent scorecard (LEED-NC 2009). The following bullet point will analyze the Sterling and Francine Clark Art Institute LEED draft scorecard. They will be broken down according to main categories of the scorecard where the sub-bullet points are broken down to the positive credits achieved and negative credits missed respectively.

- Sustainable Sites:
    - The Sterling and Francine Clark Art Institute is reducing pollution and land development impacts from automobile use. For instance, the building provides bicycle racks within 200 yards of the building entrance, shower and changing facilities in the building, and no new parking. The building also reduces pollution from storm water runoff and eliminating contaminants by implementing a storm water runoff management plan.
    - The Sterling and Francine Clark Art Institute did not have many options to choose where to build the new addition. As a result, they could not get the best building location, to avoid the development of inappropriate sites and reduce the environmental impact, according to LEED specifications. They did not reduce pressure on undeveloped lands by rehabilitating damaged sites (Brownfields). In terms of vehicular pollution, they did not meet the requirements for Alternative Transportation—Public Transportation Access to reduce pollution and land development impacts. Also, they did not reduce the input power of all nonemergency interior luminaires with a direct line of sight to any openings in the envelope neither shielded All openings in the envelope (translucent or transparent) with a direct line of sight to any nonemergency luminaires. That resulted in not meeting the requirements of light pollution reduction credits.
- Water Efficiency:
    - The new addition is maximizing water efficiency within the building. It is almost achieving the maximum possible points in this category. In terms of water efficient landscaping, the building eliminates the use of potable water for irrigation. Moreover, it reduces potable water use for building sewage by 50% through the use of the plumbing fixtures that hold water such as efficient water closets and urinals. With all the efforts combined, the building can save 30% of its total water usage.

- Energy Atmosphere:
    - The building is going in the direction of reducing the impacts associated with excessive energy use. It increases the levels of energy performance further than the energy atmosphere category prerequisites by 21%.
    - The institute is still working on the feasibility on applying most of the requirements of LEED in the Energy Atmosphere category while they applied only two of them. The lack of renewable energy used on site has affected the institute's LEED score negatively.
- Materials and Resources:
    - In terms of materials used in the building, a minimum of 10% of materials were either extracted or manufactured within the building region (within 500 miles radius). Furthermore, a construction and waste management plan is developed and implemented and a minimum of 50% of debris to be recycled.
    - Since the institute decided to demolish an existing building and not to use any of its structure, envelope, and framing as well as not using at least 5%, based on cost, of either salvaged, refurbished, or reused materials, not conserving resources, reducing waste, nor reducing environmental impacts of the new addition were results of that demolition.
- Indoor Environmental Quality:
    - An indoor air quality (IAQ) management plan was developed and implemented for the construction and before occupancy phases of the building. The goal is to reduce IAQ problems and increase construction workers and building occupants comfort. What's more, the use of paints and coatings which are odorous or harmful were minimized on the interior of the building to increase comfort as well as well-being of workers and future occupants. Another aspect is controllability of lighting systems. The flexible controllability of 90% gives the luxury to occupants to adjust lighting according to their needs to improve their productivity, comfort, and most importantly to decrease energy usage.
    - The new addition lacks the following LEED requirements of the indoor environmental quality. The outdoor air monitoring system is to help promoting occupant comfort and well-being. A permanent monitoring system has to be installed in the building to ensure that ventilation systems maintain design minimum requirements according to LEED requirements. Furthermore, LEED requires an improved IQA by ventilating spaces either mechanically (30% more than ASHRAE standards) or naturally (according to CIBSE Applications Manual 10: 2005) to promote occupant comfort and well-being as well. Minimizing and controlling the entry of pollutants into buildings and later cross-contamination of regularly occupied areas was not taken into consideration in the design. If that was implemented in the building design, the occupant exposure to potentially hazardous particulates and chemical pollutants would have been minimized. The

building also lacks thermal comfort according to LEED requirements. For example, to provide a comfortable thermal environment to promote occupant productivity and comfort the building has to provide at least 50% individual comfort controls to meet an individual needs and preferences. According to the nature of the building, lighting has to be highly controlled to serve galleries, for example, at best. So, the building lost the connection between indoor and outdoor spaces through the daylight and outdoor views into the regularly occupied areas of the building.

- Innovation and Design Process & Regional Priority Credits
    - The Sterling and Francine Clark Art Institute new addition gained all maximum possible points in those categories.

Refer to Appendix G for the LEED Scorecard.

4.8 Building Information Modeling Use Evaluation

The Building Information Model (BIM) consists of "*a digital representation of physical and functional characteristics of a facility*" according to the National Building Information Modeling Standard [(1)]. The key elements to have a successful BIM plan are to have a well-defined plan and to make sure that every team involved in a certain project knows their opportunities and responsibilities applied to them. According to the BIM Execution Planning Guide, "A completed BIM Project Execution Plan should define the appropriate uses for BIM on a project (e.g., design authoring, cost estimating, and design coordination), along with a detailed design and documentation of the process for executing BIM throughout a project's lifecycle."[(2)] For this Assignment, a less detailed BIM documentation will be provided. It will include a Level One Process Map and Goal Use Analysis (Goal Identification and BIM Use Analysis).

The Sterling & Francine Clark Art Institute didn't develop any BIM plans. So, the following BIM use suggestions were developed to show how the institute would have benefited from applying BIM on the new addition.

The first most beneficial BIM use is Asset Management. The asset Management is a process that can aid the maintenance and operation of the Art Museum and its assets and artifacts. The building asset can include the building itself, including its artifacts, and building systems and equipment. This process ensures maintaining, upgrading, and operating assets efficiently at appropriate costs that satisfy both the owner and tenants.

The second use is Engineering Analysis which is a process that manipulates certain tools for structural, lighting, energy, mechanical, and other types of building system analyses to improve the project design. Therefore, it can be applied to analyze the automated systems used in the project (Thermal Comfort and Lighting) to improve the project energy consumption and the quality of the building services.

The third use is Building Systems Analysis, a process that compares the actual building performance to the design specifications and it includes the building mechanical system and its energy use. Mainly, it ensures that building performance matches and maintains design standards. If not, the process will identify areas for improvements. This process can be a supplemental process to the Engineering Analysis and the Sustainability (LEED) Evaluation (next use) processes.

Fourth use of BIM is Sustainability (LEED) Evaluation which is a process that evaluates the project based on U.S. Green Building Council for LEED requirements. Applying this process can speed up design review time and LEED certification process and improve communication within project teams. As mentioned, the Building Systems Analysis can ensure that the building performance matches design specifications to continue maintaining LEED standards after building occupancy.

Fifth use of BIM is 3D Coordination which is an essential process that can detect any field conflicts may happen in the building during coordination process. By applying this process, it will be easier for the team to get a clearer image of the building and its systems as it is important for applying most of BIM processes as well. This process helps the team visualizing the construction, increase productivity by eliminating conflicts and comparing 3D models of building systems while decreasing construction time, and reducing construction costs.

The last suggest BIM use is Space Management and Tracking. It is a process that allocates, manages, and track assigned workspaces effectively. A 3D model is essential here where the specialized team will utilize it to manage future changes in the use of the space throughout the building's life. The owner is planning to transform one of new addition's spaces to a restaurant. Thus, the Space Management and Tracking process can assist in planning for implementing the future restaurant.

Refer to Appendix H for BIM Worksheets and Plans.

[1], [2] The Computer Integrated Construction Research Program at The Pennsylvania State University. *BIM Project Execution Planning Version 2.0*. Univevrsity Park: Computer Integrated Construction Research Program at The Pennsylvania State University, 2010. Print.

5.0 Analysis 1: Implementation of MEP Prefabrication

5.1 The Problem

The complex MEP system that is embedded in the 2 ½' thick mat slab is the main construction issue. The issue required the construction team to better coordinate the MEP layout in the slab. The team took the extra effort, time, and cost to generate a 3D model to avoid future field conflicts which would be challenging and expensive to resolve. That made more it critical to better coordinate what is in the mat slab. Also, since the project is delayed by almost a month, there were options considered by the team to make up time such as doubling shifts or working on Saturdays and Sundays. Another option, was not considered by the team, that can significantly accelerate the schedule is installing MEP prefabricated units.

5.2 The Goal

The goal of implementing the MEP prefabrication analysis is to catch up with the schedule. It is also to determine the cost and benefits of this implementation.

5.3 The Method

- Gathering the required information about the required performance of the MEP system.
- Gathering the required information on the MEP system to determine what will best serve the prefabrication implementation.
- Determining how the generated 3D model will be beneficial to the MEP prefabrication.
- Locating and choosing the best prefabrication facility in terms of value and not limited to distance or cost.
- Calculating time of transportation.
- Effect on logistics and equipment.
- Determining a typical area to research the cost and time differences and benefits between the new and the current systems.

5.4 Background Information

The nature of the Sterling and Francine Clark Art Institute new addition has shaped the building design. The building can, virtually, be divided into two parts. The northern side of the building is mainly a new plant feeding the new addition itself and one of the existing buildings. On the other hand, the southern part of their building is the new museum space, the VECC for Visitor, Exhibition, and Conference Center. The next figure (Figure 5-1) better illustrates what have been said.

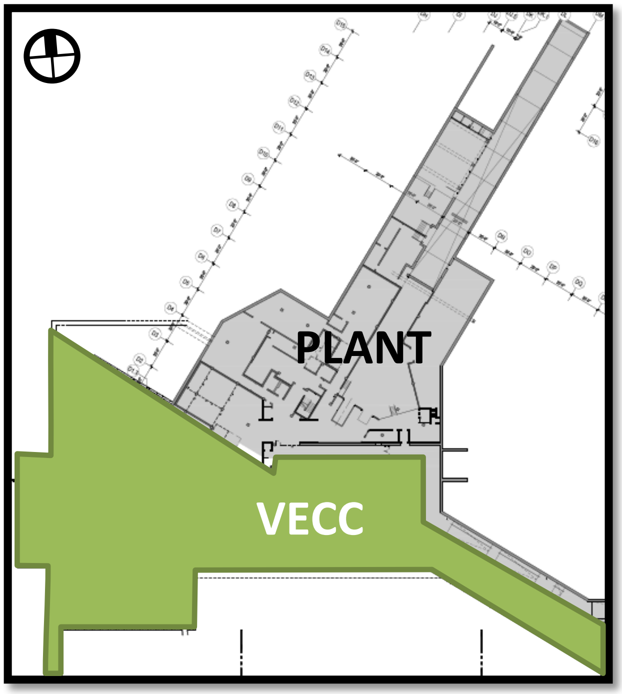


Figure 5-1: The Two Building Phases

The plant houses most of the mechanical equipment such as boilers, chillers, air handling units, and an emergency generator. As a result, there are intensive amount of piping and conduits embedded in the mat slab of the building. To better coordinate the mess resulted from the piping and conduits embedded, the project team decided to build a 3D model and run clash detection test on the model. Afterwards, they decided to take 3D model to be method of coordination the entire MEP of the entire building by elaborating the details in it to fit their needs. According to a conversation conducted with the project engineer, Robert Stewart, the 3D model has proven to be a powerful tool to coordinate the complex MEP system in advance prior field work and fix clashes on the 3D model which reduces onsite conflicts. As a result, the 3D model can reduce time, effort, and money.

The 3D model can be more utilized to increase efficiency, further reduction in time, effort, and money by using it to apply the idea of prefabrication. The MEP prefabrication process starts at the MEP shop taking same or a little less time to prefabricate a unit or a module. On the other hand, it produces a higher quality product, creates a safer environment for labors, lessens installation time, and many other advantages. The presence of the 3D eases the prefabrication process greatly (will more discussed later in the chapter). The analysis will discuss the prefabrication process of one of the embedded MEP systems in the mat slab more in detail in the rest of this chapter.

5.5 Analysis Summery

There are two MEP systems in the mat slab, electrical and plumbing. This analysis will discuss the application of prefabricating the plumbing pipes embedded in the mat slab of the Sterling and Francine Clark Art Institute new addition on the plant's section of the building. That area of the building is where most MEP complications occur. So, the best of prefabrication can be seized there. There are two main plumbing pipe types, black and grey water and they are 4", 6" and 8" in pipe sizes (the size of pipe taken by the length of its diameter). The time savings is per the following: shop prefabrication time is 15% less than field time, and 50% less installation time and 3.5 days of the critical path. The cost savings was determined to be $57,771from labor time savings. All costs in this report include overhead and profit. Costs from project team are not contractual costs; they reflect typical costs for the project. Some costs were obtained from RSMeans when costs can't be retrieved from the project team due to confidentiality.

5.6 The Prefabrication Process

There are essential steps that need to be followed carefully to perform this analysis successfully. Initially, the problem has to be examined closely. Then a particular system was chosen to be prefabricated. Afterwards, a quantity takeoff of the system component has to be conducted. Another important step is to examine the constraints and the limitations of the system and its location. Finally, coordination with other trades working at the same time in the same place.

5.6.1 The Problem & System Location and Selection

The system was selected mainly based on the location of where the problem occurs at most and gets complicated. The plant section of the building has very long plumbing runs with a pitch of 1/8" which is why this system was selected. As per to the structural engineer specifications, all embedded MEP's have to be with in the middle third of the mat slab (Figure5-2).

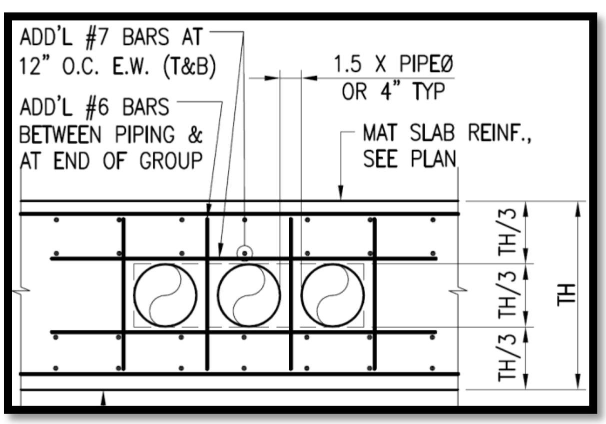


Figure 5-2: Embedded Piping Location in Mat Slab

The mat slab is 30"thick. So, the plumbing subcontractor has to keep the piping within the middle 10" of the slab. With the long runs that can exceed 100' long such as the highlighted 6" sanitary pipe in (Figure 5-3), they would be going more than 10” already. As a result, the mat slab has to be thickened and additionally reinforced wherever the pipes exceed the 10” which creates conflicts between different trades, increases time, and incorporates additional costs. That is why that particular location was selected.

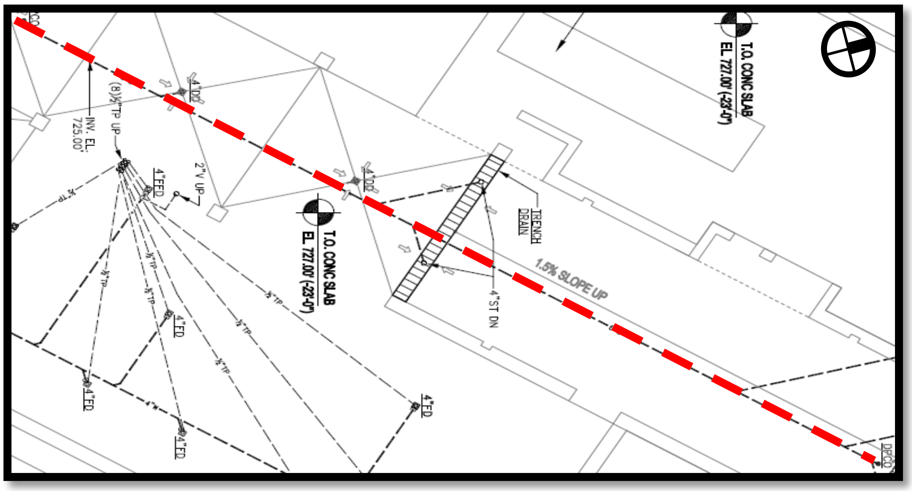


Figure (5-3): 96’ Pipe Run in the Plant

Defining the embedded systems in the slab is an essential step to proceed with the analysis. There are two MEP systems embedded in the mat slab, the cast iron plumbing piping and electrical conduits. For the sake of this report, the study will be conducted on the plumbing piping in the mat slab only. There are two plumbing piping types, grey water and black water. The piping starts from the north side (plan north) of the building plan, where the mechanical spaces are located, and branches out towards different section of the building (Figure 5-4).

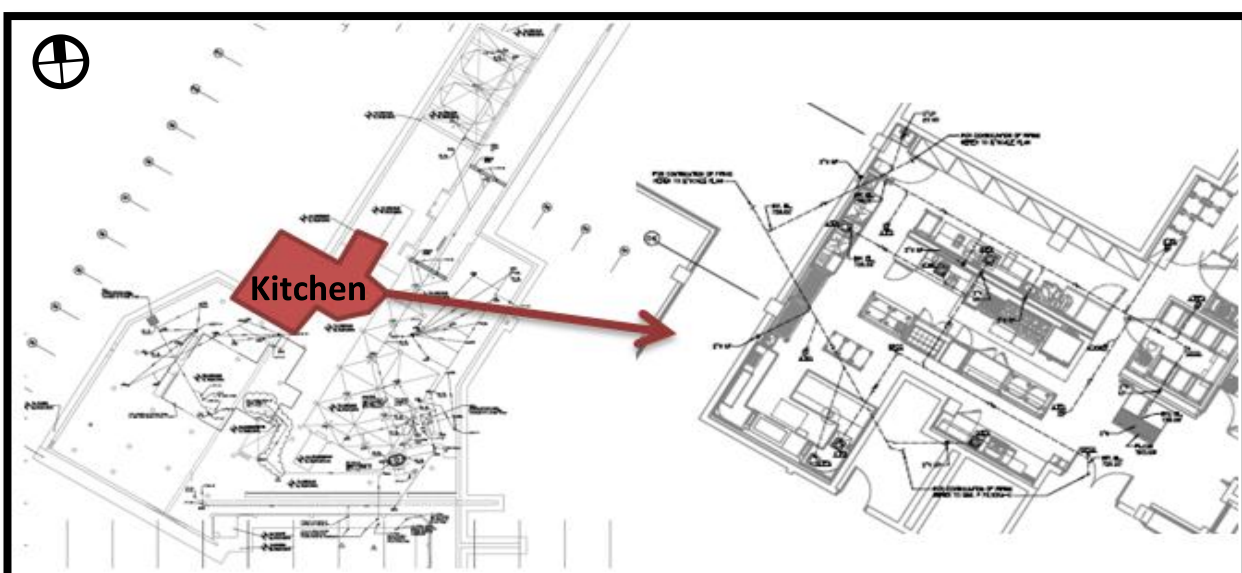


Figure 5-4: Plant Plumbing Plan

5.6.2Quantity Take-Off

After selecting the desired system to prefab, it is essential to know what exactly in the system. The importance of quantity takeoff is not only for economical purposes, it a step before determining how would the prefabricated units be sectioned or devided.

Table 5-1: Plumbing Piping Quantity Take-Off

Pipe size	Sanitary	Waste	Pipe total length	Cost/LF	Total Cost
4"	426.6'	437.12'	863.72	$0.59	$510
6"	194.57'	0'	194.57'	$1.45	$282
8"	106.47'	0'	106.47'	$4.74	$505

Table 5-1 shows a quantity take-off for the plumbing system in the slab. The prices were obtained from AB&I Foundry (www.abifoundry.com) since the project's costs are confidential.

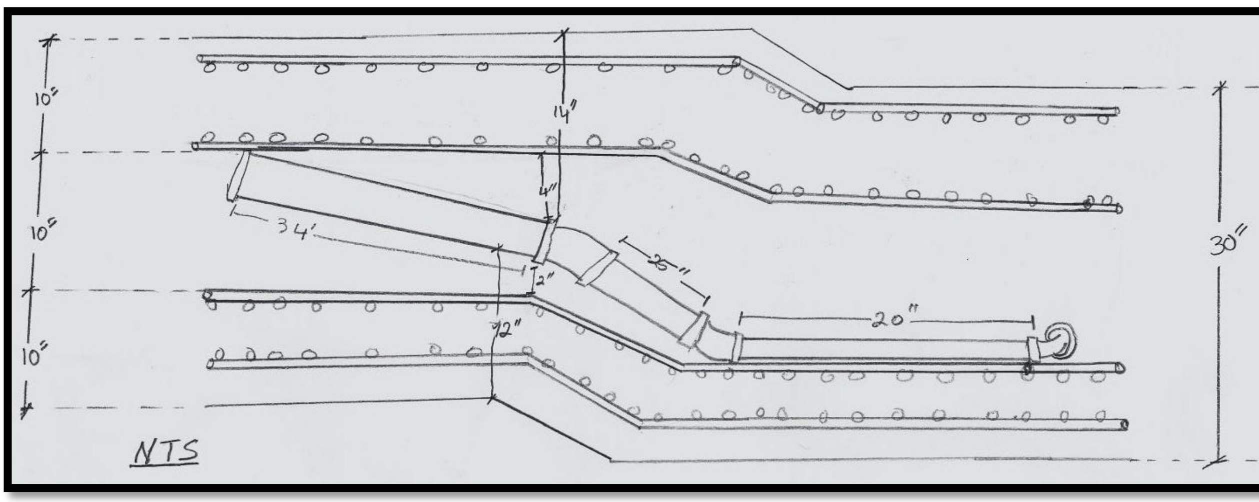


Figure 5-5: Hand Sketched 4" Pipe Location in the Mat Slab

The hand sketched figure (Figure 5-5) is showing the location of a pipe in the mat slab to express how complicated it is to lay, support, and fulfill the expected mechanical requirements with the structural constraints discussed earlier. To get the detailed location of the pipe, the 3D MEP model was utilized using Navisworks Manage to get the dimensions and the location of the pipe. There are many other hand sketches that helped in the process of quantity take off and defining the constraints and difficulties that can be faced in the mat slab during construction.

5.6.3 Prefabricated Units Size Constraints

The quantity takeoff helps in determining the size of each prefabricated unit. The prefabricated units of the sanitary pipes are driven by the capacity of fright transporting the units to site, in terms of size and weight, connections, and run sizes. The standard flatbed fright size that does not require special traffic permits is 48' long, 99" wide, 8'-6" max load height, and 46,000 lbs (Figure 5-6) as a maximum load weight which is a constraint in determining the size of a prefabricated unit.

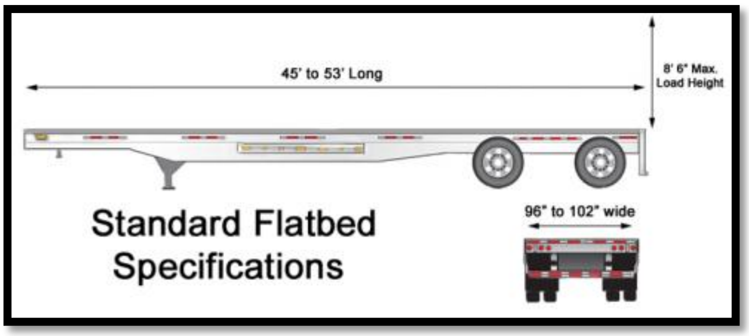


Figure (5-6): Standard Flatbed Specifications

The prefabricated units were divided based on the number of connection per segment. The number of connections were maximized by having the maximum number of joints possible that would fit on one truck (Figure 5-7) to increase efficiency and reduce the amount of labor work on site to better serve the prefabrication purposes.

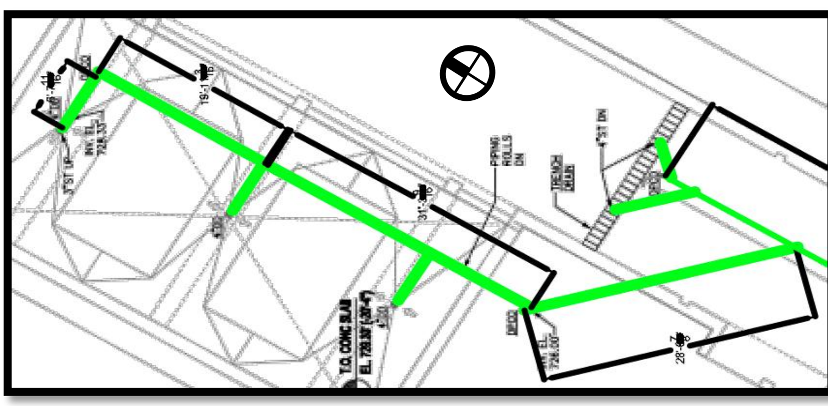


Figure 5-7 shows how the units were divided where each dimension line represents a single unit.

The average unit length is 34' (they range from 13' to 46'). If the truck rack's height is 25 ½", it will have four racks without violating traffic regulations. The weight of the units won't be an issue since the heaviest pipe is 16.5 plf which results in 56.1 lbs/unit on average. Having four racks in a truck, the heaviest it can get is 2,244 lbs while the weight capacity of the truck is 46,000 lbs. That implies that the main drive of unit size is the truck's flatbed size. So, the average number of units in a truck is four units resulting in seven deliveries on average. The placing method is not an issue in this scenario since it is going to be hoisted by a Manitowoc 1000 crawler crane which has a 250' of a reach and 100 USt. The crew size is relatively small. The reason is that each section of the building is divided into four areas. So, after finishing each area, the crew will move to the next area. It is assumed that there will be no conflicts in the way building divided in terms of where a unit might fall in between two different areas where concrete pouring time may differ and cause issues. The crew has one foreman and four fitters. In terms of crane and its crew, the crane is to be used on the site from August 2011 to October 2012 to aid in material relocation and to reduce congestion in the construction site. The MEP work starts on November 18, 2011 and finishes on April 13, 2012.

5.6.4 Prefabrication Shop

According to Joseph H. Rossetti, MEP BIM coordinator on site, it is the most convenient for the plumbing subcontractor to prefabricate the plumbing piping in his own shop. The shop is located about ten miles away. The subcontractor has prefabricated some complicated units earlier in shop for this project. The previous prefabrications turned out to be a very successful experience which is a good reason to go with this analysis. The advantages of prefabricating MEP's off site are numerous. The most beneficial advantage is having the system(s) being built in a controlled environment. That itself will lead to many other advantages such as having a better quality product with high accuracy, safer and easier for labors, assembly line efficiencies, and less waste which can help in getting more LEED points for a cleaner construction. Another advantage of shop prefabricating is that it is weather independent, which increases labor efficiency and eliminates any weather implications or delays that may happen on site and can be a potential catch up plan.

5.7 Site Challenges and Constraints

This particular site has its unique challenges. Mainly, the challenges arise from the thick mat slab and the fact that there is an intensive amount of reinforcement bars in the slab while the piping run in the middle of the 30" thick slab. Laying out piping so they come out of the slab at exact locations through the reinforcement bars for final fixture installation or other connections outside of the slab is a big challenge (Figure 5-5). Another challenge is placing piping in the proper zone within the 30" concrete slab without disrupting the reinforcement and firmly mounting and supporting the piping within the rebar prior to concrete placement so they don't move from their place during concrete placement. An added challenge to the list is achieving the proper drainage 1/8" pitch while doing the mentioned challenges.

The prefabrication of the piping can certainly overcome the mentioned challenges or at least will make them easier. Using the 3D model generated, precise locations can be determined and built on the shop. Also, the accuracy increases in the shop as it is a controlled environment as mentioned earlier. So, it is easier to get the units have the right pitch within the specified zone in the slab without disturbing the rebars above and below the piping and not violating specifications.

5.8 Site Coordination

5.8.1 Method and Placement Sequence

The current method of installing the entire MEP system is by piece building it on site as they go. Afterwards, they would install the built piece in its designated place. However, the prefabricated plumbing units arrive the site prebuilt, and just need to be hoisted in place.

Pipe supports will be up to the subcontractor to figure out under the 'means and methods' terms. The way the subcontractor is supporting the pipes is by iron angles welded on the mat slab's rebars, threaded bars, and brackets. The subcontractor has shown efficiency and success in supporting the pipes this way. "It is cheap and efficient" according to the project engineer, Robert Stewart.

Another costly, yet quicker, way to do it is by buying saddles with yolks. The saddles are height adjustable as well as the yolks. Also, the saddles will have adhesives on them to better support the pipes. According to grainger.com, one saddle support with yolk will cost $214.25 for 4" pipe, $221 for 6" pipe, and $246.25 for 8" pipe. Therefore, it is better to follow the subcontractor support method and the project engineer recommendation.

The project team has planned the sequence of placing the MEP system well. The prefabricated units will follow the same sequence of the original system. The sequence will be as the following steps:

- Mud mat preparation.
- Reinforce the bottom mat slab layer.
- Lay the prefabricated sanitary cast iron pipes.
- Support the pipes.
- Reinforce the top mat slab layer.
- Adjust supports to make tight enough so pipes don't move during concrete pouring.
- Pipe testing.
- Concrete pouring and curing.

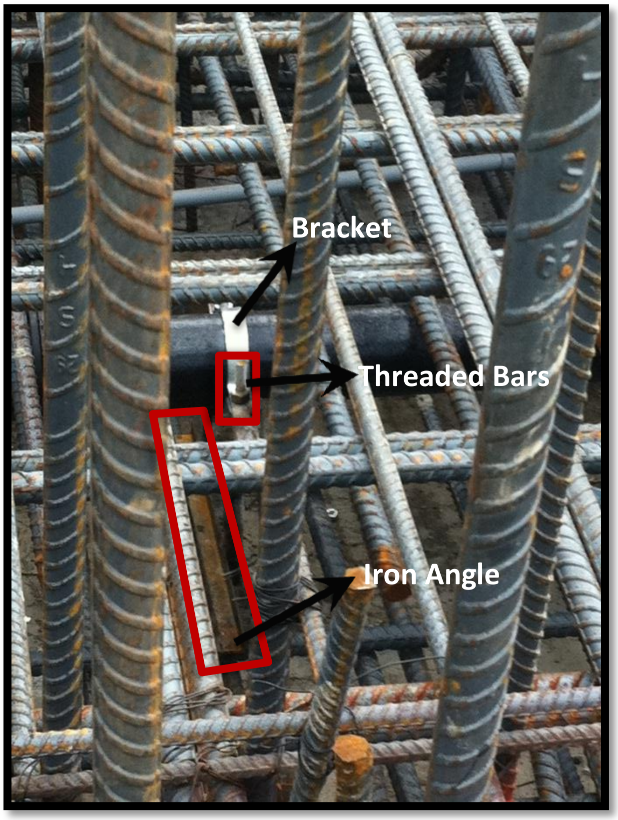


Figure 5-7: Sanitary Pipe in Place

5.8.2 Coordination with Other Trades and Logistics

The 3D model has made coordination easier. Utilizing the 3D model helped determining where the turns and twists of the piping are. It also helped determining where the piping will penetrate walls and slabs to be connected to fixtures or to other pipes. The 3D model took into account where the mat slab drops down and where it slopes upward which helps in transitioning the pipe heights and keeping proper pitch. With that being said, keeping the pipe in the right location whether it is penetrating walls and slabs or transitioning through uneven slab elevations helps in not affecting other trades. Other trades can be affected by dislocating pipes. For instance, pipe dislocation can affect the location of rebars and electrical conduits crossing either from above or below the plumbing pipes.

The site is not relatively tight to have multiple cranes at the same time. However, the amount of work is a lot in the basement level which calls the need to have cranes in the early stages. Other than the crane that will assist other trades materials relocation, there will be delivery trucks and a crane hoisting the prefabricated plumbing pipes from delivery trucks to place. Figure 5-8 is a snap shot of the logistics in one area. For more detailed logistics plan, refer to Appendix C.

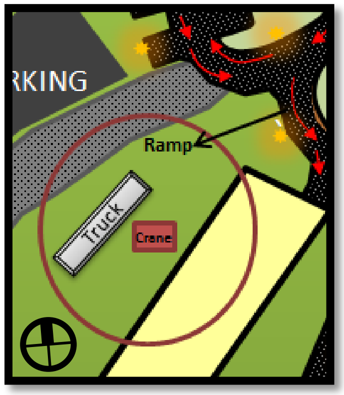


Figure 5-8: Plumbing Logistics in the North Area of the Building

5.9 Prefabrication Benefits

Prefabricating the plumbing system at the Sterling and Francine Clark Art Institute new project can have numerous benefits, some are tangible and others are intangible. While there might be an increase in the system cost to get it prefabricated, the benefits of prefabrication can justify the cost increase. Generally, the main goal of prefabricating a system is to save time which can have potential cost reduction. This section will discuss the tangible and intangible benefits and potential schedule and cost reduction with the application of prefabrication in the Sterling and Francine Clark Art Institute new addition.

5.9.1 Tangible and Intangible Benefits of Prefabrication

There are many advantages of prefabricating the plumbing piping in a prefabrication shop as discussed earlier in section 5.6.4. In a nut shell, prefabricating in an offsite shop is a convenient, better yet, safe way to fabricate piping for labors which help them produce better products. Also, the shop will be a controlled environment for labors to work in. That will result in increasing product quality, accuracy, and efficiency. Moreover, offsite shop help reducing waste and gaining more LEED points for a cleaner construction site. It also reduces congestion in the construction site. Most importantly, it eliminates the weather factor which reduces the risk of a delay due to weather and can be a potential time saving in winter time. Also, there will be no waiting time for empty laydowns/shake out areas so won't be affected by other trades needing the areas. Furthermore, indirect cost benefits can be found with prefabrication in reduced testing and inspection time on site as they are tested and inspected on the shop, reduced waste, reduced onsite supervision, and potential general conditions savings.

5.9.2 Schedule and Cost Benefits

With the numerous resources about MEP design, there were not enough resources found offering comprehensive lists of average schedule time to prefabricate the plumbing system chosen. To figure out as much close schedule as possible, RSMeans and project team were referred to as the main two references in this analysis.

According to Joseph Rossetti, it take a crew about 2.5 hours to lay 60 LF piece of pipe while it will only take half of the time to install a prefabricated piece of pipe of the same size. In addition, according to Robert Stewart, there is more time savings in terms of fabricating a pipe, the shop fabrication consumes 15% less time. The table on the top of next page (Table 5-2), compares the time it takes to prefabricate pipes onsite vs. offsite.

Table 5-2: Prefabrication Onsite Vs. Offsite Time Savings

Size	Length	Time To Build on Site	Time To Prefab in Shop	Time Savings	Percent Time Saving
4”	863.72 LF	15.7 Days	13.3 Days	2.4 Days	15%
6”	194.57 LF	2.7 Days	2.3 Days	0.4 Days	15%
8”	106.47 LF	1.8 Days	1.5 Days	0.3 Days	15%
Tot.	1164.76 LF	20.2 Days	17.1 Days	3 Days	15%

Table 5-2 shows the time it takes to build piping onsite and offsite and the time savings for offsite prefabricating.

From the table, it is apparent that there is a total of three days in time savings. The duration of the prefabrication were interpreted from RS Means Building Construction Data. The three days time savings can be considered as 3 days of crew cost savings. The crew consists of one foreman and four fitters saving $7,680 for the three days (crew costs from the project team).

Table 5-3: Prefabrication Schedule Savings

Activity	Original Schedule			Installation Time Savings	Percent Time Savings	Original Cost	Prefab. Cost
	Duration (Days)	Start	Finish				
Install In-Slab Plumbing Area 1	7	18-Nov-11	30-Nov-11	3.5 Days	50%	$17,920	$8,960
Install In-Slab Plumbing Area 2	7	20-Dec-11	29-Dec-11	3.5 Days	50%	$17,920	$8,960
Install In-Slab Plumbing Area 3	7	06-Dec-11	14-Dec-11	3.5 Days	50%	$17,920	$8,960
Install In-Slab Plumbing Area 4	7	05-Apr-12	13-Apr-12	3.5 Days	50%	$17,920	$8,960
Total	28 Days	18-Nov-11	13-Apr-12	14 Days	50%	Tot: $71,680	Tot: $35,840
Total Savings	N/A			3.5 Days	12.5%	N/A	50%

Table 5-3 is showing the cost benefits of employing the prefabrication analysis on the project.

Table 5-3 shows the schedule and time savings by applying the prefabrication to the project. The time the prefabrication saves is 14 days. However, the prefabrication saved 3.5 days of the total schedule since the first activity falls into the critical path of the project. The savings turned out to be $14,611 of the general conditions cost. Additionally, the installation time is cut in half. As a result, the cost of labor is reduced in half as well. That yields to $35,480 in labor cost savings. Accordingly, the total cost savings is $57,771.

5.10 Where Does It Fail?

Every system or method has its advantages and disadvantages. And the best way to test a system or a method is to test where the system or the method would fail. The first thing to come to mind is when all of the coordination of the prefabrication process will take place. Any prefabricated system needs to be well coordinated early in a project. The need for the greater coordination to prefabricate a system comes from site complications that may occur on the site at the time of installing the system. If that happened, the team would have to rework the prefabricated system once it arrives the site due to the miscalculations or inaccurate system specifications of the ordered system. Otherwise, all efficiencies discussed could easily be lost or, in fact, be more costly.

Also, this system fails wherever it is tight to fit the prefabricated units. For instance, the average unit size in this analysis is 34’, it will impossible to fit this size of a unit in hallway that has turns. This is issue is not applicable in this case. For example, the analysis will not work if it was for the overhead MEP’s in the tunnel connecting the new addition to the museum where they would need to leave the ceiling open during installation time.

5.11 Conclusion and Recommendation

In the mat slab, there are electrical and plumbing piping systems. This analysis discussed the application of prefabricating the plumbing pipes (grey and black water) embedded in the mat slab of the Sterling and Francine Clark Art Institute new addition on the plant's section of the building. That area of the building is where most MEP complication occurs where complications arise. The total schedule time savings is 3.5 days of the critical path. The cost savings was determined to be $57,771from labor time savings.

After studying the problem thoroughly, the following recommendations have been made:

- It is best to apply the analysis on the building to save time and money.
- Utilizing the 3D model helps the prefabrication process to deliver accurate dimensions to the prefabricated system and increases efficiency.
- The 3D model will aid the coordination process.
- Prefabricating the system helps the environment and achieving better LEED rating.

6.0 Analysis 2: Building Information Modeling – Virtual Mockup

6.1 The Problem

For the Sterling and Francine Clark Art Institute, Building Information Modeling (BIM) was only utilized as a clash detection tool and was implemented after document completion. They decided to use it as a clash detection tool since it helped coordinating the MEP system in the mat slab. The owner and project team could have benefitted more from different BIM uses to either add more value to the building or increase the construction efficiency. From AE 473, buildings which are sustainability evaluated, which is one BIM use, has a better value, their rent increased, occupancy rate increased, etc.

6.2 The Goal

The goal of implementing more relative BIM uses, as they are project specific, is to increase efficiency and add value to the building.

6.3 The Method

- Determining how Construction System Design (Virtual Mockup) is an effective BIM use that will serve the project at best. The uses were selected per to the following criteria:
  - The nature of the building and its assets and the value added to the owner
  - The construction issues faced by the team
  - Future modification to the building spaces
  - General Contractor interest and how they will increase productivity
- Research the mentioned BIM use more in depth through a case study.
- Contacting Turner Construction to find out how beneficial BIM was to either past or current projects.
- This BIM use can better show how effective it is to implement the first analysis, the MEP prefabrication, to the building utilizing the virtual mock up.
- Cost and benefits will be analyzed to determine whether this BIM use worth the effort.

6.4 Background Information

Once the project team detected potential problems in the embedded MEP system in the mat slab, they decided to have it coordinated through a 3D BIM model. The 3D BIM model proved to be a successful tool for smoother coordination on the construction field where the benefits came from eliminating and fixing lots of issues and conflicts on the BIM model before system installation rather than fixing conflicts in the field.

The team started working on the BIM coordination model on August 2011 and they will continue working on it till the end of construction. They included all the MEP systems in the mat slab at the beginning of the project. Once they felt the benefits of the BIM model, they modeled all MEP's in the building. Additionally, they modeled the entire building structure. To regulate the construction process aided by the BIM model, the project team holds regular meetings to revise field progress and issues if any.

With that being said, a further step in BIM uses can enhance the coordination and result in many benefits in many different ways. The virtual mockup is a more detailed 3D model that includes all building systems with all finite details to the point that shows where the screws are located (Figure 6-7). It is to lessen field construction implications since it includes all details as well as delivering higher quality products. Also, it improves the communication between all parties involved which eliminates any language barriers. That can be reflected with significant cost reduction.

6.5 Analysis Summery

The virtual mockup is a 3D model in a great detail where all building systems are modeled. It is to increase the efficiency of all aspects in the construction of the project, better yet, the entire project life span. The analysis will discuss different benefits from different point of views such as the owner's point of view, the contractor, and the architect. For this analysis, a section of the building was built virtually using AutoCAD 2012 and 3ds Max Design 2012. The section modeled may cost $1,795; however, labor interpretation time savings will reduce it to be $240.55 only. The analysis will also discuss the disadvantages of the system later in the chapter.

*6.6 Case Study**

The best way to prove an idea is perform a research on approaches used on other projects that can be applied to the project. The following case study will show how the project team, Rogers-O'Brien (R-O), at the "1400 Hi Line Residence Tower" in Dallas, Texas has gained a lot of benefits out of the virtual mockup BIM use.

RO*
Rogers-O'Brien Construction

The team has overcome economic difficulties at the time of construction with utilizing the BIM virtual mockup expertise early in the project provided by R-O construction which entitled the building in great details. The virtual mockup also helped the architect, Gromatzky Dupree & Associates, in resolving design issues that can't be figured from the ordinary 2D drawings. This BIM use helped R-O in the coordination of construction, logistics, exact quantities needed for the building's concrete frame, glass and stucco exterior skin, and other materials, and design details as well resulting in less field complications. That also allowed the developer and the financial partner a solid understanding of the project and its financials.

To be more specific in terms coordination, the virtual mock up helped answering questions about design, eliminating rework in waterproofing details, minimizing waste and construction time, minimizing request for information forms (RFI's), and performing fast construction.

Figure 7-1*: Rendered Street View Image of the 1400 Hi Line Residence Tower, Dallas, Texas

The need to issue RFI's was dramatically reduced since everything was coordinated in great detail. That almost eliminated RFI's needed for detail clarification as well due to the presence of the detailed virtual mockup. The construction team ended up saving time, two month shorter than the original schedule, due to the rare changes in the scope of work.

The architect was benefited from the virtual mockup as well. After meeting and reviewing the 3D models of the plenum spaces and tight spaces with R-O, it has been determined that there will be issues during construction in those areas. As a result, the architect has to redesign them and made the plenum space higher in prominent areas.

What's more, the virtual mockup helped in making prefabrication more efficient. The architect was able to order casework from China confidently with the virtual mockup's precise dimensions for absolute clearance for the units. Moreover, it helped in prefabricating some of the MEP systems on the project efficiently.

Additionally, the team gets to build the project twice, once in the computer and then in the field. That will point out conflicts and construction issues and eliminates field surprises which are very costly time consuming making financing the project more attractive. In fact, the virtual mockup eased the process of bank loans and other additional funding funded by developer partners.

Figure 6-2*: Rendered Image of the 1400 Hi Line Residence Tower Roof, Dallas, Texas

The benefits were not exclusively for the contractor or the architect, better yet, the owner gained some benefits as well. As the virtual mockup outcomes were helpful to R-O, they gave the confidence to the owner that R-O would be able to control the subcontractors in maintain the right quantities to not to go over budget. Another great value to the owner, the virtual mockup allowed the owner to have a virtual walk through the building to gain a better understanding of the entire building. That itself has another valuable benefit. Many projects have change of orders not because of subcontractors' mistakes; they are due to owner's taste changes. While having the opportunity to give the owner a walk through, the owner can change what he/she may not like virtually without any great losses.

6.7 The Process

To get the best out of the virtual mockup BIM use, it is essential to start building the virtual mockup model in the early stages of the project as it is recommended with the regular 3D model BIM use. The modeling process should continue its development through the entire project to increase model accuracy. Additionally, the project teams need to have the ability to manipulate the virtual mockup model. The reason is to enable them to make the appropriate decisions according to what issues they can point out from the model.

To build up virtual mockup for this analysis, the following steps where followed. First, the Penn State BIM execution guide was referenced. While it is unrealistic to do all BIM uses, the best applicable BIM use was chosen, the construction system design (virtual mockup). Some potential

* *Rogers-O'Brien Construction. "CASE STUDY: 1400 Hi Line Dallas, Texas." BIM Expertise Clarifies Design and Development Challenges of Dallas' Newest Residential Tower. Rogers-O'Brien Construction, 14 Feb. 2011. Web. 30 Mar. 2012. <http://www.rogers-obrien.com/media/65832/r-o_case_study_-_hi_line.pdf>.*

values were mentioned, however, in reality there were more values. Also, the execution guide highlighted the BIM use requirements.

The second essential step is choosing the right software to build the model. AutoCAD 2012 was chosen to model the virtual mockup since it has the ability to model all the finite details with great freedom. Afterwards, the model will be sent 3ds Max Design 2012 to apply animations and materials on the model so it looks realistic to better convey the virtual mockup goal.

Third, a section of the building was chosen. To get the best out of the model, the chosen section has lots of connections and shows the relations between different spaces. The section is considered one of the complicated sections of the building according to the project engineer Robert Stewart.

Most importantly, the fourth step is to determine what goes in the section chosen. The following list defines the section's components:

1. Architectural Concrete.
2. Cast in Place Concrete.
3. Concrete Pavers.
4. Curtain Wall Reinforcement.
5. Metal Panels.
6. Extruded-Polystyrene Insulation.
7. Mini-Fiber Blanket Insulation.
8. Sealants.
9. Girt.
10. Gypsum Board.
11. Floor Hydrant Radiant Heating.
12. Insulating Glass.
13. Gutter:
    - Gutter Bracket.
    - Gutter Flashing.
    - Gutter Heating Cables.
    - Gutter Metal.
    - Gutter Leaf Guard.
    - Gutter Zinc Cladding.
14. Sheathing.
15. Reglet.
16. Wood Blocks.
17. Water Proofing Membrane.
18. Screws.

2D drawing reading was read carefully to extract the section components and how they align with each other. Then they were redrawn in AutoCAD to make the 3D drawing and eventually the virtual mockup.

Finally, the model was taken to 3ds Max design to apply the materials on and animations.

The following figures (Figure 6-3 to 6-10) will show different views of the section modeled captured from AutoCAD 2012.

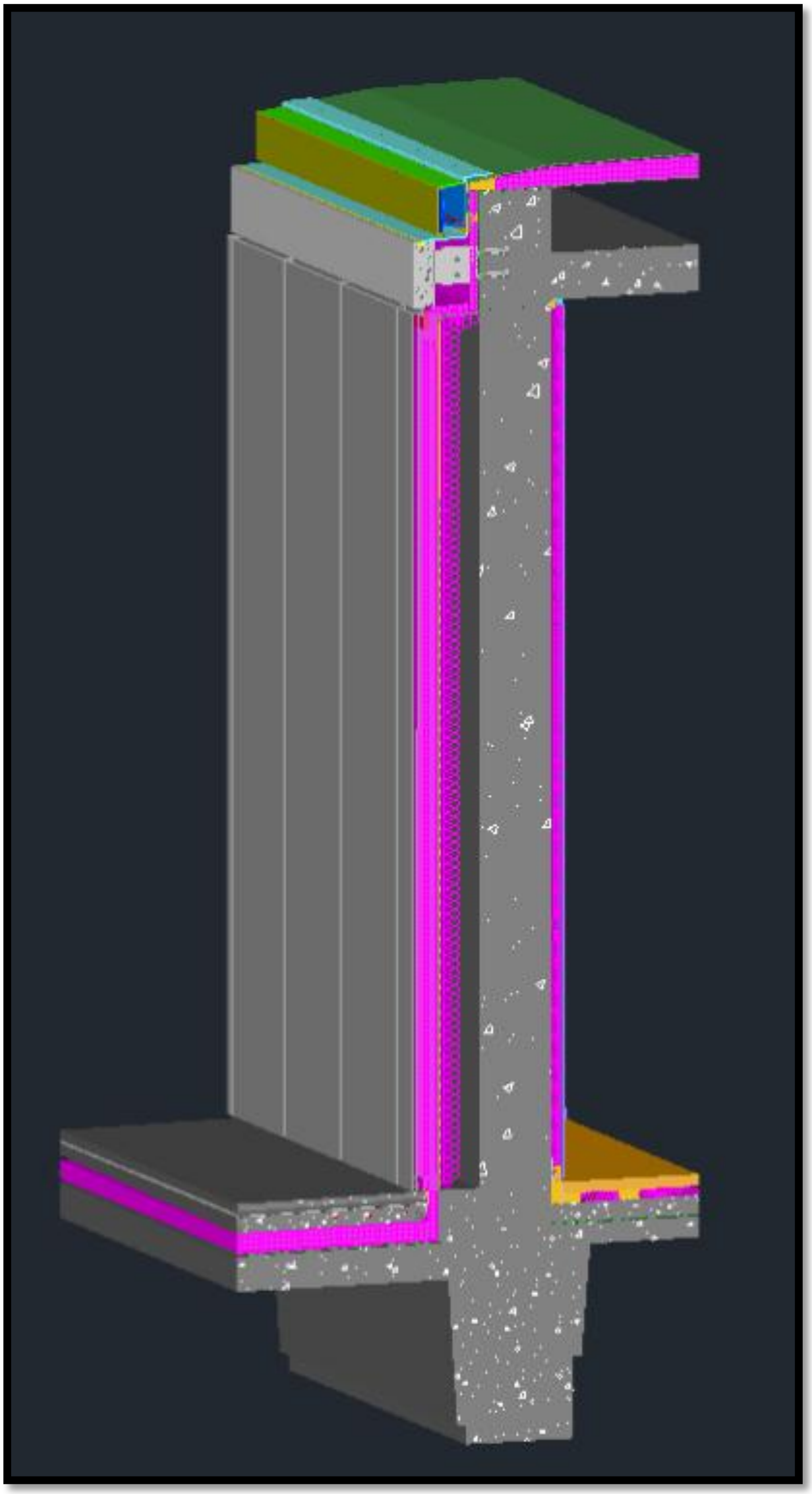


Figure 6-3: Overall Look at the Virtual Mockup Section

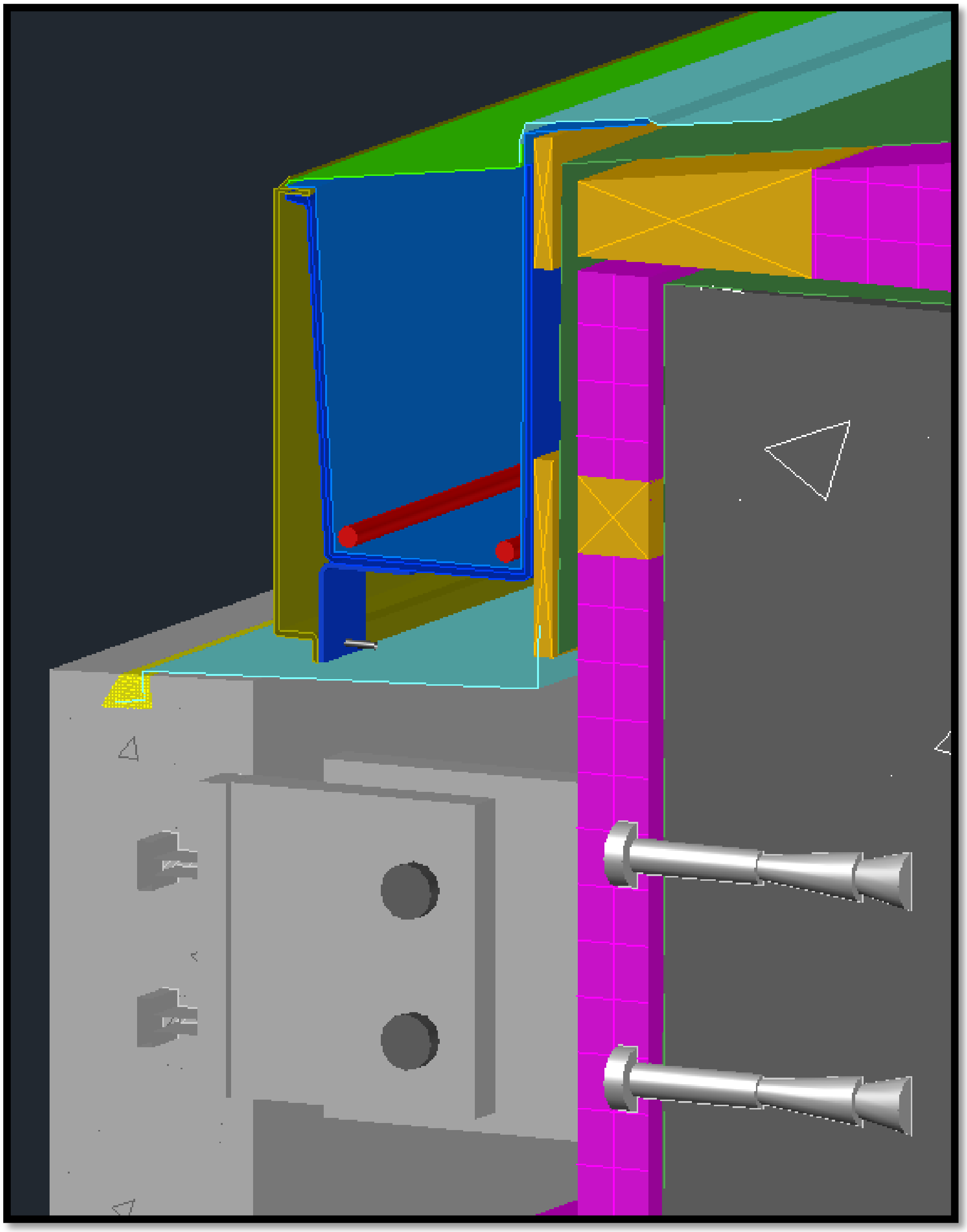


Figure 6-4: A close up image of the virtual mockup showing how the arch. conc., gutter system, insulation, roofing, and water proofing are connected the concrete wall.

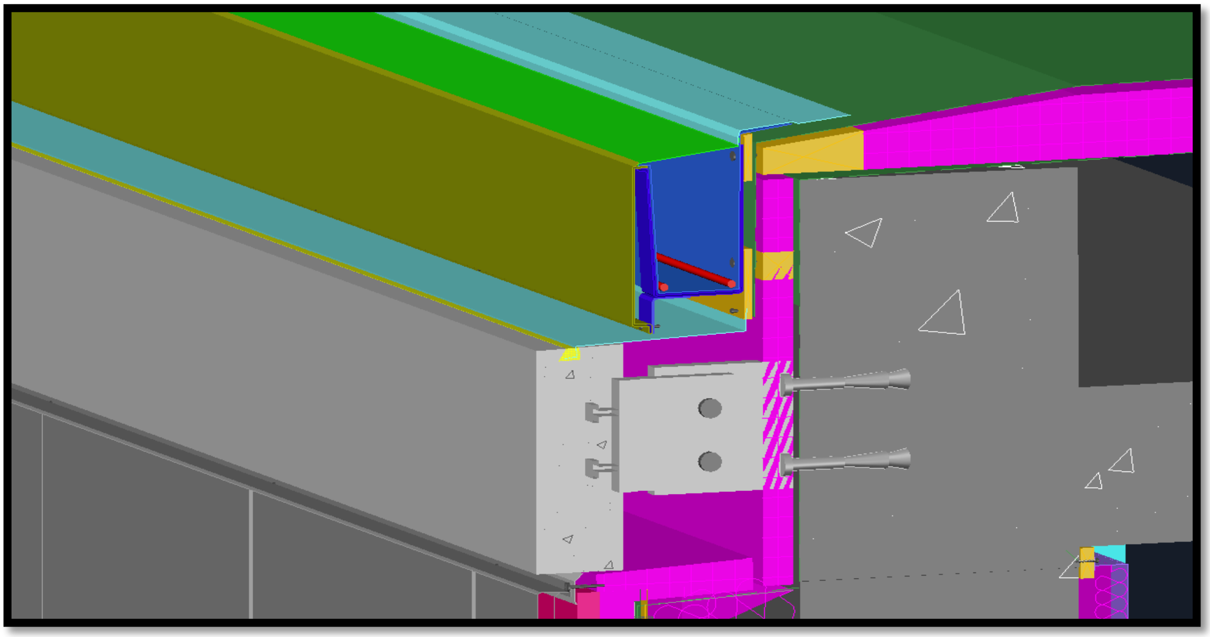


Figure 6-5: Another view of Figure 6-4 showing how the arch. conc., gutter system, insulation, roofing, water proofing, metal panels, and gypsum board are connected to the concrete wall.

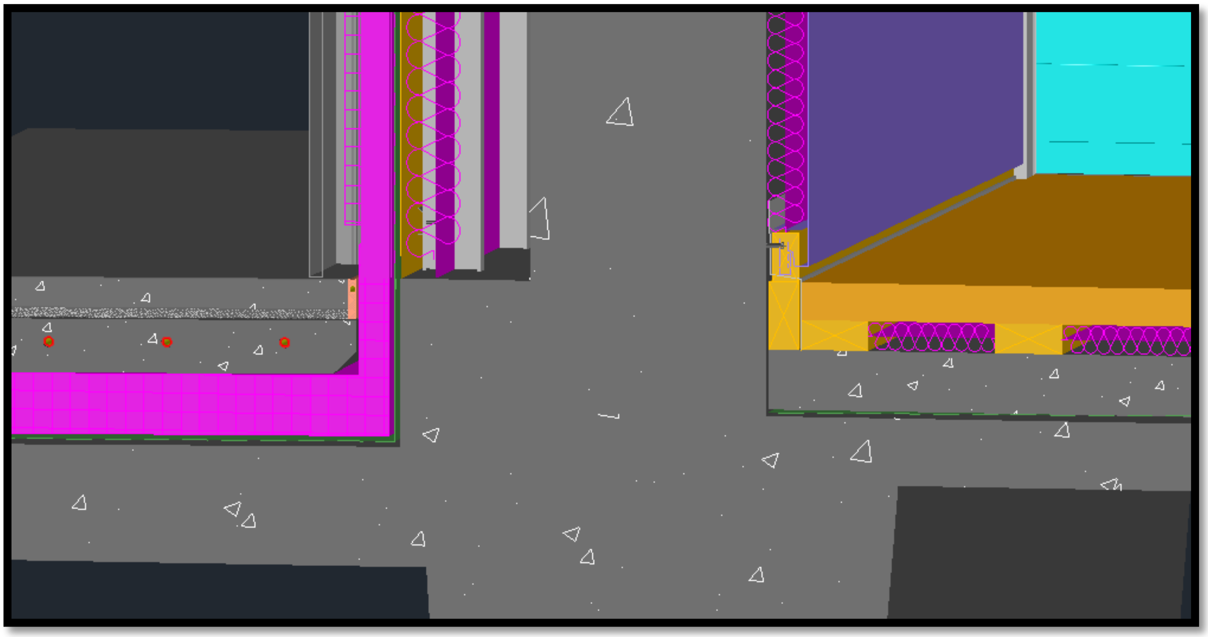


Figure 6-6: A close up image of the virtual mockup showing the exterior side of the building (on the left side) and the interior finishes (on the right side) of the building.

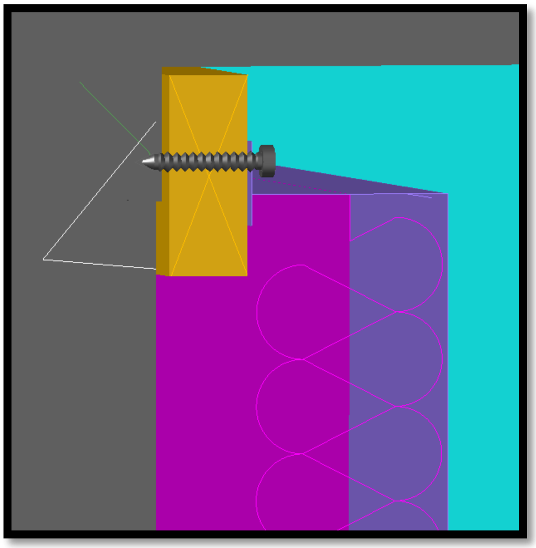


Figure 6-7: A finite detail where a screw is shown tying the gypsum board system to the concrete wall.

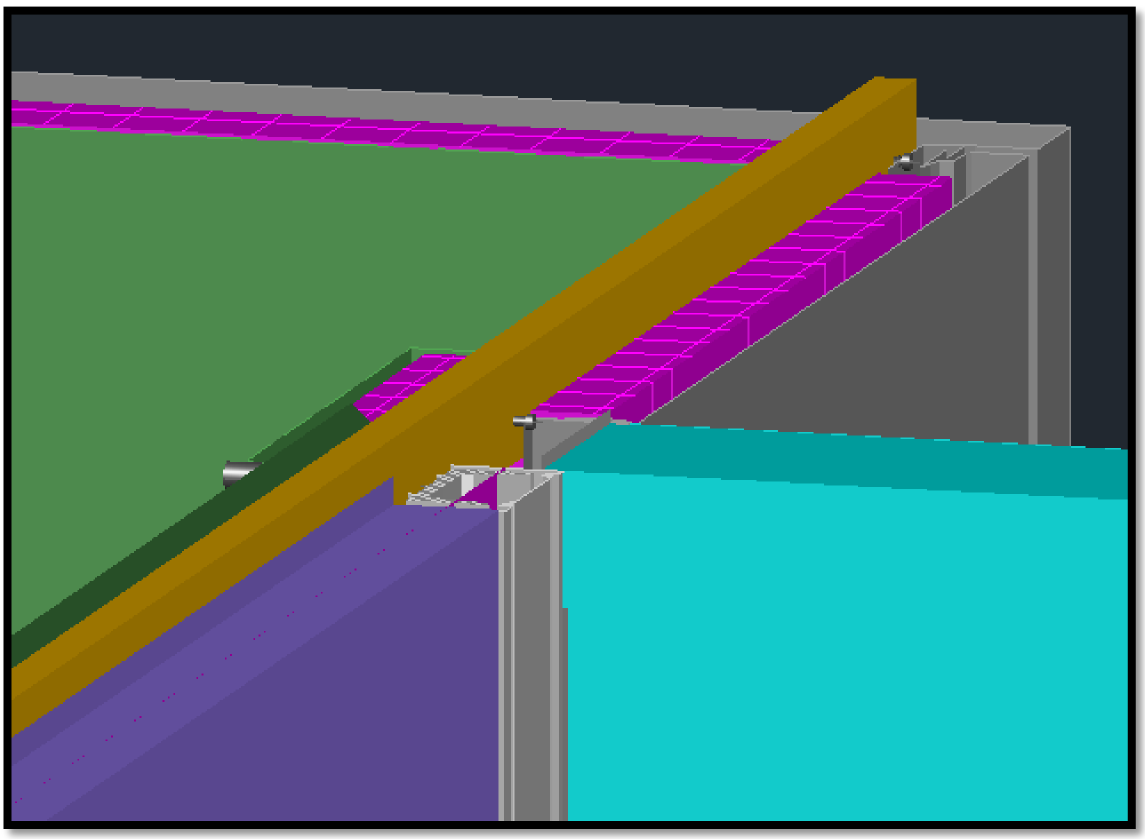


Figure 6-8: Another image of the virtual mockup showing how the metal panels and their

structural supports, glazing, insulation, water proofing, and gypsum board are connected to the concrete wall. Figure 6-9 shows a closer look.

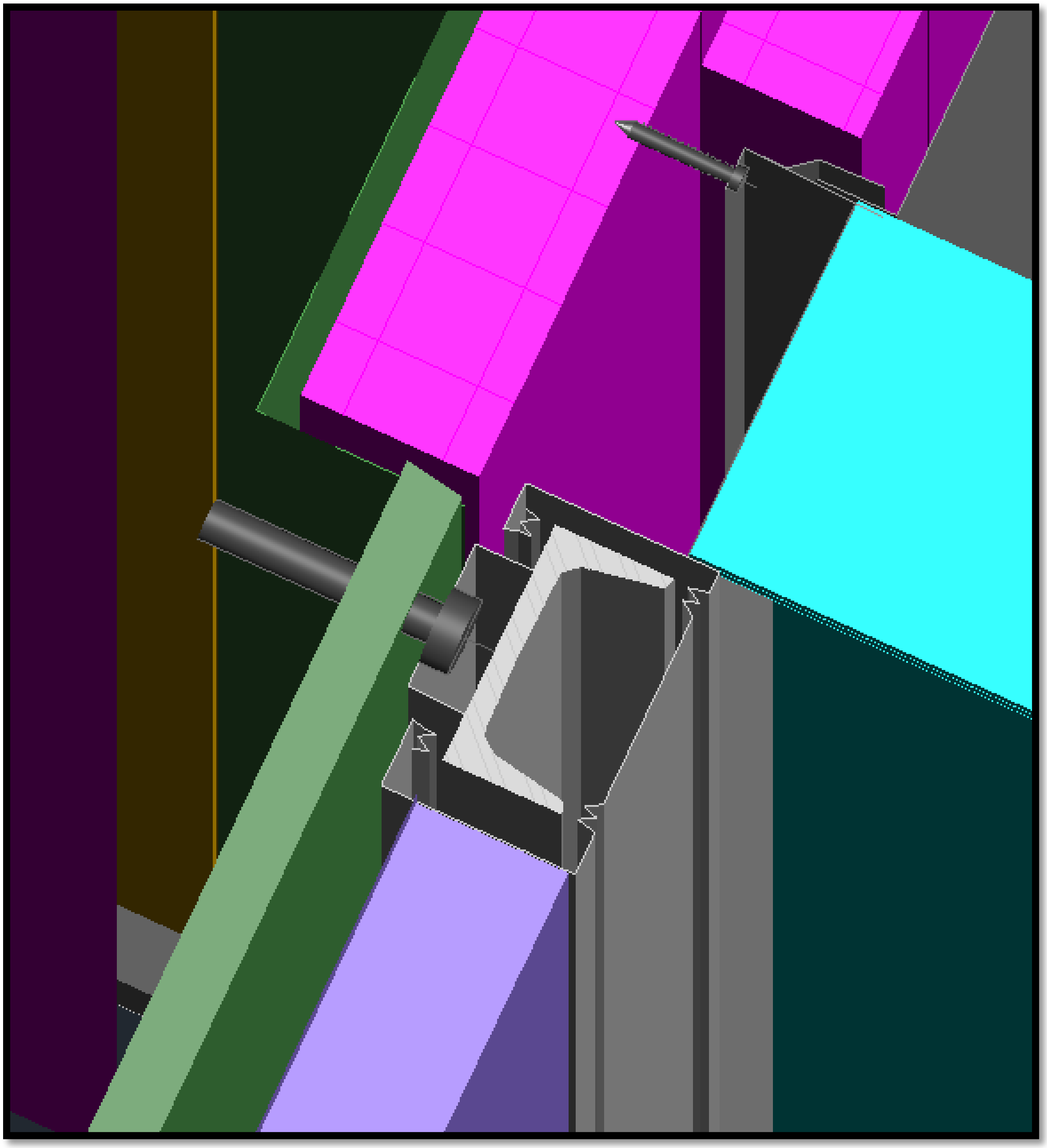


Figure 6-9: This image shows a closer look of Figure 6-8. It shows how the metal panels and their structural supports, glazing, insulation, water proofing, and gypsum board are connected to the concrete wall.

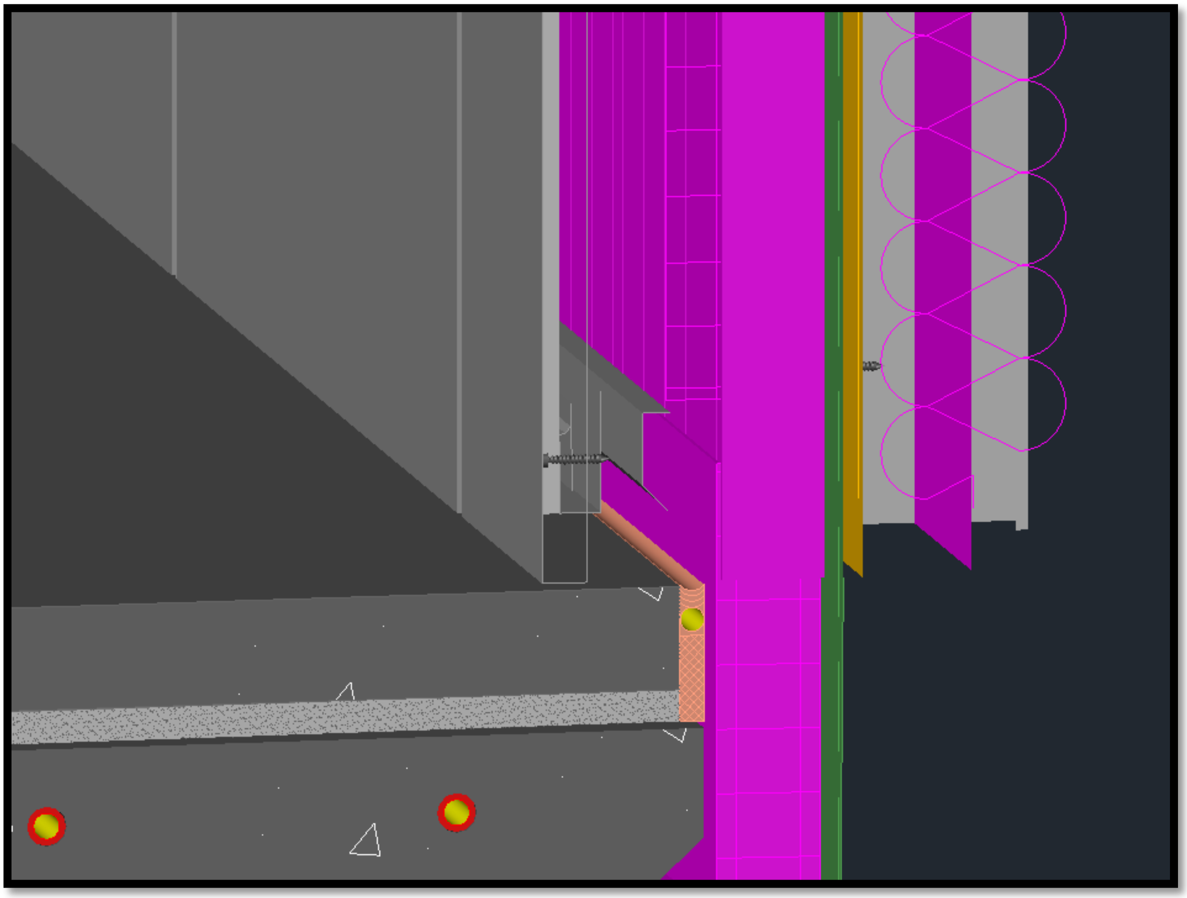


Figure 6-10: A close up image of the virtual mockup showing how the concrete paver, embedded hydrant radiant heating pipes, insulation, sealants, and water proofing are connected.

6.8 Virtual Mockup Benefits

6.8.1 Benefits from Case Study

The case study cited highlighted lots of the virtual mockup benefits. Utilizing the virtual mockup helped the team overcome economic difficulties. It also helped the architect in solving design issues early in the project before construction begins. Another added value, the contractor utilized the model in coordination, less RFI's, logistics, quantity take-off, design details, and increase prefabrication efficiency resulting in minimizing field implications. The project teams had the opportunity to build the building twice, virtually and physically. Moreover, the virtual mockup eased the process of bank loans and other additional funding funded by developer partners. From the owner standpoint, it provided the confidence to the owner that the contractor will maintain the budget agreed on. Furthermore, it provided a scale of 1:1 to the owner to experience the building virtually.

6.8.2 Turner Project Engineer Feedback

Other than great insights the case study provided, the project engineer, Robert Stewart, has highlighted additional valuable benefits after presenting the virtual mockup built for this analysis to him. He mentioned that the virtual mockup can be useful in tagging and tracking the entire building components from the massive mechanical equipment to the tiny sprinkler heads. That will ease locating any component for future maintenance which is an added value to the owner. Moreover, it can ease future building renovations, better yet, the future restaurant that will be incorporated in the building. Furthermore, it can help the MEP prefabrication as proposed on analysis 1 on this report.

6.8.3 Additional Benefits to the Owner

Additional values to the owner can be addressed. The owner can keep monitoring the project through updates in the virtual mock-up throughout the project. That enables close budget, schedule, and quality monitoring to the owner's final product. As mentioned, it will help the owner in implementing the future planned restaurant and keeping a database for the used equipment and their locations for building maintenance. Also, it will allow the owner to feel the finished spaces and may elect to change anything the owner does not like beforehand.

6.8.4 Cost Benefits

The benefits section will end with the cost benefits which are the biggest derive to go with any proposal. If it is financially feasible, it is most likely to be doable. The first fact comes to one's mind when thinking about applying the virtual mockup to the Sterling and Francine Clark Art

Institute new addition is why not expand the 3D model built to a complete virtual mockup. That will reduce much of the work needed if the virtual mockup would be built from scratch as it is the case for this analysis.

One of the cost savings is to minimize code violation by having code officials check building systems virtually. That results in less site checks and less change of order requests (COR's) if any violations were found.

Another potential cost savings can be gained as a result of having less field implications and conflicts which can occur due to many reasons. One of the factors the will minimize those implication is a better visualization of what's going to be built which will be illustrated in the following two tables. Table 6-1 is going to show how long it may take and how much it will cost the produce the section modeled for this analysis.

Table 6-1: Cost and Time Spent on Virtual Mockup Section

Task	Time Took AE Student to Perform Task (Hrs.)	Professional Wage ($/Hr)*	Professional to take 100% of the time		Professional to take 75% of the time		Professional to take 50% of the time	
			(Hrs.)	Cost*	(Hrs.)	Cost*	(Hrs.)	Cost*
Determining a section to model	1	$97	1	$97	¾	$72.75	½	$48.5
Determining What is in the section	8	$97	8	$776	6	$582	3	$291
Section modeling	40	$97	40	$3,880	30	$2,910	15	$1,455
Total	49	$97	49	$4,753	36 ¾	$3,564.75	18 ½	$1,795

Table 6-1 shows a comparison between the AE student and a professional for the time it takes to build the virtual mockup.
* The professional wage is obtained from RSMeans and includes overhead and profit and modification multipliers.

If takes the professional half the time to produce the virtual mockup it would cost $1,795. Table 6-2, in the next page, will show one simple way of how to justify the cost spent on the virtual mockup.

Table 6-2: Field 2D Drawings Interpretation Time

Foreman Trade	Foreman Wage ($/Hr)*	Interpretation Time Savings (2 Hrs)
Concrete	$55.20	$110.40
Iron	$83.08	$166.16
Plumbing	$75.72	$151.43
Glazing	$54.43	$108.86
Gypsum Boards	$66.18	$132.36
Gutter	$83.08	$166.16
Sheeting	$66.18	$132.35
Metal Panels	$83.08	$166.16
Roofer	$66.18	$132.35
Wood Flooring	$45.38	$90.76
Sealants	$44.30	$88.60
Water Proofing	$54.43	$108.86
Total		$1,554.45

Table 6-2 discusses the cost savings by minimizing interpretation time on the field by each trade foreman involved in the virtual mockup modeled for this analysis.
* The foreman wage is obtained from RSMeans and includes overhead and profit and modification multipliers.

Assuming the virtual mockup model will lessen interpretation time by two hours for each trade foreman, it will save $1,554.45. The interpretation time will lessen due to many factors. One important factor is language barriers and miscommunications. As a result, the net cost for the section modeled will be $240.55 only. That is not including all mentioned benefits. When adding all the benefits discussed in the chapter, it will not only justify itself, it will have money earnings to the overall project.

Additional cost benefits can obtained from less COR's. Not to mention construction slips, COR's can be made by the owner if he/she elect to change some details. COR's may not affect the cost directly but will affect it indirectly, not to mention the headache the make to the project team.

6.9 Virtual Mockup Disadvantages

There has to be disadvantages for any proposal as it is the case for the virtual mockup. One of the disadvantages is code validation. Even though it is helpful to have code officials check the building systems, that move might have gaps nowadays. However, according to the PACE conference on 2011, the gaps is shrinking as BIM is growing and having more influence the construction industry. Another related disadvantage to virtual mockups is testing. It is true that virtual mockups provide detailed systems dimensions and locations, but it cannot test the performance of those systems.

Another disadvantage is although the virtual mock can have finite details and fine renderings as discussed earlier, it may not reflect the final material look on reality. According to Robert Stewart "Labors need to build something and throw it out." That can give workers a feel of how to construct building. So, they would have to build a physical mock up no matter what.

6.10 Conclusion and Recommendation

The virtual mockup is to increase the efficiency of all aspects during and after the construction. The analysis discussed different benefits that were applied on different parties involved on the project such as the owner, the contractor, and the architect. More specifically, during construction, it will help increase efficiency of the coordination process and accuracy and decrease waste, time, RFI's, COR's and miscommunications. On the other hand, after construction it will help the owner in future renovations and maintenance. The analysis discussed a section of the building that was built virtually using AutoCAD 2012 to build and 3ds Max Design 2012 to apply materials and animate the model. The section modeled may cost $1,795; however, labor interpretation time savings will reduce it to be $240.55 only. There would more benefits and advantages that can result in earnings to the project which will justify all initial costs.

Since the cost of building the virtual mockup can be justified with the benefits it has, and the project team can't give up the actual mock as discussed earlier, it is recommended to have the virtual mockup build. That is because of the fact that they would now experience the building three times, virtually, the physical mockup, and the building itself as well as increasing coordination efficiency. Also, the owner will benefit from the virtual mockup after construction is done for the future restaurant and renovations if needed and future maintenance.

7.0 Analysis 3: Precast Roof Planks

7.1 The Problem

The Sterling and Francine Clark Art Institute new addition has an irregular shaped geometry due to the complexity of the architectural design. So, pouring concrete in tight areas, especially corners where there are many, can increase constructability issues. As a result, labor costs will increase as well as time. The precast planks will cover the roof area over the basement.

7.2 The Goal

The goal of using precast roof planks is to increase productivity and constructability of the complex building geometry and to put the schedule back on track.

7.3 The Method

- Gathering the required information about the required area's performance structurally.
- Finding the ultimate unite size to minimize joints and construction issues.
- Locating and choosing the best precast facility in terms of value and not limited to distance or cost.
- Calculating time and cost of transportation.
- Effects on logistics and equipment.
- Determining the entire roof system area to research the cost and time differences and benefits between the new over the current systems. All units will have a typical size with the exception of the corner units to minimize joints and onsite adjustments.

7.4 Background Information

The Sterling and Francine Clark Art Institute new addition has cast in place (CIP) roof. The project had gone through major delays due to weather and other inefficiencies. Due to the irregular geometry, the pouring on tight areas can be difficult and raises constructability issues. That can risk taking even more time to perform the task which will lead to many delays for the following trades. Additionally, there are congestions on the site where other trades are working on other overlapping tasks that can be affected or might be hit with a delay as well.

Prefabricated planks are usually efficient and relatively fast to erect. They also reduce onsite congestions caused by labor or materials. That is due to the amount of work done on those planks in the prefabrication factory. So, custom ready planks are delivered to site to get erected into place right after superstructure is fully cured in this case. By doing so, it is expected to have time and cost savings that will be discussed later in this chapter of the report.

7.5Analysis Summary

This analysis is to investigate a solution to improve the efficiency and make some time up to get the schedule back on track as much as possible. This solution will have other benefits as well. The area to be prefabricated is 21,450 SQF using 4'x20'x8"+2" topping planks. The precast planks analysis will achieve time savings of 18 days of the critical path. Additional costs will occur to implement this analysis by 16.6% over the original system. However, the cost savings from the general conditions, which is $75,142, is going to justify the additional costs and making it a net savings of $47,601. Costs of the existing system are either estimated by RSMeans or a typical cost was obtained from the project team as contractual costs are confidential. Cost source will be mentioned throughout the text.

7.6 Initial Planning

The project fell behind by more than a month. That is because of weather and multiple change of order requests due to the quality of the finished roof. The building is aiming to obtain a LEED silver rating certificate. The mentioned points called the desire of implementing the precast roof planks. Not to say this is not going to work on other structural members or roofs, however, the roof of the VECC is partially to be prefabricated as shown in the **red** shaded area in (Figure 7-1). The VECC is going to be partially prefabricated. The only exception for this analysis is the reservoir, shaded in **blue**, feeding the water feature that cannot be prefabricated to eliminate any water leakage risks through planks joints.

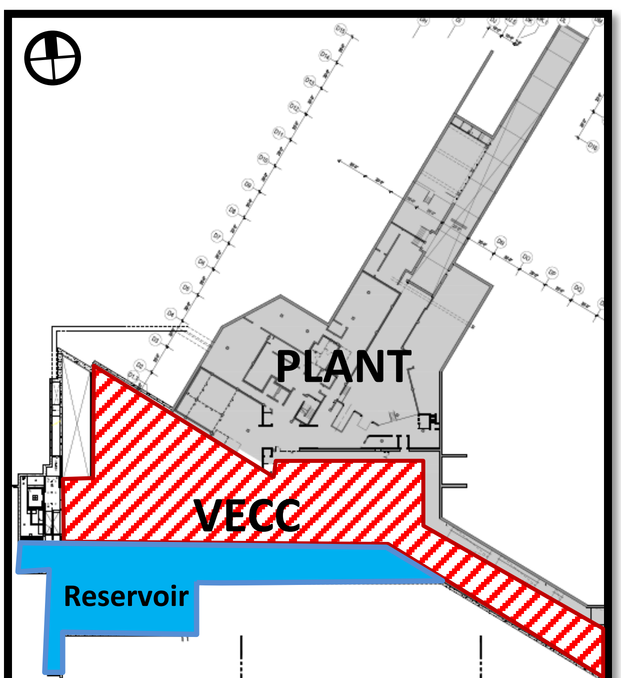


Figure 7-1: Precast Planks Application Location

7.7 The Process

7.7.1 Why Precast Planks?

The problem was the big delays faced the team. One of the first solutions comes to mind is prefabrication. Precast planks are a solution that can help the team to catch up and may result cost savings as well. Most importantly, precast manufacturing is weather dependent which is why this solution helpful for the project. Additionally, since this building is aiming to achieve a LEED silver rating certification, there are potential points that can be earned due to the clean construction site. The premade planks can be a ready deck for the following trades. Moreover, the planks will be made in a controlled environment which increases efficiency and the quality and durability of the product. Last but not least, the application of this analysis will reduce the congested work area which increases the safety on site.

7.7.2 Precast Plank Selection

After investigating the problem carefully from different aspects, it has been determined that the precast planks will help the project team to put the project back on the right time path. First, a plank size was chosen based on construction constraints and easiness. Second, the area where this analysis is applicable was determined. The area is almost for the entire building except the reservoir roof (shaded in **blue** in Figure 7-1) of the VECC section of the building to eliminate leakage risks. Nevertheless, this chapter of the report will only be focused on the applicable area of the VECC (shaded in **red** in Figure 7-1). Then, coordination and logistics were planned according to the new changes in the roof system. Finally and most importantly, the structural performance and feasibility (Structural Breadth) was determined. To calculate costs, time, structural performance, and determine plank size, a typical bay was studied and then applied to the entire square footage of the area chosen to apply this analysis on. The next figure (Figure 7-2) depicts the typical bay chosen.

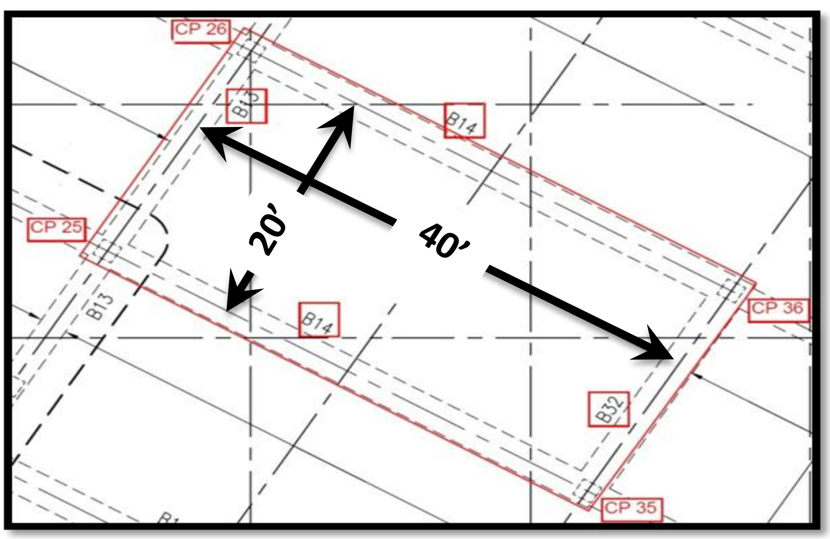


Figure 7-2: The Typical Bay Chosen to Apply Analysis Calculations on

Figure 7-2 show is the typical bay that will be studied in detail to perform this analysis. The typical bay size is 40’x20’ (midpoint to midpoint). A reasonable plank size was chosen based on the typical bay constraints. The bay constraints are as the following: size and thickness, loads on the bay, easiness of handling, construction, and shipping as well. The plank size was chosen to be 4’x20’x8” with 2” topping to match the 10” thick roof. So, ten planks will cover one bay. The area that will be covered is 21,450 SQF which needs 268.125 planks. The 0.125 plank can be precut in the factory on site where it is relatively easy to adjust the plank size. For this analysis, the 0.125 plank will be precut in the factory.

7.7.3 Precast Plant and Transportation

The precast plant chosen for this analysis is going to be the closest precast plant of the Nitterhouse Concrete Products, Inc. which is about two to three hours away from the site. Mr. Mark Taylor, P.E., President of the Nitterhouse Concrete Products, Inc. was contacted to gather the cost and delivery information needed to perform the analysis. The maximum truck load would be 45,000 so no special traffic permits to be obtained. The 8” plank weighs 42 PSF. As a result, 20 delivery trucks will be needed to cover the determined area. The hauler can wait on site upon delivery for two hours and charges $100 per hour for additional needed time.

7.8 Schedule and Cost Benefits

7.8.1 Schedule Benefits

Precast concrete is widely known for its fast erection and schedule reduction capabilities. That was the main goal of applying this analysis on the sterling and Francine Clark Art Institute new addition project. To better illustrate the time savings by applying the analysis on the new addition, it is necessary to compare both systems time wise. RSMeans was referenced to get durations for precast erections and daily outputs for labor. Although RSMeans provide good average durations, it still has its limitations. For example, the erection time for a basement, which is the case, is different than the time it takes to erect the same amount of precast planks to the fifth floor. RSMeans may not account for all factors for each individual building; however, it would only provide the average time based on their data and assumptions. From RSMeans, the daily output is to be 3600 SQF/day. On that basis, the duration in the following table was determined

The following table (Table 7-1), on the top of next page, shows a detailed schedule of both new and existing systems. The time savings found from Table 7-1 found to be 18 days out of the critical path. That is due to Area# 1 which is on the critical path. The time savings can justify the delay occurred by weather or any other laggings have happened or may happen during construction not to mention the additional float the application of the analysis yields. Moreover, finishing early means next trades can get in earlier. For instance, the green roof subcontractor will be able to come to the site and get mobilized and start working a lot sooner. Another example, the overhead MEP fit-outs can be installed sooner as well as finishes.

Table 7-1: Detailed Schedule of New And Existing Systems								
Task Name	Cast In Place			Precast			Time Savings	Percent Time Savings
	Duration	Start	Finish	Duration	Start	Finish		
Area# 1	**97 days**	**Sat 11/19/11**	**Mon 4/2/12**	**73 days**	**Sat 11/19/11**	**Tue 2/28/12**	24 Days	24.74%
FRP Superstructure	61 days	Sat 11/19/11	Fri 2/10/12	61 days	Sat 11/19/11	Fri 2/10/12	0 Days	0%
Deck FRP/Erection	26 days	Mon 2/13/12	Mon 3/19/12	2 days	Mon 2/13/12	Tue 2/14/12	24 Days	92.3 %
Waterproofing	10 days	Tue 3/20/12	Mon 4/2/12	10 days	Wed 2/15/12	Tue 2/28/12	0 Days	0%
Area# 2	**135 days**	**Wed 11/2/11**	**Tue 5/8/12**	**112 days**	**Wed 11/2/11**	**Tue 4/5/12**	23 Days	23.71%
FRP Superstructure	99 days	Wed 11/2/11	Mon 3/19/12	99 days	Wed 11/2/11	Mon 3/19/12	0 Days	0%
Deck FRP/Erection	26 days	Tue 3/20/12	Tue 4/24/12	3 days	Tue 3/20/12	Thu 3/22/12	23 Days	88.46%
Waterproofing	10 days	Wed 4/25/12	Tue 5/8/12	10 days	Fri 3/23/12	Thu 4/5/12	0 Days	0%
Area# 3	**98 days**	**Wed 10/26/11**	**Fri 3/9/12**	**85 days**	**Wed 10/26/11**	**Tue 2/21/12**	13 Days	13.40%
FRP Superstructure	74 days	Wed 10/26/11	Mon 2/6/12	74 days	Wed 10/26/11	Mon 2/6/12	0 Days	0%
Deck FRP/Erection	14 days	Tue 2/7/12	Fri 2/24/12	1 day	Tue 2/7/12	Tue 2/7/12	13 Days	92.86%
Waterproofing	10 days	Mon 2/27/12	Fri 3/9/12	10 days	Wed 2/8/12	Tue 2/21/12	0 Days	0%
Area# 4	**93 days**	**Wed 2/29/12**	**Fri 7/6/12**	**70 days**	**Wed 2/29/12**	**Tue 6/5/12**	23 Days	23.71%
FRP Superstructure	58 days	Wed 2/29/12	Fri 5/18/12	58 days	Wed 2/29/12	Fri 5/18/12	0 Days	0%
Deck FRP/Erection	26 days	Mon 5/21/12	Mon 6/25/12	2 days	Mon 5/21/12	Tue 5/22/12	23 Days	88.46%
Waterproofing	10 days	Mon 6/25/12	Fri 7/6/12	10 days	Wed 5/23/12	Tue 6/5/12	0 Days	0%

Table 7-1 shows the duration of each area for the proposed

Per to Mark Taylor, the lead time needed to manufacture the precast system is three months. That is doable in this case since the submittals finishes on August 2011 and construction of the roof decks start on November 2011.

7.8.2 Cost Benefits

In order to extract the cost benefits from the analysis, another comparison is necessary to be made. Table 7- 2 illustrates the comparison between the existing and proposed system showing the net savings by applying the analysis on the new addition.

Table 7-2: Net Costs & Savings From Applying The New System				
System	**Cost**	**Extra Cost**	**Cost Savings**	**Percent Extra Cost**
Cast In Place	$165,509	$47,662	N/A	28.8%
Precast Planks	$117,908	N/A	$47,662	N/A

Table 7-2 shows a comparison between the existing and the proposed system determining the net savings

As seen from the table, the net savings is $47,662. Initially, if one would calculate the cost of the CIP system versus the precast planks system, he/she would find that the cost of precast surpasses the price of CIP. Contrariwise, after considering other factors it has been determined the opposite.

According to the project team, the typical cost of one cubic yard of a delivered pumped concrete with all its accessories was determined to be $250/CY. The 21,450 SQF yields 662.03 CY which costs $165,509. On the other hand, according to Mark Taylor, precast concrete for the Sterling and Francine Clark Art Institute new additions location costs $9/SQF (price includes manufacturing, delivery, and erection) which is $193,050. After investigating schedule savings of 18 days, a potential cost reduction can be made from the projects general condition. From the previous AE Senior Thesis Technical Reports, it has been estimated that general conditions costs $4,174.56/day. As a result, the total savings is $75,142 yielding net savings of $47,662.

7.9 Site Logistics

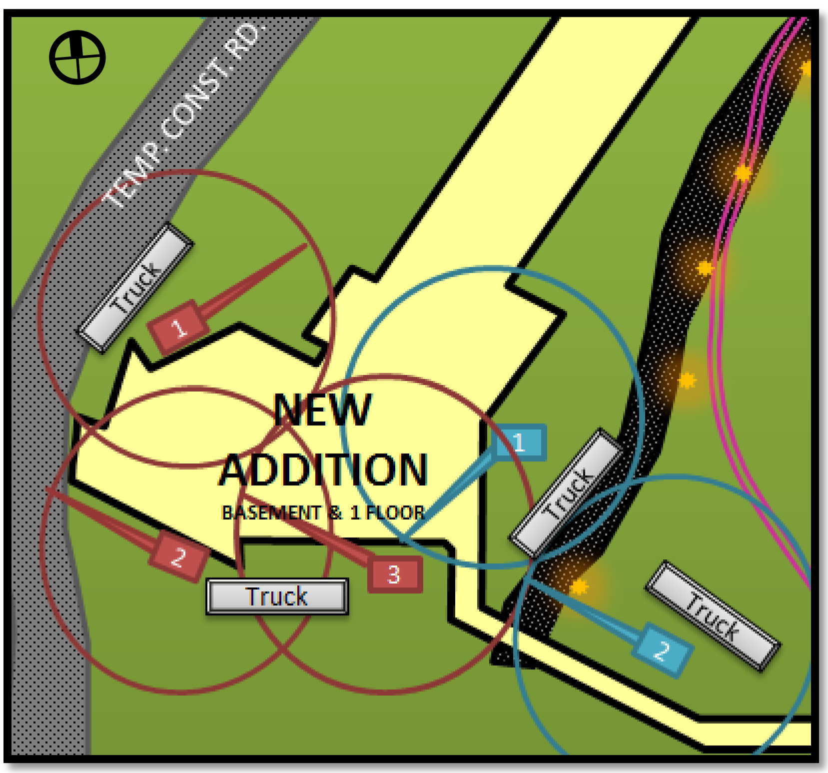


Figure 7-3: Logistics Plan for the Precast Planks

The site itself is not congested, however, the working space in the building footprint is very congested which increases many constructability issues. Those can be safety issues and inefficiencies due to the different trades on site. It is true that the new precast system will add another stage to the project construction, in contrast, it will definitely reduce all the risks and the issues can associated the current CIP system. The shorter duration of performing the task, will lessen the congestion as the trade will leave quicker leaving the space for other trades. Also, since everything is ready made, there will be no need for mortar mixers or mixing concrete onsite. Most importantly, this is a weather independent task. That means that they may work during relatively harsh weather while other trades are offsite which decreases space congestions and increases safety at the same time when other trades comeback onsite.

Figure 7-3 shows a snapshot of the logistics plan (full plan in Appendix C). The cranes shown in the figure will not work simultaneously. Alternatively, the red crane is one crane and the numbers 1, 2, and 3 is a sequence of the location of the crane. Similarly scenario will be applied to the blue crane. Still, the blue and the red cranes will not work simultaneously. That is because the **red** crane with position# 1 covers area# 1 partially, position# 2 covers areas# 1 and 2 partially, position# 3 covers areas# 2, 3, and 4 partially, and the **blue** crane with position# 1 covers area# 3 partially, and position# 2 covers rest of area# 4.

The precast panels need to be placed once the superstructure is done. To connect the precast to the existing structures it would need to be tied through dowels left at the top of the existing structures by the CIP subcontractor. It would be a lot easier and faster if the existing structure is was precast. In that cast, the roof will be connected through iron connections which are relatively a lot faster and easier.

7.10 Precast Disadvantages

When one is applying a great prefabricated system such as the precast concrete planks, the first question come to one's mind is "If it is that great, why not apply it on all buildings?" Well, with all the great benefits discussed about precast concrete planks, there are some issues with precast as with any other system. One of the precast disadvantages of precast is the interior finishing. This is a 'Tadao Ando' project. That means everything has to be in pure clean fine lines and very symmetrical. There are spaces where false ceiling is employed. Unfortunately that is not the case everywhere in the building. There are some spaces, yet important, that have exposed concrete ceiling and have some sort of special concrete finishes that precast concrete can't serve even if it is an architectural precast concrete.

Another issue with precast planks, in general, is that they are not very flexible for future renovations. For example, if the owner decided to take a wall down it would be very difficult to do if not impossible. Also, it difficult to penetrate through the planks, if additional piping is needed for instance, after installing if not coordinated with the factory beforehand.

Also, the lead time required and the amount of coordination for the precast planks system can be sometimes an issue for some projects. For this case, there is enough time to do so for the selected area. However, if the owner would go precast with the rest of the building it will not be possible due to the lead time needed.

Additionally, the precast concrete planks cannot be erected unless the superstructure is ready for it. That may lag the process if weather delayed the superstructure construction. That might increase the cost of precast since the planks might need to be put in storage and redelivered to site or laid down in the staging area which may take the space of other trades. This system may work at its best of the columns and beams were precast concrete as well to better eliminate the weather factor and for easier connections and construction.

One more critical disadvantage of precast, that is specifically associated with this building location, comes from the heavy weight of the precast planks. As a result, there will be a relatively high number of deliveries. That does not affect the site logistics; it affects the small town the building is located at in addition to being located next to Williams College where there are a lot of student traffic. Additionally, there are not much of wide streets that can hold that much of truck deliveries. According to a member of the project team, the town might be required to close the streets for the deliveries which will not be acceptable by the traffic authorities.

7.11 Value Comparison

This section will summarize the overall value of each system wich will be summed in the following table (Table 7-3). A recommendation will be made based on the presented information so far on this analysis.

Table 7-3: Systems Value Comparison

	Cast In Place	Precast
Cost	↓	↑ $47,662 Net Savings
Schedule	↓	↑18 Days of Critical Path
Lead Time	↑ 0	↓ 3 Months
Following Trades	↓	↑
LEED	↓	↑
Congestion	↓ Congested	↑ Less Congestion
Value	GOOD	**BEST**

Table 7-3 shows a comparison between both, current and new systems. The arrows represent weather the point of comparison is a higher (in green) or lower (in red) value. For instance, the lead time, CIP has a better value since it takes less time than Precast which takes 3 months. Another example, CIP has more congestion on the building footprint which is a lower value. On the other hand, Precast has a higher value in this case since it makes the site less congested.

7.12 Structural Impact (Structural Breadth)

Changing the roof system in the project will definitely have structural changes and impacts. Consequently, it is vital to check the structural performance and compatibility of the building structure with new change. The density of the concrete used matches the density of the precast planks which is 150 PCF. However, the precast planks are 51% lighter. The CIP concrete weighs 125 PSF and the planks weigh 61.25 PSF not to mention the added strength of the precast planks. With that being said, the only check needs to be performed is deflection. The same typical bay (Figure 7-4) will be studied as well since the loads will be consistent thorough out the space.

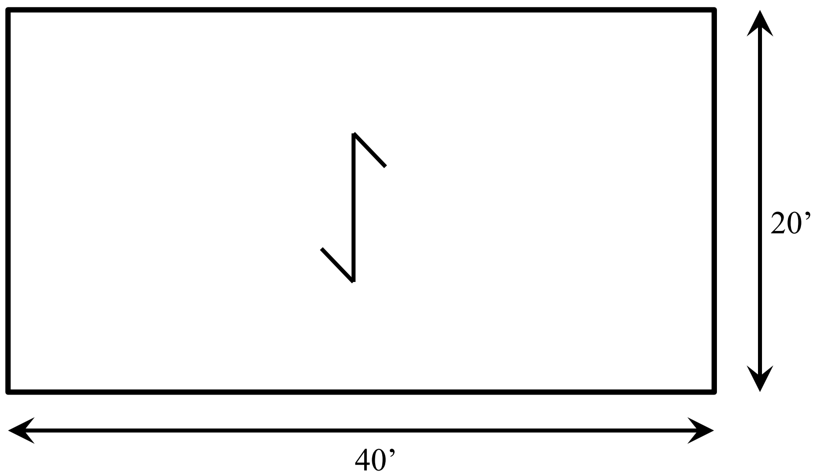


Figure 7-4 shows the typical be studied to perform the structural impact (structural breadth) on the building.

Precast planks layout: 4’x20’ – Span in the 20’ direction

Precast plank sizing:

- Loads:
  - Green Roof = 110 PSF
  - Live Load = 100 PSF
- Load combination applied : 1.2D + 1.6L
  - Total weight = 1.2(110) + 1.6(100) = 292 PSF ≤ 299 PSF

SAFE SUPERIMPOSED SERVICE LOADS		IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)																		
Strand Pattern		SPAN (FEET)																		
		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
4 - 1/2"ø	LOAD (PSF)	280	248	214	185	159	138	118	102	87	74	62	52	42						
6 - 1/2"ø	LOAD (PSF)	366	341	318	299	271	239	211	187	165	146	129	114	101	88	77	67	58	50	42
7 - 1/2"ø	LOAD (PSF)	367	342	320	300	282	265	243	221	202	181	161	144	128	114	101	90	79	70	61

Figure 7-5 shows a table captured from the precast plank spec sheet marked with the selected type of plank based on the load combination calculated. Spec sheet is courtesy of Nitterhouse.com and can be found in Appendix I.

The allowable roof deflection by the International Building Code (IBC) is:

$$Roof\ \Delta_{LL} = {}^{L}/_{240} = {}^{(20)(12)}/_{240} = 1"$$

$$E = 5700 \times \sqrt{f'_c} = 5700 \times \sqrt{6000} = 441520.1\ PSI$$

$$Deflection:\ \Delta_{actual} = {}^{5wl^4}/_{384\ EIc} = {}^{(5)(282)(1728)(20)^4}/_{(384)(441520.1)(3134)} = 0.76"$$

$$\Delta_{LL} \geq \Delta_{actual}\ \therefore OK$$

For further detailed calculations and shear and moment diagrams, refer to Appendix J.

As a result, the existing structure will hold the new system and will perform perfectly.

7.13 Conclusion and Recommendation

The precast panels will be applied on an area of 21,450 SQF using 4’x20’x8”+2” topping planks. The analysis showed time savings of 18 days of the critical path and cost savings of $75,142 that justified the additional costs and made it a net savings of $47,601.

With all the great benefits discussed, especially the cost and schedule savings, it is not recommended to apply the analysis on the building. The reason is because of the nature and the location of the building. As discussed in analysis 2 in chapter 6, there will be future restaurant. Also, as the project being a museum, future renovations are expected. With precast, that is not an easy task. Also, with the high end building aesthetics, the precast concrete may not serve the interior finishes expected by the architect. A further limitation, with the building location, the high number of truck deliveries is an issue that may not be resolved. The traffic authorities may not vacate the streets for deliveries in addition to Williams College student traffic.

8.0 Analysis 4: Feasibility Study and Design for Solar Photovoltaic Panels Application

8.1 The Problem

The Sterling and Francine Clark Art Institute new addition is a state of the art facility with high end art galleries and research labs. The building has high energy consumption rates. That is due to the nature of the building as it has different complex HVAC systems to better control the air quality in different spaces in the building. In addition, the lighting system is considered to be one of the building's systems that has high energy consumption rates to adequately light artifacts in galleries not to mention the energy consumed in labs. This new project may not be able to achieve the aimed Silver LEED rating according to the latest version of LEED score card. Employing the benefits of the solar Photovoltaic (PV) panels will not only contribute to better LEED rating, better yet, it will reduce the dependency on relying on power grid, decrease the use of generators, and essentially decrease energy costs.

8.2 The Goal

The goal is to determine the reduction in energy costs in the long term by determining the payback period and how effective energy produced by the PV panels.

8.3 The Method

- Studying the solar intake of the building.
- Determining the most effective solar angle that will produce the highest energy rates.
- Defining the most applicable and effective panels to the location and energy performance needed of the building.
- Calculating how much of energy can the panels produce with the given location, solar intake, and type of the selected panel. Then, determining the panels cost, energy savings, and payback period.
- Construction analysis in terms of:
  - Detailed cost estimate.
  - Electrical Tie-in.

8.4 Background Information

The main goal of this analysis is to reduce the amount of energy used on the new addition of the sterling and Francine Clark Art Institute along with energy cost reductions using a solar PV system. The existing museum building was built on May 17, 1955. That is about 56 years and 11 months to the date if this report. Therefore, the new addition will definitely last longer than 50 years. PV systems life span can definitely hold more than half of that period and they come with a warranty of 25 years. So it is expected to last even longer. Furthermore, PV systems are an attraction point for investors due to their relatively shorter payback periods. Most PV systems have payback periods of 10 to 15 years to cover their initial costs. Add in, they add an essential value to the building by gaining more LEED points. From AE 473, Building Construction Management and Control, it was stated that greener buildings gain more value. To illustrate, residential buildings which are LEED certified have a better occupation and higher rent rates. With that being said PV panels will not only help the building to achieve the LEED certification they are aiming for, better yet, it will increase the building's value.

PV systems are getting less expensive every year and they are getting more popular every year. In addition, they come with governmental supports and rebates. So, that will help owners to get their payback periods even shorter and start generating free clean energy. They can be very successful in the Sterling and Francine Clark Art Institute new addition by utilizing the adjacent existing building flat roof. This analysis will study and illustrate the initial design of the PV system and the feasibility of applying the system to Sterling and Francine Clark Art Institute new addition using various reliable resources and means with the expectation of getting financially feasible, valuable, and greener outcomes.

8.5 Analysis Summary

The PV panels will be applied on Sterling and Francine Clark Art Institute new addition by placing them on one of the adjacent existing buildings, the Manton, top roof. The useable roof area was calculated to be 24,600 SQF. A total of 49 PV arrays, each has 8 panels/modules, and one inverter will be incorporated. Each array produces 1,920 watts and the inverter's capacity is 95 kW. The system will produce 94.08 kW at maximum efficiency (lab and optimum conditions). However, it will produce 32.23 kWdc in the given the conditions. The system is to power the lights of the following spaces: family room, lobby, café, two retail spaces, and the vestibule that requires 31.13 kWac of electrical loads. The PV system is going to be a grid-tie system, i.e., the method of connection is the net metering method. The system costs $261,910 and labor costs $517,440 and the net system cost would be $227,646 after incentives and rebates. Per to the payback period calculated at the end of the chapter, the owner will start making money on the sixth year earning $23,754.70 and will end up saving $544,520 over the 25 years.

8.6 How Does It Work?

The way PV systems work is fairly simple. After deciding where the system will be applied and what type of the roof - in some cases they are installed on the ground - is being installed at, flat vs. pitch, connection method is next to choose. For this case, grid-tie connection is the method of connection. Then the solar modules will be installed on the roof and generating DC currents from the collected sun/solar rays. The many PV panels will be connected to a combiner to combine the collected currents. Then they will be sent to an inverter to transform the current from DC to AC current. Finally, the AC current will be combined with the building's grid feed at the meter box. The following figure (Figure 8-1) show a simple representation of how grid-tie PV systems work.

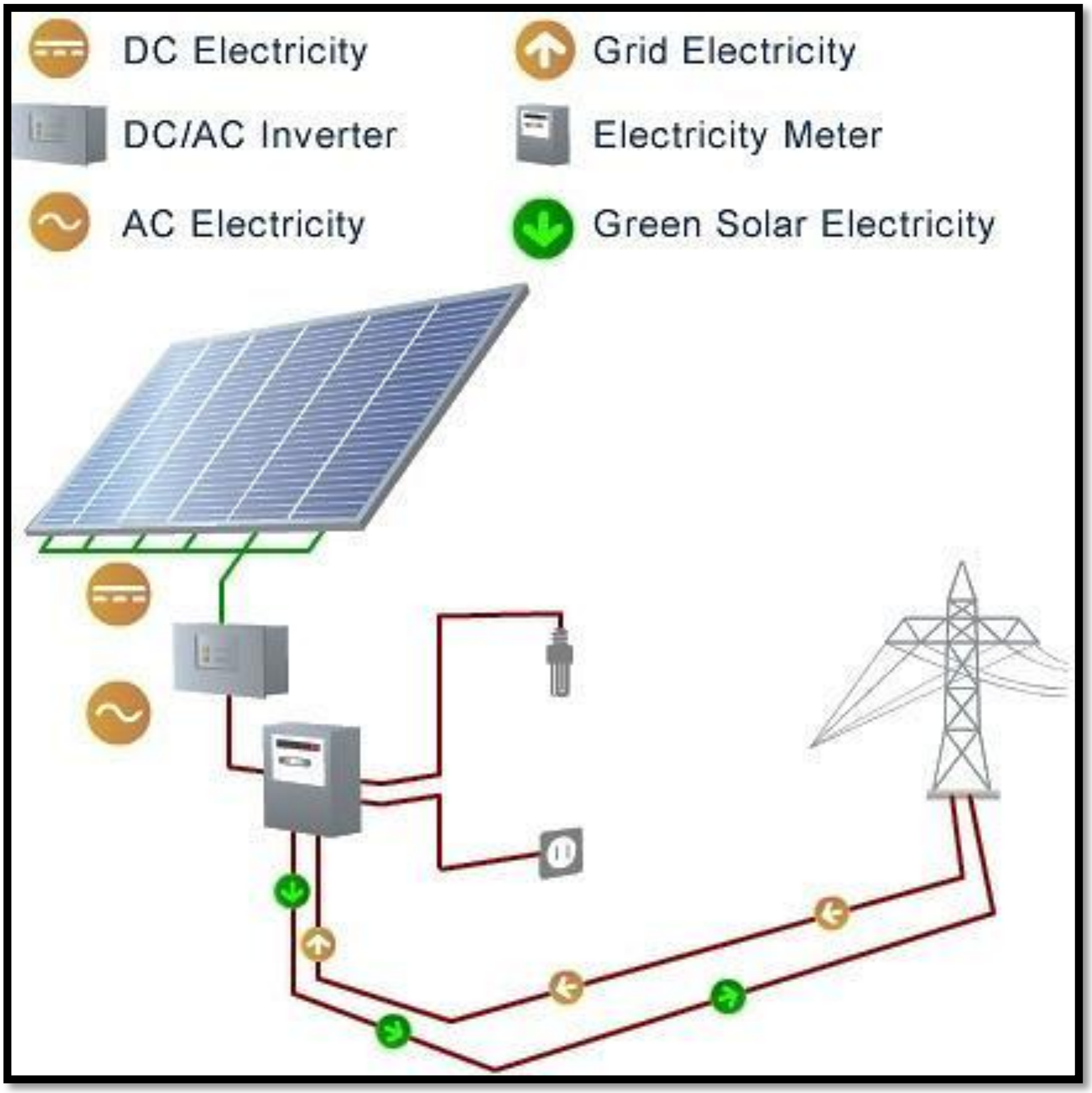


Figure 8-1: How the grid-tie PV system works – *Image courtesy of* Raycity.com

8.7 Initial Building Planning

The leading limitation for determining the feasibility of applying any PV system on a building, is studying the building location carefully (Figure 8-2).

Figure 8-2: Site Location – *Image courtesy of Bing Images*

The Sterling and Francine Clark Art Institute new addition is noted by the number 1, the Museum building is noted by number 2, and the Manton, where the PV panels will be at, is noted by number 3. The captured picture doesn't show any shadows that may impede solar rays to reach the panels. The tree located on the south side is not affecting the top roof as it is not high enough to cast its shadow on it. So, it will be ignored for the rest of the analysis. The Manton's roof area was calculated to be about 24,600 SQF. The calculated roof area accounted for the housed mechanical equipment and a 10' clearance from roof edges. Later in this section of the report, there will be a roof plan showing mechanical equipment locations and the 10' offset from the roof edges. The location was chosen based on the following reasons: reserving the aesthetics of the new addition, large open roof area, close to the new building, and since the building is facing south, that will the useable space and solar rays collection.

The next step is to perform a shadow analysis for the Manton building, where the PV system will be placed at. There are several software that can do such simulations. Google Sketch-Up v8 will be used to perform this analysis in this section. The Google Sketch-Up model will study the effects of the adjacent buildings on different times of the year. In this analysis, summer and winter solstices and spring and fall equinoxes at 9:00 am and 4:00 pm of each will be analyzed on the building. The next figure (Figure 8-3) shows the overall location of the Manton along with the new addition and the museum.

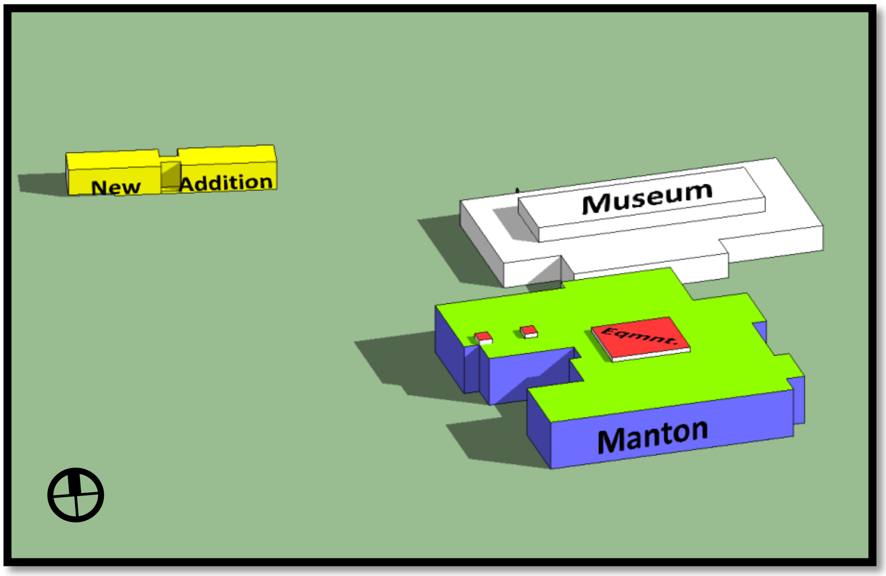


Figure 8-3: Manton Building Location in Relation with Adjacent Buildings

The **yellow** building in the top left corner is the first floor of the Sterling and Francine Clark Art Institute new addition. Where the **white** building is the Museum and the **blue** building is the Manton. The Manton's roof shaded in **green** is where the panels will be placed and the areas shaded in **red** are where the mechanical equipment is located.

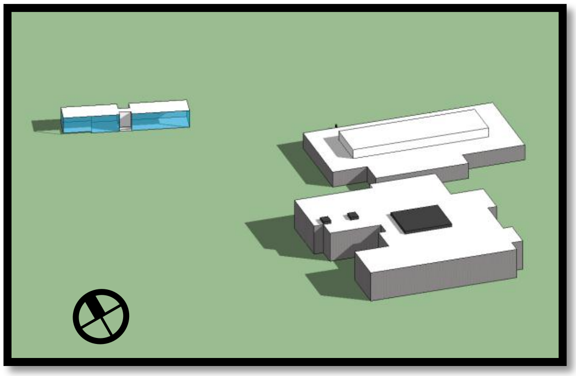
The following information in the table (Table 8-1) is essential to run the simulation accurately in Google Sketch-Up and the rest of the analysis.

Table 8-1: Information Needed To Perform Solar Analysis	
Building Location	N 42° 42' 28.5156" W 73° 12' 54.9806"
Elevation of Roof	32 Feet
Average Sunlight Hrs/Day	4.2
System Orientation	Facing South
System Tilt Angle	42.7°
Summer/Winter Tilt Angle Adjustment	± 15°
Spring Equinox (Year 2012)	March 20
Summer Solstice (Year 2012)	June 20
Fall Equinox (Year 2012)	September 22
Winter Solstice (Year 2012)	December 21

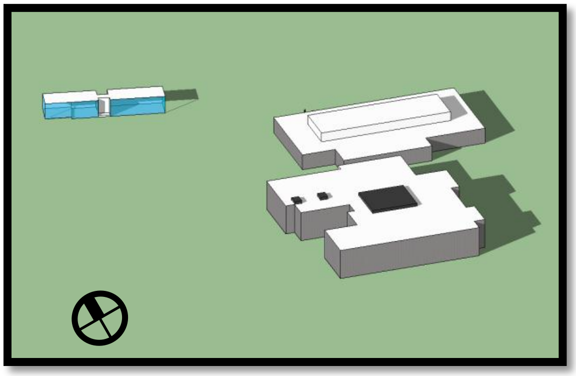
Table 8-1 shows the information needed to perform the solar analysis on the building to achieve the maximum solar rays collection.

The next eight captured images from Google Sketch-Up in figure (Figure 8-4) will show the casted shows on the designated area for the PV system.

Spring Equinox 2012:

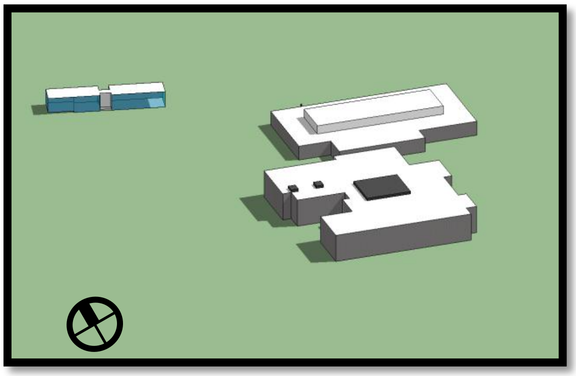


9:00 AM

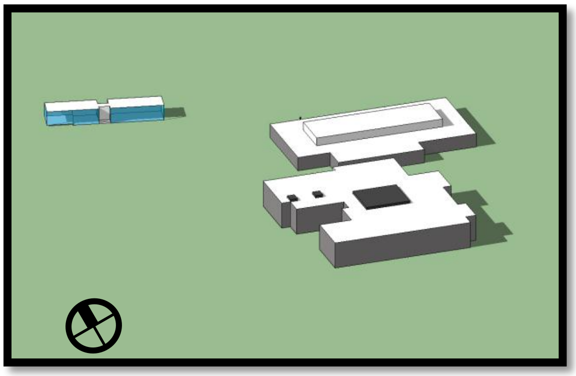


4:00 PM

Summer Solstice 2012:

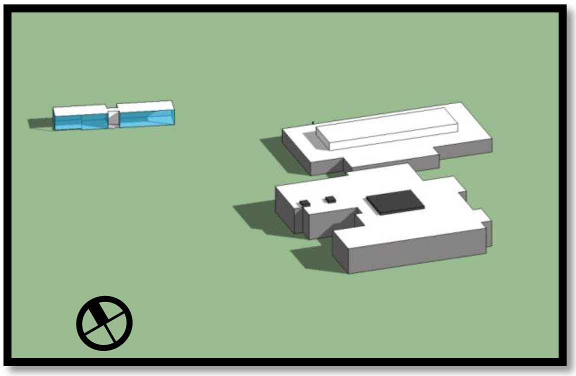


9:00 AM

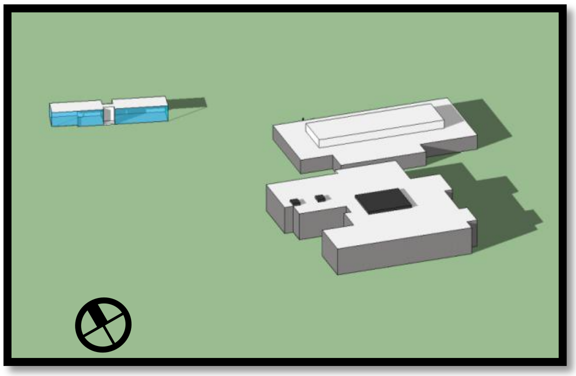


4:00 PM

Fall Equinox 2012:

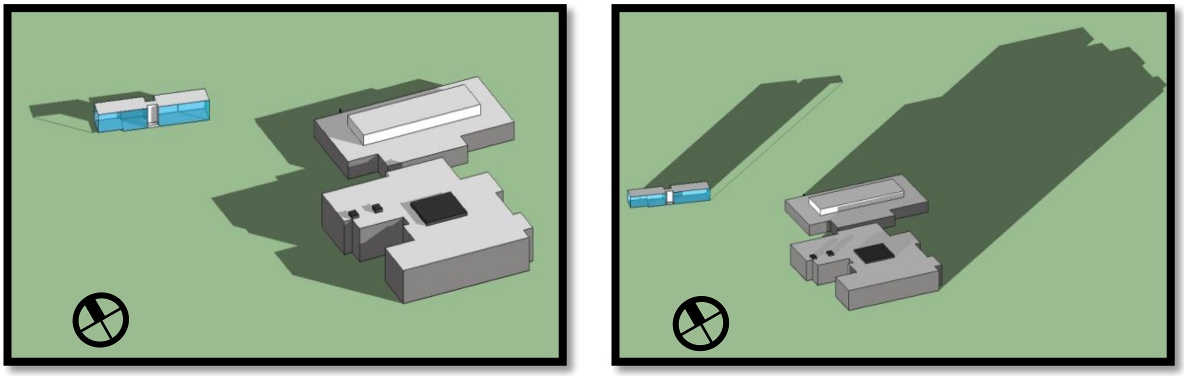


9:00 AM



4:00 PM

Winter Solstice 2012:



9:00 AM 4:00 PM

Figure 8-4: Shadow Casting on the Manton by Google Sketch-Up

As seen from the previous images in Figure 8-4, the casted shadows on the roof of the Manton building is insignificant except at winter solstice later in the day which still not significant impact on the energy generation.

8.8 Realistic Potential Energy Reductions

Nowadays, it is still difficult to power the entire building of this size with PV panels. It would be more practical if a system building system be powered by solar power or even powered partially. The lighting system of the Sterling and Francine Clark Art Institute new addition demands a 174.4 kWac. Given the location restrictions, especially architecturally, it is not possible to even power the lighting system. However, certain spaces' lights will be powered by the proposed PV system. The lights of the spaces that will be power by solar power are the new addition's café, lobby, two retail spaces, vestibule, and the family room. The mentioned spaces demand a total of 31.13 kWac. Assuming a nine hours of operation per day the system will consume 280.17 kWh/day, 8405.1 kWh/month, and 100861.2kWh/year. Since the cost of energy is 12.5 ¢/kWh, then the monthly cost can be calculated which would be $1,050.64 for those spaces only.

Other limitations include roof useable area and PV panel size. It has been determined by the roof useable area that only 24,600 SQF for PV panels to be placed. As mentioned, the existing mechanical equipment and 10' clearance from the roof edges were taking care of in the useable roof space calculations. The size of each PV array, each has eight panels/modules, is about 139.2 SQF and the inner row shading length from one array to the next one is 13'-9 ¼" yielding a total number of 49 arrays of the selected system. The next captured image from AutoCAD 2012 (Figure 8-5) illustrates the dimensions of an array. The system selection and layout processes will be discussed in the sections 8.8.1 and 8.8.2 (refer to Table 8-2 for system selection and Figure 8-7 for system layout).

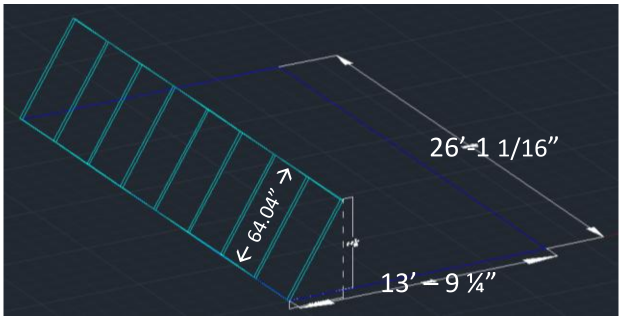


Figure 8-5: PV Array Dimensions and Inner Row Shading Length

8.8.1 System Selection and Connection Method

The PV system chosen is a “grid-tie” PV system. That means it gets connected to the grid feed side entering the building rather than connecting it to the one of the building’s panel boards for instance. To better visualize this type of connection, examine the next figure (Figure 8-6). A more detailed 3-line (Figure 8-7) diagram of the system will be discussed later in this chapter of the report.

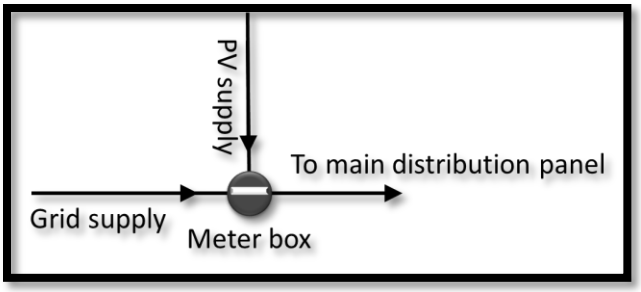


Figure 8-6: Grid-Tie Connection

This type of connection is also known as the “net metering” connection method. This is the most common method to tie in the system to the building and there are many advantages to it. One is that it is the simplest way to tie it to the building and requires a minimum efforts and components to do it and it works well with grid feed. Another is its ability to run the meter readings backwards in a sense. In another words, you can sell electricity to the electric company. So, in the course of the year, the electric company will cut a check for the owner for the amount of electricity sold to the company. Then, the owner would have to pay the difference or will get paid if he consumes less than what he sold. For this analysis, the owner probably won’t get paid, however, the owner will definitely will save money.

After selecting the connection method, selecting a PV panel comes into place. The next table (Table 8-2) will show a comparison between three manufacturers based on rated power output, dimensions and weight of the panel, price, and manufacturer warranty.

Table 8-2 : PV System Manufacturers Comparison

Manufacturer	ASTRONERGY	SHARP	AUO Solar
Rated Power Output	240 Wdc	235 Wdc	250 Wdc
Dimensions	64" x 39" x 1.8"	64.6" x 39" x 1.8"	65" x 39" x 1.6"
Weight	44 lbs	41.9 lbs	48.4 lbs
Price	$335	$415	$700
Warranty	25 year on **90%** power output	25 year on **80%** power output	25 year on **80%** power output
Advantages & Disadvantages	- 2nd Highest Wattage - Smallest (Area) - 2nd Lightest in Weight - Cheapest - Best Warranty	- Lowest Wattage - 2nd Smallest (Area) - Lightest in Weight - 2nd Cheapest - Worst Warranty	- Highest Wattage - Largest (Area) - Heaviest in Weight - Most Expensive - Worst Warranty
Value	**Highest**	**Mid**	**Lowest**

From the above table, it is apparent that ASTRONERGY Panels has the highest value. That is because it is the most inexpensive one of three, holds the best warranty, the smallest in area, and the second lightest in weight and in power output. Refer to Appendix K for PV panel product detail.

8.8.2 PV System Roof Layout

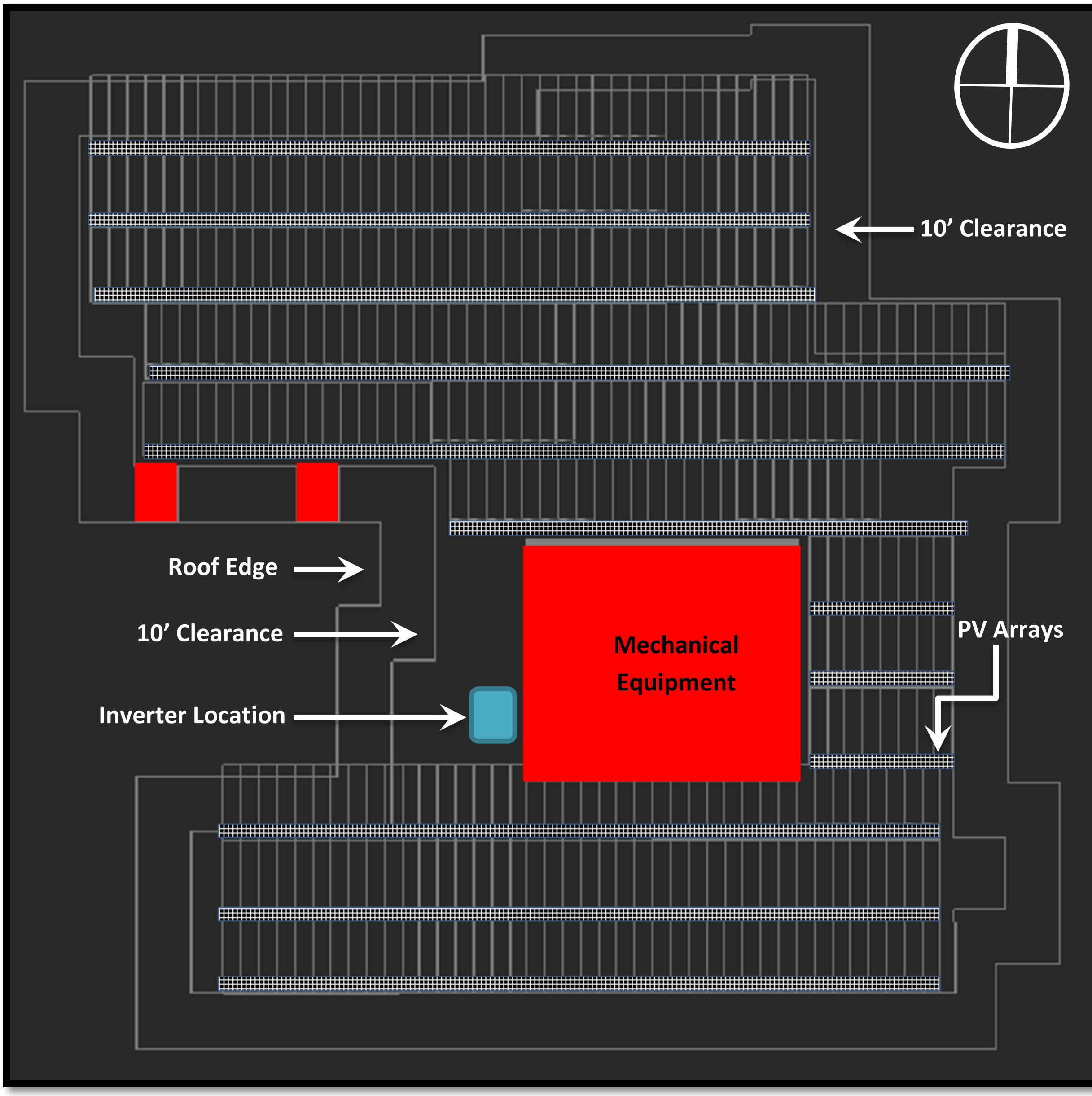


Figure 8-7: PV System Layout on The Manton's Roof

From Figure 8-7, the layout of the PV system on the Manton's roof is showing how they are spaced and how they are lined next to each other. The hatchings represent the location of the PV arrays. The long portrait rectangles are the casted shadows of each panel (each rectangle represents a panel casted shadow). The outer line is the roof edge where the inner one is a reference line to show the 10' feet clearance from the roof edge. The red boxes are the housed equipment on the Manton's roof. They were shown in red as well in the Google Sketch-Up model pictures in Figure7-3 earlier in the report. The useable roof area for PV system application is 42,600 SQF which can house 49 PV arrays yielding 94.1 kWdc of the generated solar power.

8.9 Energy Impact (Electrical Breadth)

8.9.1 Energy Production

One of the early steps of determining the feasibility of implementing the PV system to the building, the potential energy production of the selected PV array needs to be determined. So, calculating the AC energy output of the system is necessary. The chosen PV system consists of 49 arrays, each has eight panels of 240 dcwatts, producing 94,080 dcwatts. On the National Renewable Energy Laboratory (NREL) website, a beneficial calculator was utilized called PVWatts v2 AC - Energy & Cost Savings. The calculator requires entering building location, DC rating, DC to AC derate factor, array tilt type, tilt angle, and azimuth (facing south = azimuth180°, to maximize amount of solar rays), and the cost of electricity for the location which is 12.5 ¢/kWh to calculate, AC rating, solar radiation, kWh/year, and energy value. Inputs and results are shown below in tables 7-3.1 and 7-3.2.

Table 8-3.1: Station Identification	
City	Williamstown
State:	Massachusetts
Latitude:	42.7 ° N
Longitude:	73.4 ° W
PV System Specifications	
DC Rating:	94.1 kW
DC to AC Derate Factor:	0.770
AC Rating:	72.4 kW
Array Type:	Fixed Tilt
Array Tilt:	42.7 °
Array Azimuth:	180.0 °

Table 8-3.2: Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.93	6852	856.77
2	3.69	7891	986.69
3	4.59	10387	1298.79
4	4.78	10100	1262.90
5	5.08	10620	1327.92
6	5.01	9765	1221.02
7	5.33	10550	1319.17
8	5.11	10326	1291.16
9	4.80	9661	1208.01
10	3.87	8282	1035.58
11	2.62	5536	692.22
12	2.37	5414	676.97
Year	4.19	105383	13177.1

Table 8-3: PVWatts Inputs and Results

The PVWatts calculator shows an annual AC energy production of 105,383 kWh. The energy production is more than enough to power the spaces mentioned earlier in the report that consumes 100,861.2 kWh per year. The table also shows an annual energy value of $13,177.1.

8.9.2 System Tie-in

To determine what is going to be in the PV system, it is necessary to identify the connection method to the building. The PV system chosen is a grid tie system which is also known as the "net metering" method. This is the most common method because it is relatively easier and more cost effective than other methods. With that said, the PV power supply will be tied in to the existing utility service side. Therefore, the PV power supply will combined with the utility feed coming at the meter box before it reaches to the building's main distribution panel and then one feed going out of the meter box is sent to the main distribution panel. Figure 8-8, the 3-line diagram, visualizes the entire connection of the system.

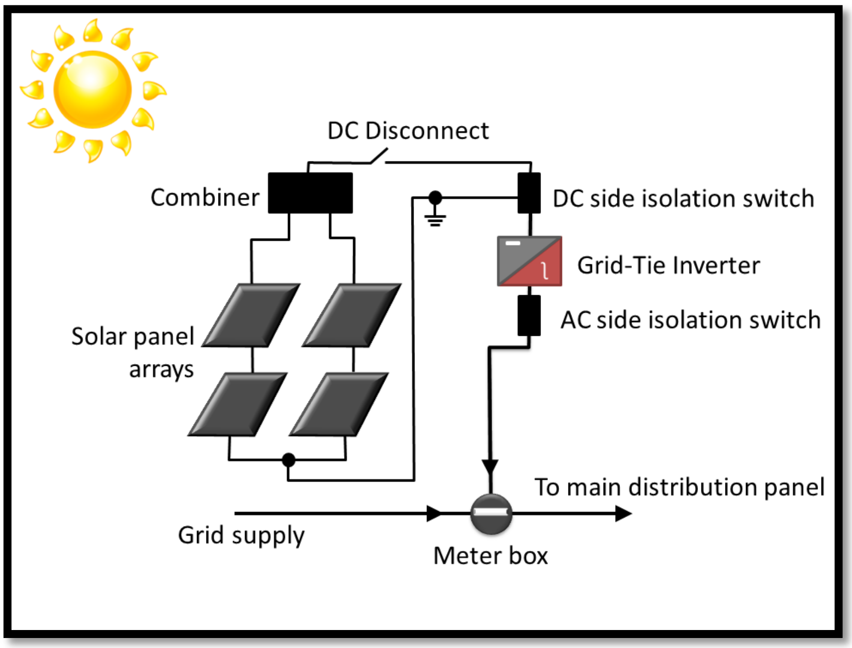


Figure 8-8: 3-Line Diagram

As shown in Figure 8-8, the PV system connections require the following:

1. DC wires
2. DC switch, disconnect
3. Combiner
4. Grid-tie inverter
5. AC wires
6. AC switch
7. Meter box (grid and PV supplies connects here)

Sizing wires is an essential part of the analysis. There is going to be two types of wires, DC and AC wires. According to the inverter's spec sheet, the DC wire is to hold 320A. Since the wire will be exposed to sun and other weather conditions and it is considered to be a service entrance, code requires a heavy duty to be used. The conduit containing the DC wires will have two feed wires and a ground wire. That will result in (2) 90°C USE-2 #350 KCMIL +(1) #1/o G. in 2 ½" C.

For the other side of the inverter, the AC side, the wires will not be exposed to sun and different weather conditions. So, standard wires and conduits will be used. The inverter AC side is rated to hold 115A. To be conservative, the next wire size will be used 130A. The conduit will hold five wires including the neutral and ground wires. That will yield to the following result
(4) 75°C THHW/THWN #1 AWG + #1 G in 2" C. See Appendix L tables used.

Since DC wires are expensive and have the possibility of relatively larger voltage drops, the inverter will be kept in the Manton building to reduce the length of the DC wires. Then, an AC feed will run from the Manton the building's electrical room. The SOLECTRIA inverter's dimensions are 76"H x 54"W x 25.3"D and weighs 1,748 lbs and delivers 95 kW at 208/240 VAC at 95.3% efficiency and 480/600 VAC at 96.5% efficiency. See Appendix K for complete product data for the selected PV system (panels and inverter).

8.10 Financial Feasibility

So far, the application of the PV system on the Sterling and Francine Clark Art Institute new addition is feasible and it is able to power the discussed spaces' lighting fixtures. However, the decision to go or no not to go with an investment for most investors rely on the financial feasibility. This section of the report will study the financial feasibility to aid the Sterling and Francine Clark Art Institute owner to whether this application is worth applying or not.

The initial cost of the system is as the following:

- Astronergy Grid-tie Solar Panels 1,920 watts per array
    - 8 Solar panels per array (240 watt; 64.04" x 39.13"x1.78"/Panel)
    - $4,590/Array
    - Total Arrays needed = 49
    - Panels Price = $224,910
        - Panels price include the following:
            - ◊ Solar modules, power boxes, UL listed disconnects and safety fuses, UL listed cables and connectors.
- 95kW Inverter, 3-Phase, 480V
    - Inverter Cost: $37,011
- PV Panels and Inverter Cost = $261,910
- Cost of Installation = $5.5/Wdc x 1920 Wdc x 49 Arrays = $517,440
- Cost of Transportation = $2,500
- **Gross System Cost = $781,850**

The government of the United States has put great monetarily efforts to support investors who are willing to power their buildings with a green technology such as the photovoltaic system in this case. The government has grants green investors with rebates and incentives. They are as the following (transportation cost will not be considered):

- MA Solar Renewable Energy Credits (SRECs): $0.3/kWh for 10 years
    - 105,383 kWh x $0.3/kWh x 10 years = $316,149
- Federal Tax Credit: 30% of Gross Cost at Installation
    - $ 234,555
- MA Renewable Energy Income Tax Credit: $1,000
- Total incentives = $551,704
- **New Net Total System Cost = $227,646**

After calculating all systems costs, installation, and the generous governmental incentives, it is essential to show the owner the payback period of the PV system. One of the most reliable PV system tools is the system advisor model (SAM: sam.nrel.gov) provided free of charge by the National renewable Energy Laboratory (NREL). SAM is a performance and financial tool where a renewable energy system specs are entered into the software to determine the system performance in the location specified as well as the financials of the system. Also, SAM is linked to PVWATTS to get the performance of the system in the location of the building. However, SAM was utilized only to obtain the payback period of the PV system.

The payback period was studied on a total of 25 years span. The following assumptions were made to calculate the payback period:

- Transportation cost of $2,500.
- No loans.
- An escalation of 2% in the production tax credit, system default.
- System degradation of 0.5%, system default.
- A scale factor of 1 for the electric load data.

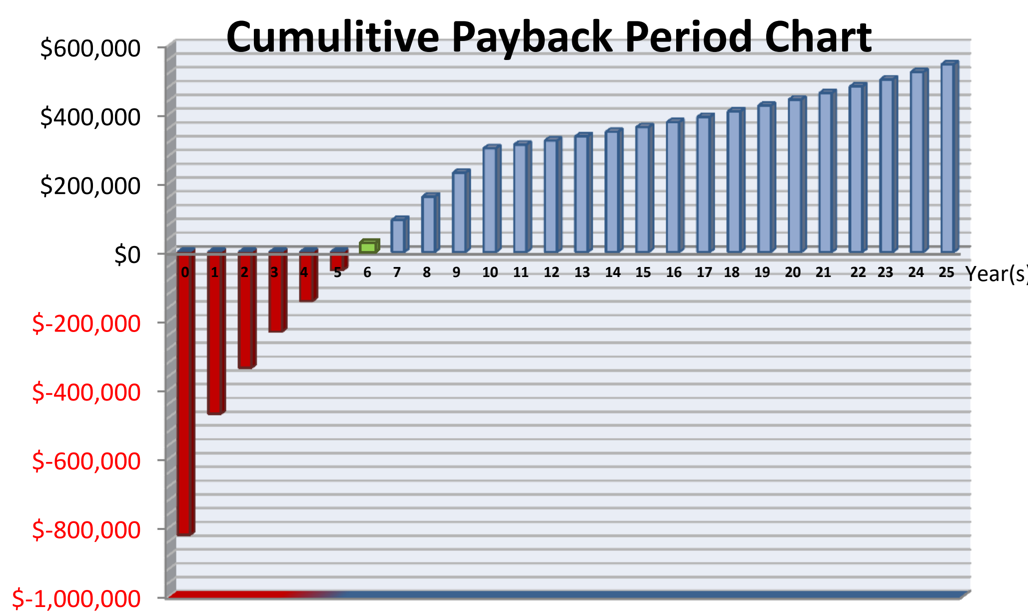


Figure 8-9: Payback Period Chart showing a return on investment on the 6th year

The payback period calculated is to have a return on the investment on the 6th year. The owner will start making money on the sixth year earning $23,754.70 and will end up saving $544,520 over the 25 years. Hence, the chart above shows 'cumulative' earnings. A cumulative cash flow table is shown in **Appendix M.**

8.11 Logistics

The logistics coordination is relatively not complicated. The delivery trucks will pull over in the Manton's parking lot. Prior trucks arrival, there will be a swing hoist ready and waiting for the new deliveries. Once the delivery trucks arrive, the swing hoist will hoist deliveries from the trucks bed to the roof. Figure 8-10 illustrates the process where Appendix C shows the full logistics plan for delivering PV panels. Regularly, 23' flatbed trucks are used for delivery. So, it has been determined that 'three' trucks will be needed based on the size of trucks, pallets, and the packaged PV panels.

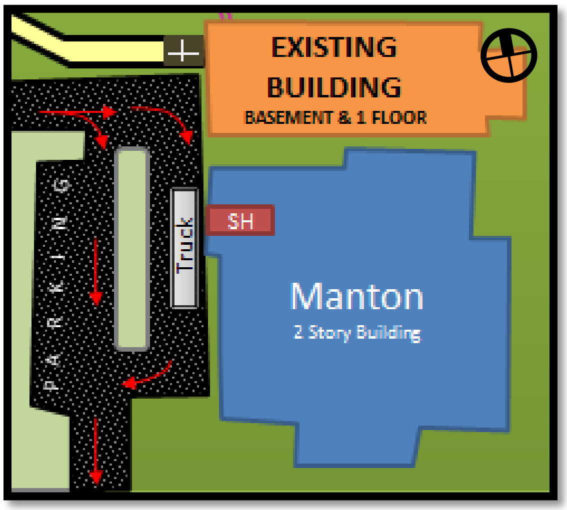


Figure 8-10 is a snap shot of the full logistics plan in Appendix C that shows the PV panels delivery trucks.

8.12 Conclusion and Recommendation

The PV panels will be applied on Sterling and Francine Clark Art Institute new addition by placing on the Manton's top roof. The useable roof area was calculated to be 24,600 SQF. A total of 49 PV arrays, each has 8 panels/modules, and one inverter will be incorporated. Each array produces 1,920 watts and the inverter's capacity is 95 kW. The system is rated to produce 94.08 kW at maximum efficiency; however, it will produce 32.23 kW in the given the conditions. The PV system is going to be a grid-tie system. The net system cost is $227,646 after all incentives and rebates. Per to the payback period calculated at the end of the chapter, the owner will start making money the sixth year earning $23,754.70 and will end up saving $544,520 over the 25 years.

After studying the feasibility of incorporating the PV panels thoroughly, it is recommended to go with the application of PV's on the building. That is due to the all the benefits discussed and the financial feasibility study performed on the system. By applying the system on the building, the environment will benefit as well as the owner.

9.0 Recommendations and Conclusions

Throughout the fall and the spring semesters of 2011/2012 academic year, a greater insight of the Sterling and Francine Clark Art Institute new addition was obtained. That allowed identifying problems and finding the best solutions possible and how to implement them on the project to make it more efficient. Mostly, the report discusses the issues and their solutions from a construction management standpoint. However, other construction fields were kept in mind such as structural impacts, electrical impacts, and architectural impacts.

The Senior Thesis Final Report discussed and provided a comprehensive background and four enhancements to the construction of the Sterling and Francine Clark Art Institute new addition. The four enhancements/analyses presented in this report are: the Implementation of MEP Prefabrication, Building Information Modeling – Virtual Mockup, Precast Roof Planks, and Feasibility Study and Design for Solar Photovoltaic Panels Application. The following four paragraphs conclude the findings of the four analyses performed on the Sterling and Francine Clark Art Institute new addition.

Analysis 1: Implementation of MEP Prefabrication (Chapter 5)

The analysis was applied on the plant side of the building prefabricating the embedded plumbing system. The area was chosen due to the complexity of the building structure where the opportunity of minimizing construction issues through prefabrication increases. By applying the analysis the project team can save 15% of fabrication time, 50% of installation time, and 3.5 days of the critical path. The time savings resulted in a net cost savings of $57,771.

Analysis 2: Building Information Modeling – Virtual Mockup (Chapter 6)

This analysis in particular looked for an extraordinary method of enhancing the construction experience of the project. With the boom of new technologies, the virtual mockup is the future of 3D modeling. The analysis showed how all parties involved in the project will greatly benefit from the model not only during construction, better yet, throughout the entire life span of the project. Some of the benefits are: enhancing the coordination experience and easing future renovations and maintenance. The total cost for the virtual mockup built in this analysis is $1,795. The labor interpretation time savings reduced the cost to be $240.55. If other savings were implemented, it would result in cost and time earnings to the project and, especially, the owner.

Analysis 3: Precast Roof Planks (Chapter 7)

To better serve the project's schedule, this analysis adopted another prefabrication method. The precast roof planks are to increase efficiency and reduce time. The analysis will be applied on a roof area of 21,450 SQF, over the VECC side of the building, using 4'x20'x8"+2" topping planks. The application of the will result in 16.6% increase over the existing CIP system. On the other side of the spectrum, the cost savings from the general conditions, which is $75,142, is going to justify the additional costs and making it a net savings of $47,601. Schedule wise, it is going to save 18 days of the critical path. The nature and the location of the building are two limitations for this analysis. Since the building is a museum designed by the famous Japanese

Architect 'Tadao Ando' there will be lots of aesthetics that cannot be met with precast in terms of interior finishes. Additionally, museums usually undergo different renovations during their lifespan to accommodate changes of new artistic eras. That can be a big limitation for the owner by using precast in his/her building. Location wise, the intense amount of delivery trucks can cause congestions in the neighborhood streets which may require the traffic authorities to vacate the streets for the truck. That might be challenging since there are not alternative streets for the ones will be closed not to mention the student traffic of Williams College.

Analysis 4: Solar Photovoltaic (PV) Panels (Chapter 8)

The best way not to interfere Ando's architecture is to apply this analysis on the one of the existing buildings which is the Manton. The Manton has 24,600 SQF of flat roof with no obstacles from surroundings. In addition, it is almost perfectly facing south which eases the layout process of the PV panels and increases the amount of solar rays collected. A total of 49 PV arrays, each has 8 panels/modules, and one inverter will be incorporated. Each array produces 1,920 watts and the inverter's capacity is 95 kW. The system will produce 94.08 kWdc at maximum efficiency (lab and optimum conditions). Due to imperfections caused by the location, weather, and system degradations, the system will be able to produce 32.23 kWac. The system will generate an annual AC energy production of 105,383 kWh as well as an annual energy value of $13,177.1. The PV system is going to be a grid-tie system costing $261,910 and labor costs $517,440. However, the net system cost calculated to be $227,646 after all incentives and rebates. The payback period calculated shows that the owner will start making money on the sixth year earning $23,754.70 and will end up saving $544,520 over the 25 years.

10.0 Resources

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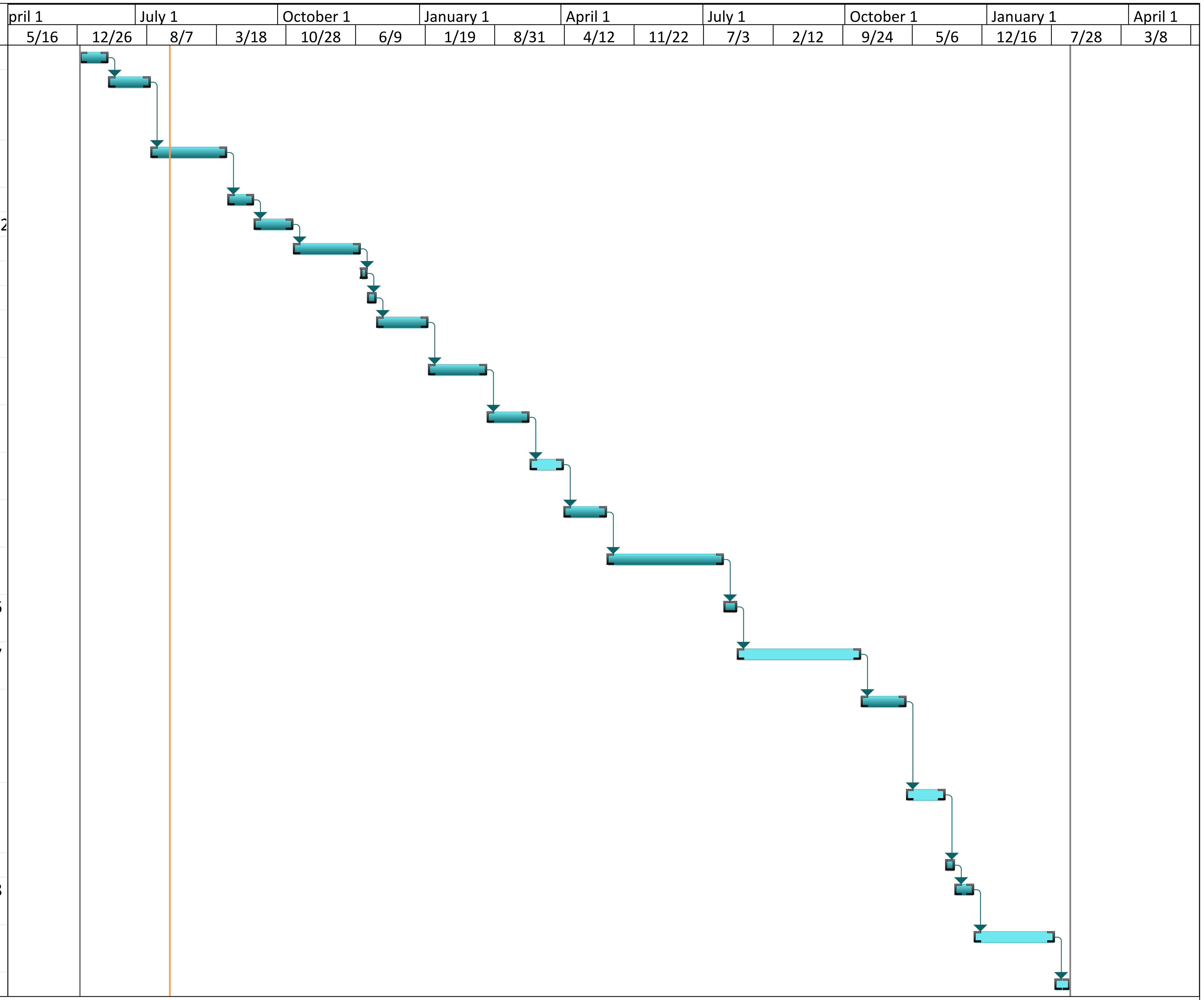
Appendix A

Project Schedule Summary

ID		Task Mode	Task Name	Duration	Start	Finish
1			Publish GMP Documents	65 days	Tue 1/4/11	Mon 4/4/11
2			Procurement (preparing contracts + Owner Review and Approval)	98 days	Tue 4/5/11	Thu 8/18/11
3			Shop Drawings & Approvals	176 days	Fri 8/19/11	Fri 4/20/12
4			MEP coordination	61 days	Mon 4/23/12	Mon 7/16/12
5			Budget Development	90 days	Tue 7/17/12	Mon 11/19/12
6			Fabrication & Delivery	155 days	Tue 11/20/12	Mon 6/24/13
7			Utility Relocation	16 days	Tue 6/25/13	Tue 7/16/13
8			Excavating	21 days	Wed 7/17/13	Wed 8/14/13
9			East Lower Lobby: FRP +Curing + Waterproofing	119 days	Thu 8/15/13	Tue 1/28/14
10			MEP/Resevoir: FRP +Curing + Waterproofing	135 days	Wed 1/29/14	Tue 8/5/14
11			Display: FRP +Curing + Waterproofing	98 days	Wed 8/6/14	Fri 12/19/14
12			East MER: FRP +Curing + Waterproofing	79 days	Mon 12/22/14	Thu 4/9/15
13			Central: FRP +Curing + Waterproofing	99 days	Fri 4/10/15	Wed 8/26/15
14			Central: Install Roof + Interior Fitout	268 days	Thu 8/27/15	Mon 9/5/16
15			West: FRP +Curing + Waterproofing	31 days	Tue 9/6/16	Tue 10/18/16
16			West: Install Rood + Interior Fitout	285 days	Wed 10/19/16	Tue 11/21/17
17			Lower Level (Displays A, B, C/ Court/MER/ Resevoir): Rough-In Overhead	104 days	Wed 11/22/17	Mon 4/16/18
18			Lower Level (Displays A, B, C/ Court/MER/ Resevoir): Finishing	90 days	Tue 4/17/18	Mon 8/20/18
19			East MEP/Link: FRP	22 days	Tue 8/21/18	Wed 9/19/18
20			East MEP/Link: Install Stone Cladding	44 days	Thu 9/20/18	Tue 11/20/18
21			East MEP/Link: Interior Fitout	186 days	Wed 11/21/18	Wed 8/7/19
22			Closeout	35 days	Thu 8/8/19	Wed 9/25/19



Project: Schedule Tech 1
Date: Thu 10/20/11

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

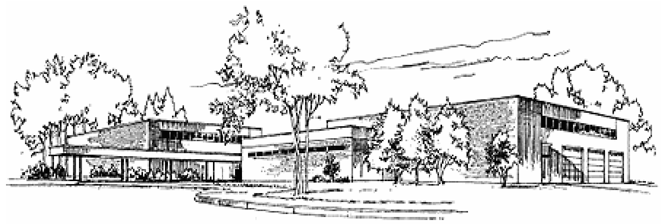
Appendix B

RSMeans Estimate

Square Foot Cost Estimate Report

Estimate Name: **Untitled**

Building Type:	**School, Vocational with Face Brick with Concrete Block Back-up / Steel Frame**
Location:	PITTSFIELD, MA
Stories Count (L.F.):	**1.00**
Stories Height	**18.00**
Floor Area (S.F.):	**68,153.00**
LaborType	**Union**
Basement Included:	Yes
Data Release:	**Year 2011 Quarter 3**
Cost Per Square Foot	**$192.75**
Total Building Cost	**$13,136,500**



Costs are derived from a building model with basic components. Scope differences and market conditions can cause costs to vary significantly.
Parameters are not within the ranges recommended byRSMeans.

		% of Total	Cost Per SF	Cost
A Substructure		**13.4%**	**19.27**	**$1,313,500**
A1010	**Standard Foundations**		**5.77**	**$393,000**
	Strip footing, concrete, reinforced, load 11.1 KLF, soil bearing capacity 6 KSF, 12" deep x 24" wide			
	Spread footings, 3000 PSI concrete, load 200K, soil bearing capacity 6 KSF, 6' - 0" square x 20" deep			
A1030	**Slab on Grade**		**5.34**	**$364,000**
	Slab on grade, 4" thick, non industrial, reinforced			
A2010	**Basement Excavation**		**3.63**	**$247,500**
	Excavate and fill, 10,000 SF, 8' deep, sand, gravel, or common earth, on site storage			
A2020	**Basement Walls**		**4.53**	**$309,000**
	Foundation wall, CIP, 12' wall height, pumped, .444 CY/LF, 21.59 PLF, 12" thick			
B Shell		**33.4%**	**48.18**	**$3,283,500**
B1010	**Floor Construction**		**20.29**	**$1,383,000**
	Cast-in-place concrete column, 12" square, tied, 200K load, 12' story height, 142 lbs/LF, 4000PSI			
	Flat slab, concrete, with drop panels, 6" slab/2.5" panel, 12" column, 15'x15' bay, 75 PSF superimposed load, 153 P			
	Floor, concrete, slab form, open web bar joist @ 2' OC, on W beam and column, 25'x30' bay, 29" deep, 100 PSF su			
	Floor, concrete, slab form, open web bar joist @ 2' OC, on W beam and column, 25'x30' bay, 29" deep, 100 PSF su			
	Fireproofing, gypsum board, fire rated, 2 layer, 1" thick, 10" steel column, 3 hour rating, 17 PLF			
B1020	**Roof Construction**		**9.10**	**$620,500**
	Floor, steel joists, beams, 1.5" 22 ga metal deck, on columns, 25'x30' bay, 25" deep, 40 PSF superimposed load, 60			
	Floor, steel joists, beams, 1.5" 22 ga metal deck, on columns, 25'x30' bay, 25" deep, 40 PSF superimposed load, 60			
B2010	**Exterior Walls**		**9.48**	**$646,000**
	Brick wall, composite double wythe, standard face/CMU back-up, 8" thick, perlite core fill			
B2020	**Exterior Windows**		**2.74**	**$186,500**
	Aluminum flush tube frame, for insulating glass, 2" x 4-1/2", 5'x6' opening, no intermediate horizontals			
	Glazing panel, insulating, 1/2" thick, 2 lites 1/8" float glass, tinted			
B2030	**Exterior Doors**		**0.58**	**$39,500**
	Door, aluminum & glass, without transom, wide stile, double door, hardware, 6'-0" x 7'-0" opening			
	Door, steel 18 gauge, hollow metal, 1 door with frame, no label, 3'-0" x 7'-0" opening			

		% of Total	Cost Per SF	Cost
	Door, steel 24 gauge, overhead, sectional, manual operation, 10'-0" x 10'-0" opening			
	Door, steel 24 gauge, overhead, sectional, electric operator, 10'-0" x 10'-0" opening			
B3010	**Roof Coverings**		**5.83**	**$397,500**
	Roofing, single ply membrane, EPDM, 60 mils, fully adhered			
	Insulation, rigid, roof deck, polyisocyanurate, 2#/CF, 2" thick			
	Roof edges, aluminum, duranodic, .050" thick, 6" face			
	Flashing, aluminum, no backing sides, .019"			
	Gravel stop, aluminum, extruded, 4", mill finish, .050" thick			
B3020	**Roof Openings**		**0.15**	**$10,500**
	Roof hatch, with curb, 1" fiberglass insulation, 2'-6" x 3'-0", galvanized steel, 165 lbs			
	Smoke hatch, unlabeled, galvanized, 2'-6" x 3', not incl hand winch operator			
C Interiors		**18.4%**	**26.53**	**$1,808,000**
C1010	**Partitions**		**5.86**	**$399,500**
	Concrere block (CMU) partition, light weight, hollow, 6" thick, no finish			
C1020	**Interior Doors**		**1.83**	**$125,000**
	Door, single leaf, kd steel frame, hollow metal, commercial quality, flush, 3'-0" x 7'-0" x 1-3/8"			
C1030	**Fittings**		**1.29**	**$88,000**
	Toilet partitions, cubicles, ceiling hung, stainless steel			
	Chalkboards, liquid chalk type, aluminum frame & chalktrough			
C2010	**Stair Construction**		**1.31**	**$89,000**
	Stairs, steel, cement filled metal pan & picket rail, 16 risers, with landing			
C3010	**Wall Finishes**		**4.93**	**$336,000**
	2 coats paint on masonry with block filler			
	Painting, masonry or concrete, latex, brushwork, primer & 2 coats			
	Painting, masonry or concrete, latex, brushwork, addition for block filler			
	Wall coatings, acrylic glazed coatings, maximum			
	Ceramic tile, thin set, 4-1/4" x 4-1/4"			
C3020	**Floor Finishes**		**6.98**	**$476,000**
	Carpet, tufted, nylon, roll goods, 12' wide, 36 oz			
	Carpet, padding, add to above, minimum			
	Terrazzo, maximum			
	Vinyl, composition tile, maximum			
C3030	**Ceiling Finishes**		**4.32**	**$294,500**
	Acoustic ceilings, 3/4"mineral fiber, 12" x 12" tile, concealed 2" bar & channel grid, suspended support			
D Services		**34.7%**	**49.98**	**$3,406,500**
D1010	**Elevators and Lifts**		**2.13**	**$145,500**
	Hydraulic passenger elevator, 2500 lb., 2 floor, 125 FPM			
D2010	**Plumbing Fixtures**		**4.61**	**$314,500**
	Water closet, vitreous china, bowl only with flush valve, floor mount			
	Urinal, vitreous china, wall hung			
	Lavatory w/trim, wall hung, PE on CI, 20" x 18"			
	Kitchen sink w/trim, countertop, stainless steel, 44" x 22" triple bowl			
	Service sink w/trim, PE on CI,wall hung w/rim guard, 24" x 20"			
	Shower, stall, baked enamel, terrazzo receptor, 36" square			
	Water cooler, electric, wall hung, dual height, 14.3 GPH			
	Bathroom, lavatory & water closet, 1 wall plumbing, share common plumbing wall*			
D2020	**Domestic Water Distribution**		**0.57**	**$39,000**
	Gas fired water heater, commercial, 100< F rise, 500 MBH input, 480 GPH			
D2040	**Rain Water Drainage**		**0.51**	**$34,500**
	Roof drain, CI, soil,single hub, 4" diam, 10' high			

		% of Total	Cost Per SF	Cost
	Roof drain, CI, soil,single hub, 4" diam, for each additional foot add			
D3010	**Energy Supply**		**9.53**	**$649,500**
	Commercial building heating system, fin tube radiation, forced hot water, 10,000 SF, 100,000 CF, total 2 floors			
	Commercial building heating systems, terminal unit heaters, forced hot water, 10,000 SF bldg,100,000 CF, total, 2 flo			
D3030	**Cooling Generating Systems**		**13.55**	**$923,500**
	Packaged chiller, water cooled, with fan coil unit, schools and colleges, 40,000 SF, 153.33 ton			
D4010	**Sprinklers**		**3.07**	**$209,500**
	Wet pipe sprinkler systems, steel, light hazard, 1 floor, 10,000 SF			
	Wet pipe sprinkler systems, steel, light hazard, each additional floor, 10,000 SF			
D4020	**Standpipes**		**0.95**	**$65,000**
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, 1 floor			
	Wet standpipe risers, class III, steel, black, sch 40, 6" diam pipe, additional floors			
D5010	**Electrical Service/Distribution**		**1.67**	**$114,000**
	Service installation, includes breakers, metering, 20' conduit & wire, 3 phase, 4 wire, 120/208 V, 800 A			
	Feeder installation 600 V, including RGS conduit and XHHW wire, 800 A			
	Switchgear installation, incl switchboard, panels & circuit breaker, 800 A			
D5020	**Lighting and Branch Wiring**		**10.18**	**$694,000**
	Receptacles incl plate, box, conduit, wire, 8 per 1000 SF, .9 W per SF, with transformer			
	Wall switches, 2.0 per 1000 SF			
	Miscellaneous power, 2 watts			
	Central air conditioning power, 4 watts			
	Fluorescent fixtures recess mounted in ceiling, 1.6 watt per SF, 40 FC, 10 fixtures @32watt per 1000 SF			
D5030	**Communications and Security**		**3.07**	**$209,000**
	Communication and alarm systems, includes outlets, boxes, conduit and wire, sound systems, 12 outlets			
	Communication and alarm systems, fire detection, addressable, 50 detectors, includes outlets, boxes, conduit and w			
	Fire alarm command center, addressable with voice, excl. wire & conduit			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, master clock systems, 10 rooms			
	Communication and alarm systems, includes outlets, boxes, conduit and wire, master TV antenna systems, 30 outle			
	Internet wiring, 2 data/voice outlets per 1000 S.F.			
D5090	**Other Electrical Systems**		**0.12**	**$8,500**
	Generator sets, w/battery, charger, muffler and transfer switch, gas/gasoline operated, 3 phase, 4 wire, 277/480 V, 1			
E Equipment & Furnishings		**0.1%**	**0.15**	**$10,000**
E1020	**Institutional Equipment**		**0.15**	**$10,000**
	Architectural equipment, laboratory equipment, counter tops, stainless steel			
E1090	**Other Equipment**		**0.00**	**$0**
F Special Construction		**0.0%**	**0.00**	**$0**
G Building Sitework		**0.0%**	**0.00**	**$0**
Sub Total		**100%**	**$144.11**	**$9,821,500**
Contractor's Overhead & Profit		**25.0%**	**$36.03**	**$2,455,500**
Architectural Fees		**7.0%**	**$12.61**	**$859,500**
User Fees		**0.0%**	**$0.00**	**$0**
Total Building Cost			**$192.75**	**$13,136,500**

Assembly Detail Report

Cost Estimate Report CostWorks® RSMeans

Year 2011 Quarter 3

Clark

Prepared By:
Mohamed Alali
emar

Date: 23-Sep-11

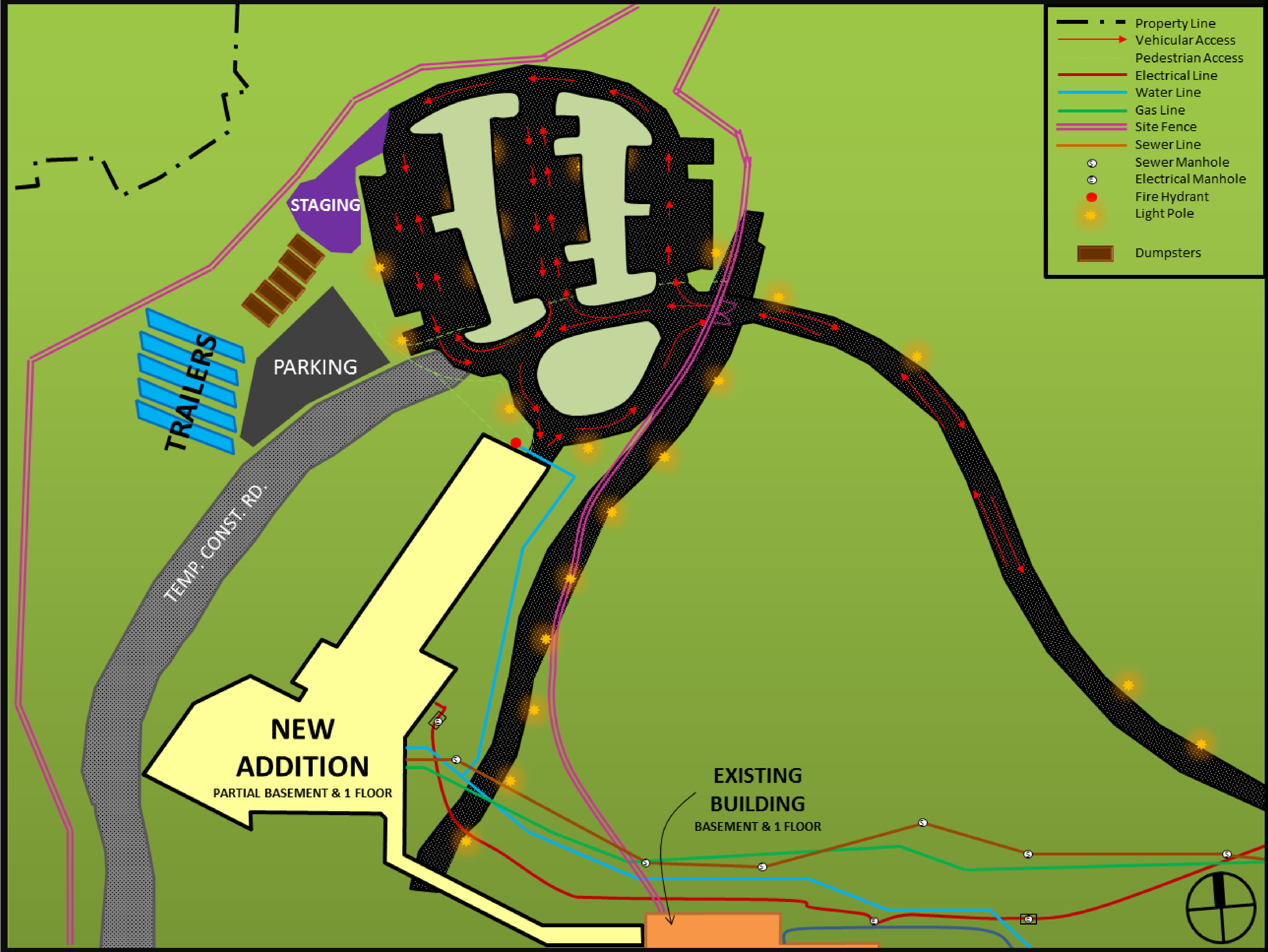
Assembly Number			Description	Quantity	Unit	Total Incl. O&P	Ext. Total Incl. O&P
D Services							
D20101102080			Water closet, vitreous china, bowl only with flush valve, wall hung	9.00	Ea.	$2,540.45	$22,864.05
D20101102160			Water closet, vitreous china, bowl only with flush valve, floor mount, 18" high bowl, ADA compliant	6.00	Ea.	$1,591.94	$9,551.64
D20102102000			Urinal, vitreous china, wall hung	5.00	Ea.	$1,398.07	$6,990.35
D20103101640			Lavatory w/trim, vanity top, PE on CI, 18" round	17.00	Ea.	$1,329.17	$22,595.89
D20104101760			Kitchen sink w/trim, countertop, PE on CI, 30" x 21" single bowl	2.00	Ea.	$1,764.35	$3,528.70
D20104101800			Kitchen sink w/trim, countertop, PE on CI, 32" x 21" double bowl	1.00	Ea.	$1,593.66	$1,593.66
D20104102160			Kitchen sink w/trim, countertop, steel, enameled, 32" x 21" double bowl	1.00	Ea.	$1,738.51	$1,738.51
D20108101920			Drinking fountain, 1 bubbler, wall mounted, non recessed, stainless steel, no back	2.00	Ea.	$1,818.08	$3,636.16
D20202401820			Electric water heater, commercial, 100< F rise, 50 gallon tank, 9 KW 37 GPH	1.00	Ea.	$5,579.78	$5,579.78
D20202401860			Electric water heater, commercial, 100< F rise, 80 gal, 12 KW 49 GPH	1.00	Ea.	$7,813.00	$7,813.00
D20402101960			Roof drain, DWV PVC, 3" diam, 10' high	5.00	Ea.	$1,146.65	$5,733.25
D20402102000			Roof drain, DWV PVC, 3" diam, for each additional foot add	18.00	Ea.	$30.85	$555.30
D20402102040			Roof drain, DWV PVC, 4" diam, diam, 10' high	22.00	Ea.	$1,306.39	$28,740.58
D20402102080			Roof drain, DWV PVC, 4" diam, for each additional foot add	99.00	Ea.	$35.21	$3,485.79
D30105202000			Commercial building heating system, fin tube radiation, forced hot water, 10,000 SF, 100,000 CF, total 2 floors	68,153.00	S.F.	$10.12	$689,708.36
D30201060700			Boiler, electric, steel, hot water, 510 KW, 1,739 MBH	2.00	Ea.	$26,398.50	$52,797.00
D30201060760			Boiler, electric, steel, hot water, 2,100 KW, 7,167 MBH	2.00	Ea.	$71,670.50	$143,341.00
D30201081320			Heating systems, CI boiler, gas, terminal unit heaters, 163 MBH, 2,140 SF bldg	2.00	S.F.	$13.96	$27.92
D30301154600			Packaged chiller, water cooled, with fan coil unit, schools and colleges, 60,000 SF, 230.00 ton	68,153.00	S.F.	$13.78	$939,148.34
D40103101100			Dry pipe sprinkler systems, steel, ordinary hazard, 1 floor, 50,000 SF	30,628.00	S.F.	$4.52	$138,438.56
D40103101240			Dry pipe sprinkler systems, steel, ordinary hazard, each additional floor, 50,000 SF	37,525.00	S.F.	$3.28	$123,082.00
D40203300580			Dry standpipe risers, class I, steel, black, sch 40, 6" diam pipe, 1 floor	1.00	Floor	$9,419.78	$9,419.78
D40203300600			Dry standpipe risers, class I, steel, black, sch 40, 6" diam pipe, additional floors	1.00	Floor	$3,098.80	$3,098.80
D50201100280			Receptacles incl plate, box, conduit, wire, 4 per 1000 SF, .5 watts per SF	68,153.00	S.F.	$1.95	$132,898.35
D50201250840			4 way switch, 15 A with box, plate, 3/4" EMT & wire	8.00	Ea.	$285.70	$2,285.60
D50201300240			Wall switches, 1.2 per 1000 SF	68,153.00	S.F.	$0.31	$21,127.43
D50202100240			Fluorescent fixtures recess mounted in ceiling, 2 watt per SF, 40 FC, 10 fixtures @40 watt per 1000 SF	155.00	S.F.	$5.03	$779.65

Assembly Number			Description	Quantity	Unit	Total Incl. O&P	Ext. Total Incl. O&P
D50202100280			Fluorescent fixtures recess mounted in ceiling, 3 watt per SF, 60 FC, 15 fixtures @40 watt per 1000 SF	200.00	S.F.	$7.58	$1,516.00
D50202100280			Fluorescent fixtures recess mounted in ceiling, 3 watt per SF, 60 FC, 15 fixtures @40 watt per 1000 SF	200.00	S.F.	$7.58	$1,516.00
D50202100280			Fluorescent fixtures recess mounted in ceiling, 3 watt per SF, 60 FC, 15 fixtures @40 watt per 1000 SF	174.00	S.F.	$7.58	$1,318.92
D50202100320			Fluorescent fixtures recess mounted in ceiling, 4 watt per SF, 80 FC, 20 fixtures @40 watt per 1000 SF	312.00	S.F.	$10.07	$3,141.84
D50202100320			Fluorescent fixtures recess mounted in ceiling, 4 watt per SF, 80 FC, 20 fixtures @40 watt per 1000 SF	50.00	S.F.	$10.07	$503.50
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	200.00	S.F.	$12.62	$2,524.00
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	100.00	S.F.	$12.62	$1,262.00
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	120.00	S.F.	$12.62	$1,514.40
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	200.00	S.F.	$12.62	$2,524.00
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	210.00	S.F.	$12.62	$2,650.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20

Assembly Number			Description	Quantity	Unit	Total Incl. O&P	Ext. Total Incl. O&P
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	10.00	S.F.	$12.62	$126.20
D50202100400			Fluorescent fixtures recess mounted in ceiling, 5 watt per SF, 100 FC, 25 fixtures @40 watt per 1000 SF	64.00	S.F.	$12.62	$807.68
D50202100580			Fluorescent fixtures recess mounted in ceiling, 4 watt per SF, 100 FC, 25 fixtures @32 watt per 1000 SF	100.00	S.F.	$12.97	$1,297.00
D50303100240			Telephone systems, underfloor duct, 5' on center, high density	68,153.00	S.F.	$14.47	$986,173.91
D50309100220			Communication and alarm systems, includes outlets, boxes, conduit and wire, sound systems, 12 outlets	1.50	Ea.	$20,339.85	$30,509.78
D50309100400			Communication and alarm systems, fire detection, non-addressable, 50 detectors, includes outlets, boxes, conduit and wire	1.50	Ea.	$33,334.40	$50,001.60
D50309100960			Communication and alarm systems, includes outlets, boxes, conduit and wire, master TV antenna systems, 12 outlets	1.50	Ea.	$15,671.25	$23,506.88
D50309200104			Internet wiring, 4 data/voice outlets per 1000 S.F.	68.15	M.S.F.	$1,210.83	$82,521.70
D50902101400			Generator sets, w/battery, charger, muffler and transfer switch, diesel engine with fuel tank, 1000 kW	1.50	kW	$283.24	$424.86
D Services Subtotal							**$3,576,166.72**
E Equipment & Furnishings							
E10903500110			Architectural equipment, kitchen equipment, bake oven, single deck	1.00	Ea.	$5,776.64	$5,776.64
E10903500120			Architectural equipment, kitchen equipment, broiler, without oven	1.00	Ea.	$4,432.81	$4,432.81
E10903500150			Architectural equipment, kitchen equipment, cooler, beverage, reach-in, 6 FT long	1.00	Ea.	$5,773.30	$5,773.30
E10903600110			Special construction, refrigerators, prefabricated, walk-in, 7'-6" high, 6' x 6'	550.00	S.F.	$189.65	$104,307.50
E Equipment & Furnishings Su							**$120,290.25**

Appendix C

Site Plans



THE STERLING & FRANCINE CLARK ART INSTITUTE

225 South Street, Williamstown, MA 01267

EXISTING CONDITIONS SITE PLAN

April 4, 2012

MOHAMED ALALI - CM

Scale

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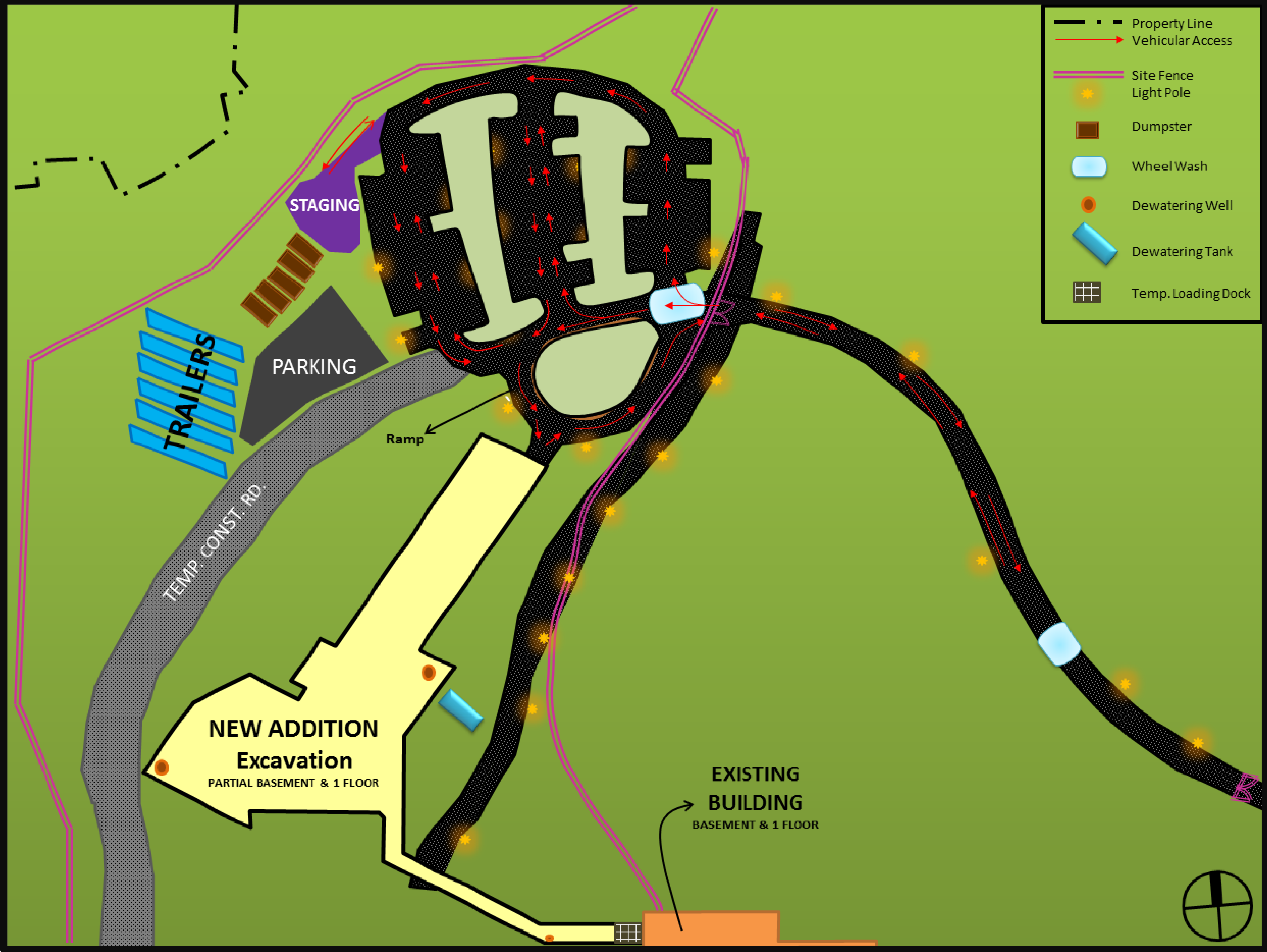

THE STERLING & FRANCINE CLARK ART INSTITUTE

225 South Street, Williamstown, MA 01267

EXCAVATION SITE PLAN

April 4, 2012

MOHAMED ALALI - CM

Scale

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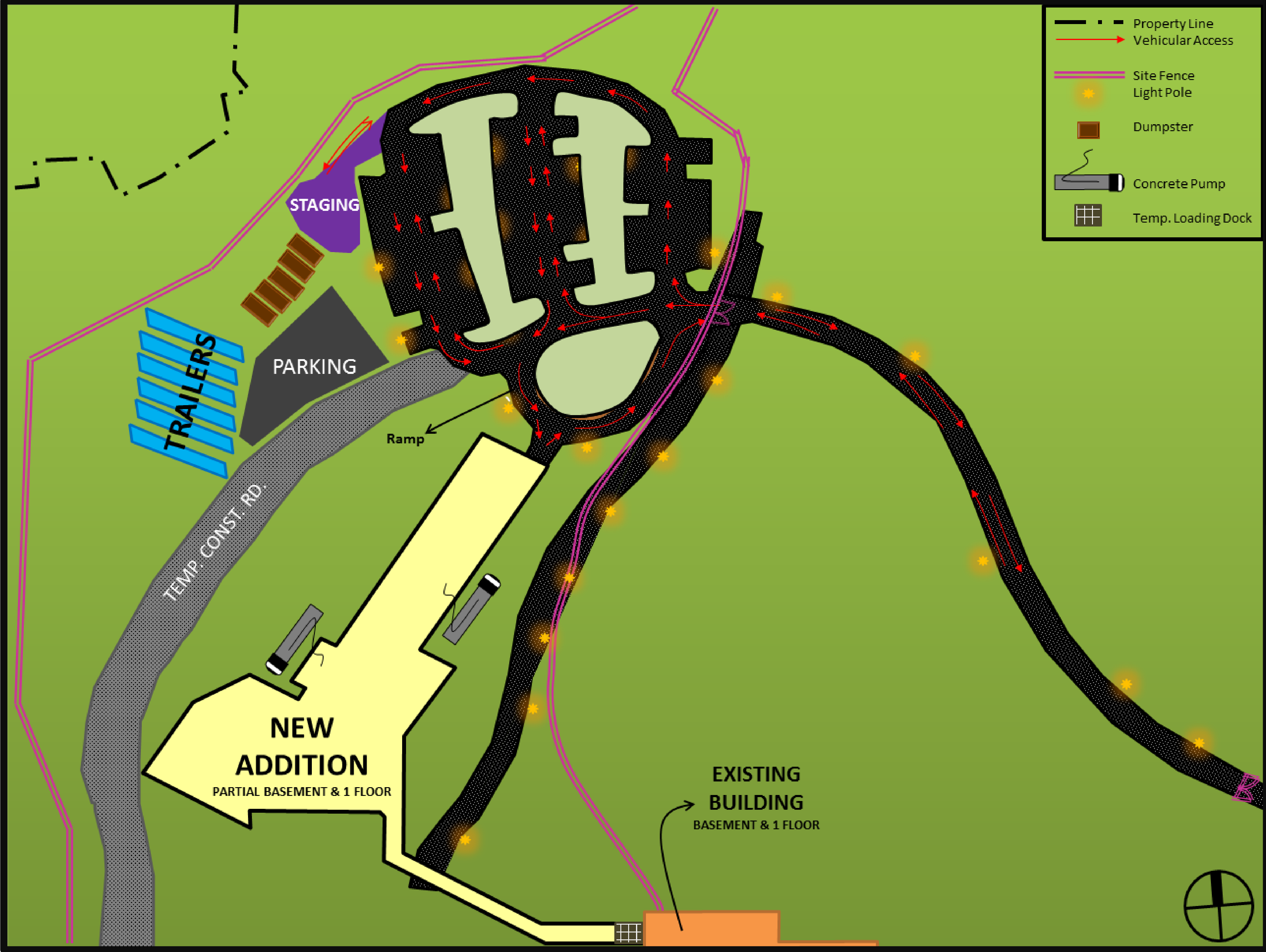


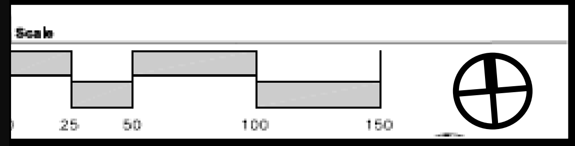
THE STERLING & FRANCINE CLARK ART INSTITUTE

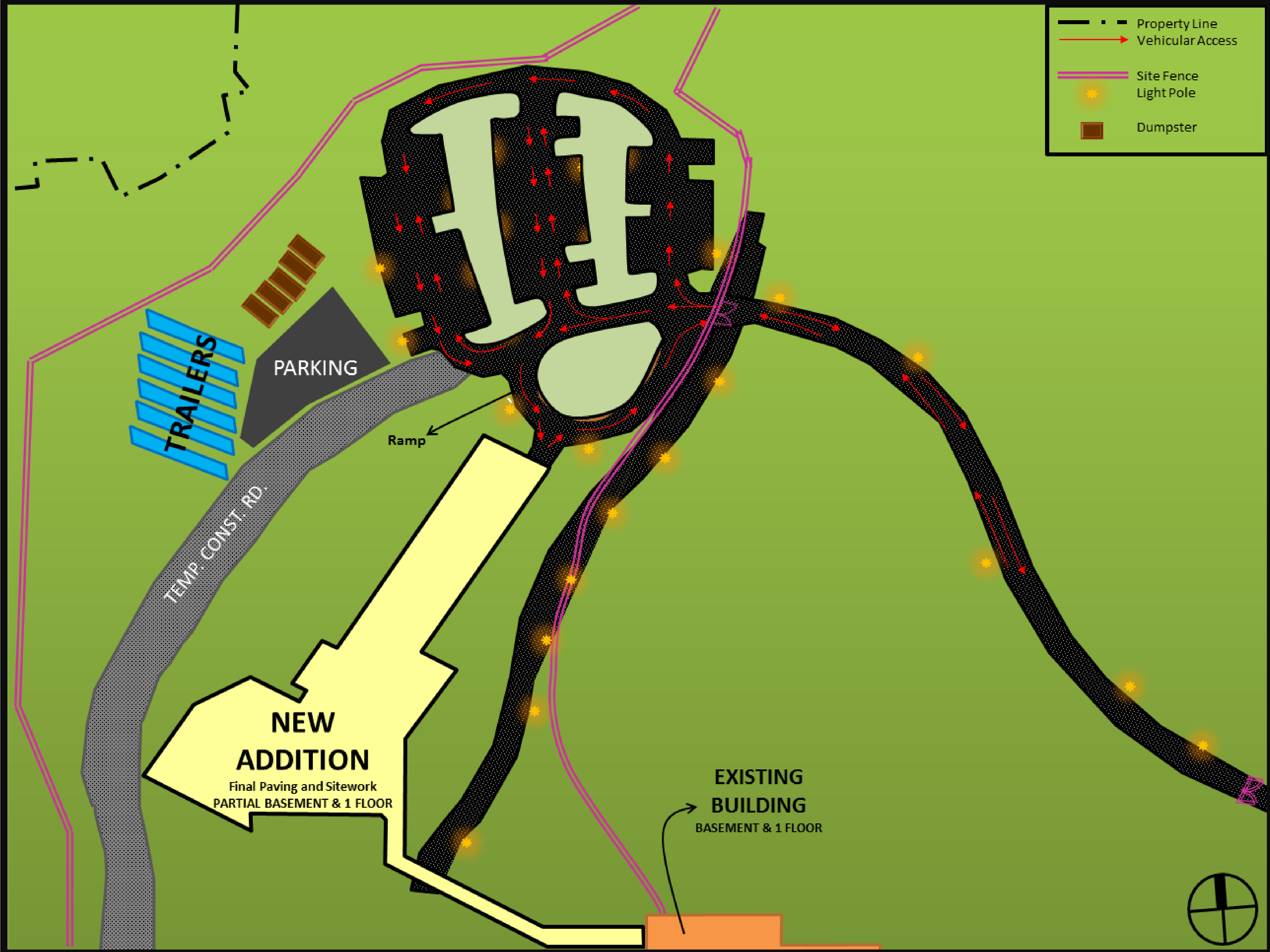
225 South Street, Williamstown, MA 01267

SUPER STRUCTURE SITE PLAN

April 4, 2012

MOHAMED ALALI - CM





THE STERLING & FRANCINE CLARK ART INSTITUTE

225 South Street, Williamstown, MA 01267

FINISHING SITE PLAN

April 4, 2012

MOHAMED ALALI - CM

Scale

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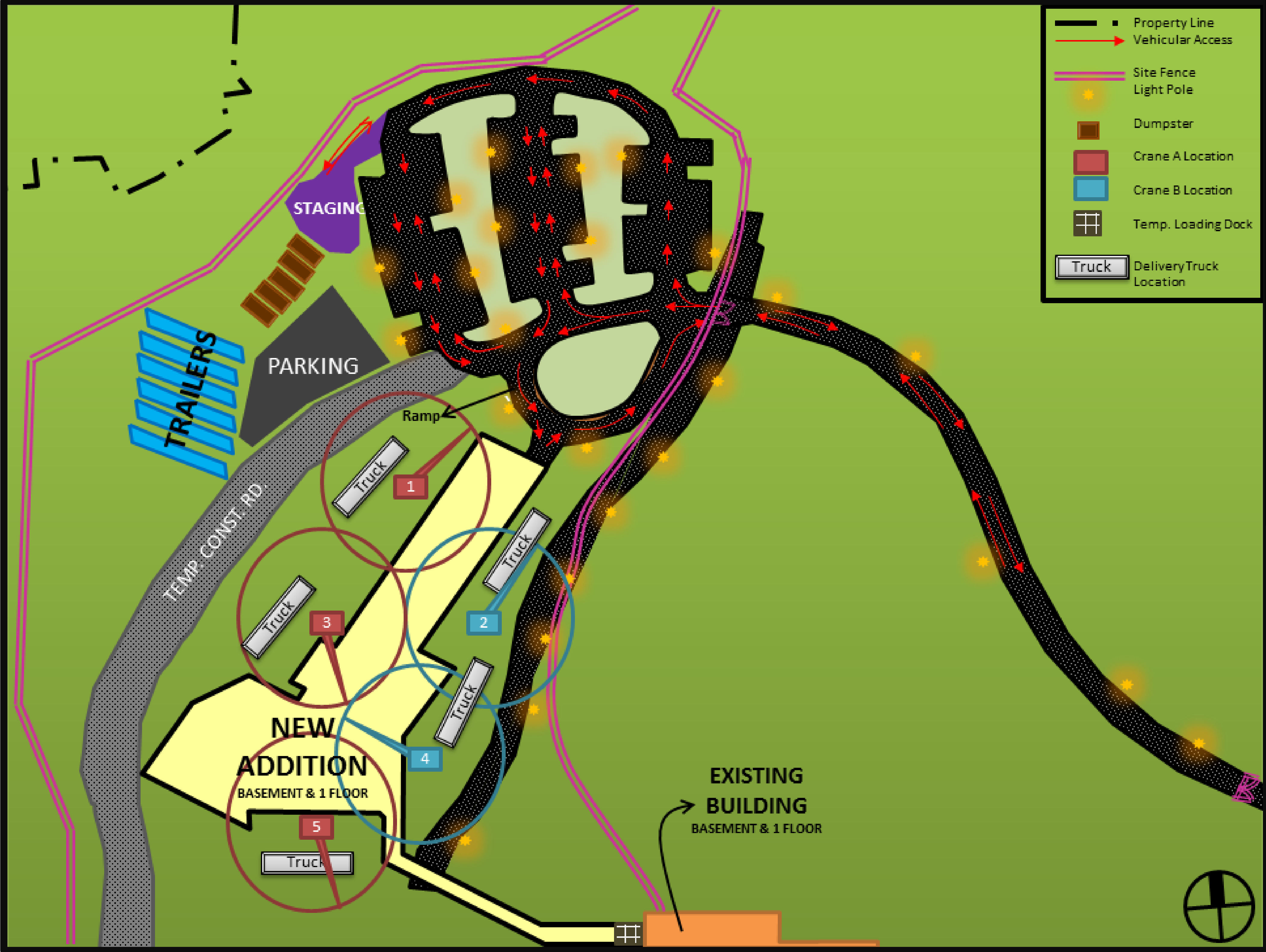


THE STERLING & FRANCINE CLARK ART INSTITUTE

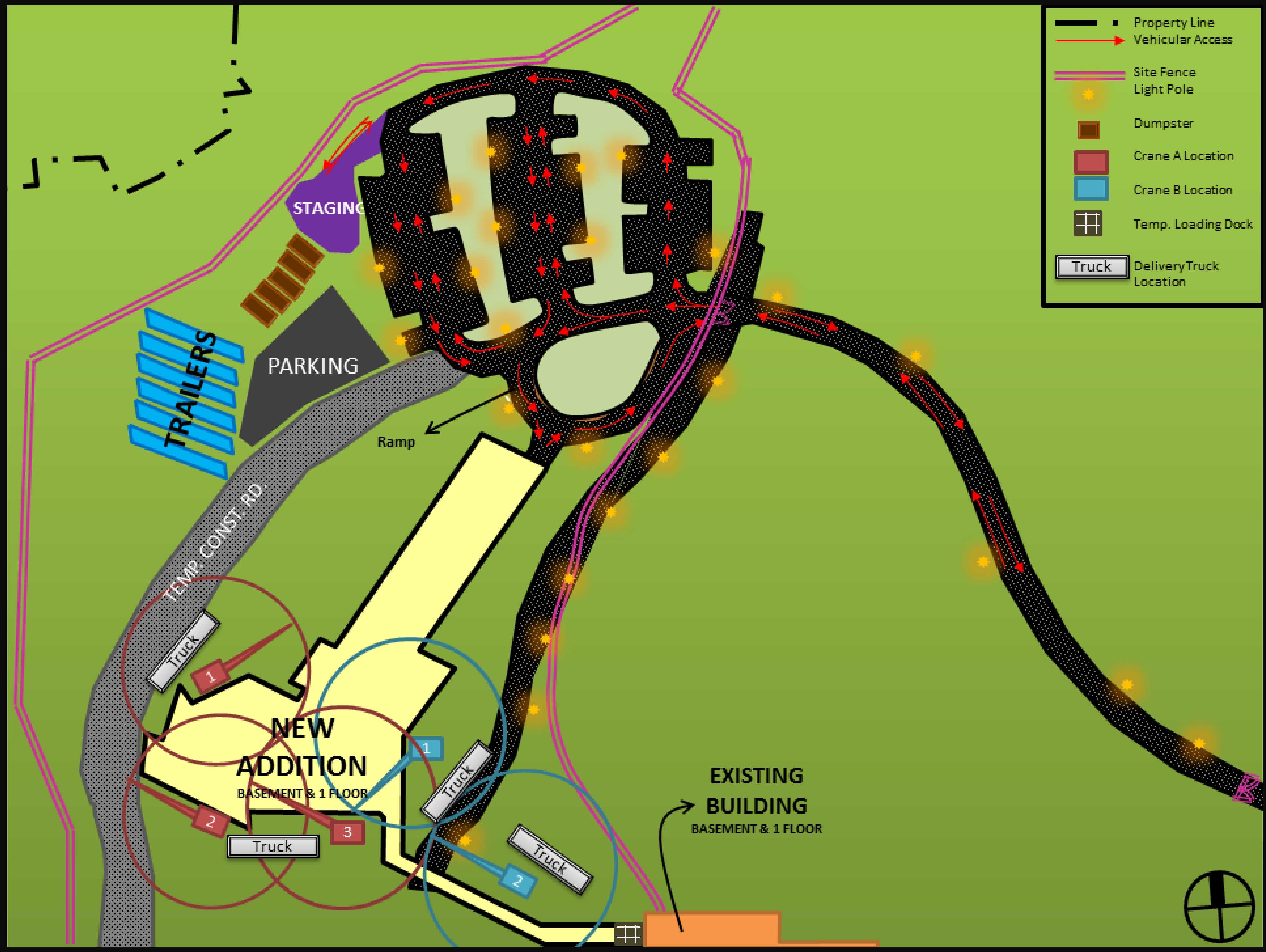
225 South Street, Williamstown, MA 01267

MEP LOGISTICS PLAN

April 4, 2012

MOHAMED ALALI - CM

Scale



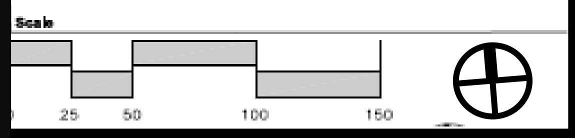
THE STERLING & FRANCINE CLARK ART INSTITUTE

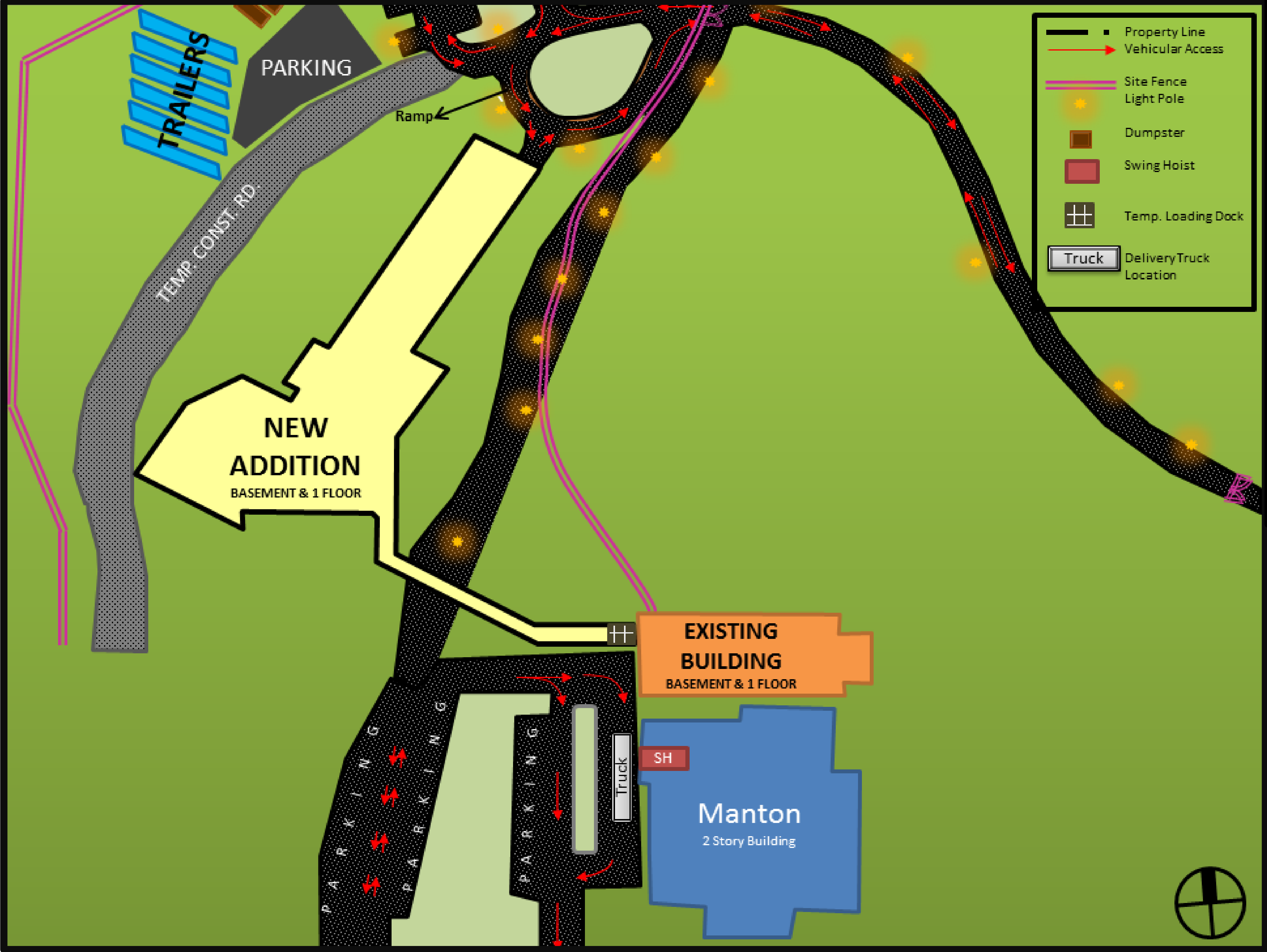
225 South Street, Williamstown, MA 01267

PRECAST LOGISTICS PLAN

April 4, 2012

MOHAMED ALALI - CM





THE STERLING & FRANCINE CLARK ART INSTITUTE

225 South Street, Williamstown, MA 01267

PV LOGISTICS PLAN

April 4, 2012

MOHAMED ALALI - CM

Scale

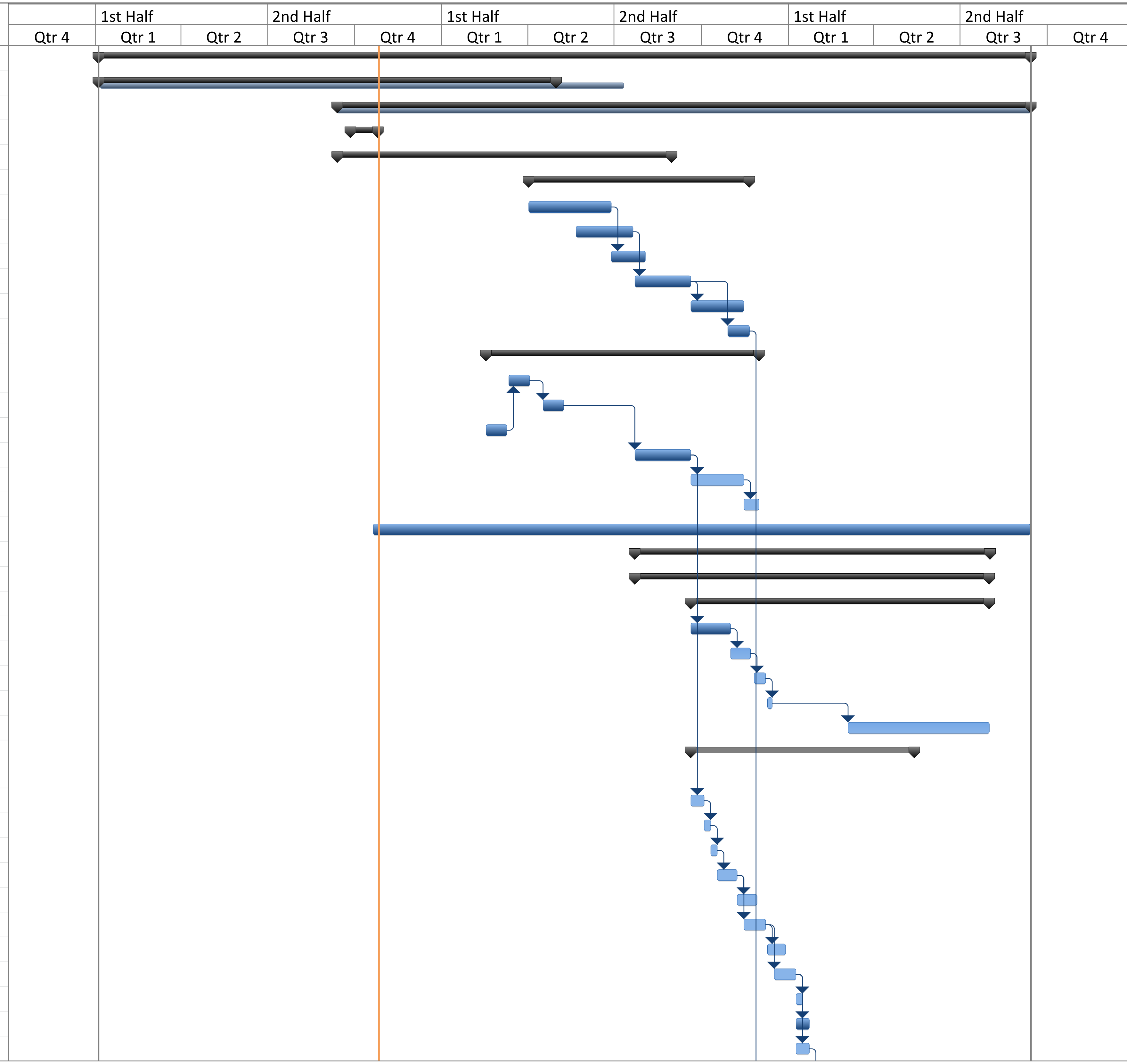
25 50 100 150

Appendix D

Detailed Project Schedule

Detailed Project Schedule

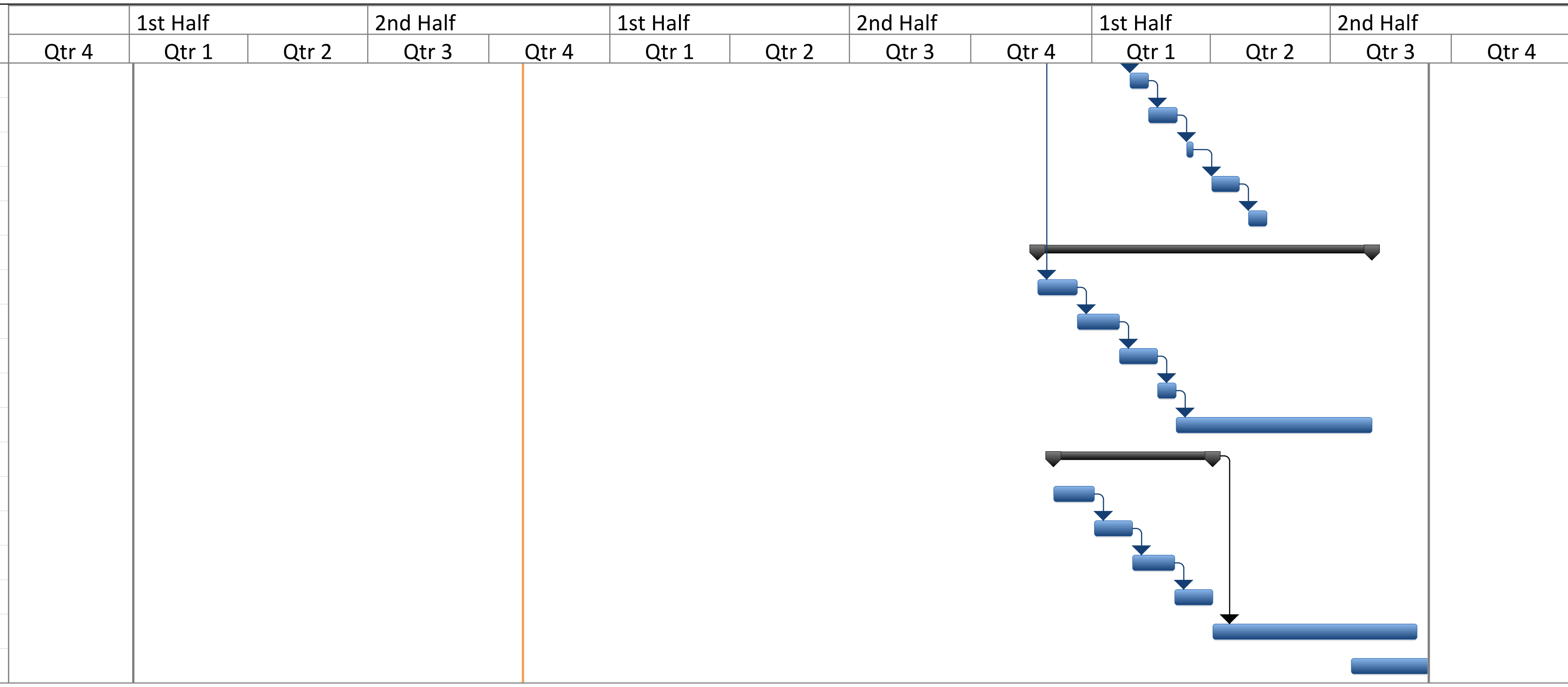
ID	Task Name	Duration	Start	Finish
1	**The Clark**	**706 days**	**Tue 1/4/11**	**Fri 9/13/13**
2	**Preconstruction**	**347 days**	**Tue 1/4/11**	**Mon 4/30/12**
28	**Construction**	**524 days**	**Tue 9/13/11**	**Fri 9/13/13**
29	**Sitework & Excavation**	**21 days**	**Tue 9/27/11**	**Tue 10/25/11**
32	**Structure**	**253 days**	**Tue 9/13/11**	**Thu 8/30/12**
66	**Enclosure**	**167 days**	**Mon 4/2/12**	**Tue 11/20/12**
67	Install Stone Cladding	63 days	Mon 4/2/12	Wed 6/27/12
68	Central: Install Curtainwall	44 days	Tue 5/22/12	Fri 7/20/12
69	West: Install Stone Cladding	26 days	Thu 6/28/12	Thu 8/2/12
70	West: Curtainwall	43 days	Mon 7/23/12	Wed 9/19/12
71	East: Install Curtainwall	40 days	Thu 9/20/12	Wed 11/14/12
72	East: Install Stone Cladding	17 days	Mon 10/29/12	Tue 11/20/12
73	**Roofing & Waterproofing**	**206 days**	**Fri 2/17/12**	**Fri 11/30/12**
74	East Lower Lobby	16 days	Mon 3/12/12	Mon 4/2/12
75	MER/ Resvoir	16 days	Tue 4/17/12	Tue 5/8/12
76	Display	16 days	Fri 2/17/12	Fri 3/9/12
77	Central	43 days	Mon 7/23/12	Wed 9/19/12
78	West	40 days	Thu 9/20/12	Wed 11/14/12
79	East	12 days	Thu 11/15/12	Fri 11/30/12
80	Water Feature	495 days	Fri 10/21/11	Thu 9/12/13
81	**Interior Fitout**	**269 days**	**Mon 7/23/12**	**Thu 8/1/13**
82	**Central**	**268 days**	**Mon 7/23/12**	**Wed 7/31/13**
89	**West**	**225 days**	**Thu 9/20/12**	**Wed 7/31/13**
90	Install Overhead HVAC	30 days	Thu 9/20/12	Wed 10/31/12
91	Install Overhead HVAC Piping	15 days	Thu 11/1/12	Wed 11/21/12
92	Install Overhead Electrical	10 days	Mon 11/26/12	Fri 12/7/12
93	Install Overhead Sprinkler	5 days	Mon 12/10/12	Fri 12/14/12
94	Finishes	107 days	Tue 3/5/13	Wed 7/31/13
95	**Lower Level: Display A, B, C / Court / MER / Resvoir**	**168 days**	**Thu 9/20/12**	**Mon 5/13/13**
96	Survey/ Layout	10 days	Thu 9/20/12	Wed 10/3/12
97	Stud Out Interior Partitions	5 days	Thu 10/4/12	Wed 10/10/12
98	Rough-In Overhead Drainage	5 days	Thu 10/11/12	Wed 10/17/12
99	Rough-In Overhead MEP pipe	15 days	Thu 10/18/12	Wed 11/7/12
100	Rough-In Overhead Ductwork	15 days	Thu 11/8/12	Wed 11/28/12
101	Rough-In Overhead Electric	17 days	Thu 11/15/12	Fri 12/7/12
102	Rough-In Overhead Sprinkler Mains	15 days	Mon 12/10/12	Fri 12/28/12
103	Install Ceiling Framing	17 days	Mon 12/17/12	Tue 1/8/13
104	Install Sprinkler Drops	5 days	Wed 1/9/13	Tue 1/15/13
105	Install Electrical Drops	10 days	Wed 1/9/13	Tue 1/22/13
106	Install Ductwork Drops	10 days	Wed 1/9/13	Tue 1/22/13



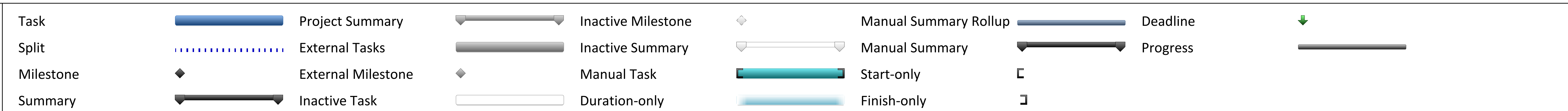
Project: Detailed project Schedule
Date: Thu 10/27/11

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

ID		Task Name	Duration	Start	Finish
107		Close Ceiling & Walls	10 days	Wed 1/30/13	Tue 2/12/13
108		Apply Accounstic Plaster - Ceiling	16 days	Wed 2/13/13	Wed 3/6/13
109		Prime & Paint Walls & Ceiling	3 days	Thu 3/14/13	Mon 3/18/13
110		Install Fixtures, Grilles & Devices	15 days	Tue 4/2/13	Mon 4/22/13
111		Lay & Finish Wood Flooring	10 days	Tue 4/30/13	Mon 5/13/13
112		**East - MEP/ Link**	**182 days**	**Wed 11/21/12**	**Thu 8/1/13**
113		Install Overhead Ductwork	22 days	Wed 11/21/12	Thu 12/20/12
114		Install Overhead HVAC Piping	22 days	Fri 12/21/12	Mon 1/21/13
115		Install Overhead Electrical	21 days	Tue 1/22/13	Tue 2/19/13
116		Install Overhead Sprinkler	10 days	Wed 2/20/13	Tue 3/5/13
117		Finishes	107 days	Wed 3/6/13	Thu 8/1/13
118		**MEP**	**87 days**	**Mon 12/3/12**	**Tue 4/2/13**
119		Set Electrical Equipment	23 days	Mon 12/3/12	Wed 1/2/13
120		Set AHUs & Pumps	21 days	Thu 1/3/13	Thu 1/31/13
121		Rterminations at HVAC systems	22 days	Fri 2/1/13	Mon 3/4/13
122		Startup HVAC systems	21 days	Tue 3/5/13	Tue 4/2/13
123		Comissioning	111 days	Wed 4/3/13	Wed 9/4/13
124		Closeout	43 days	Wed 7/17/13	Fri 9/13/13



Project: Detailed project Schedule
Date: Thu 10/27/11



Appendix E

RSMeans CostWorks, Detailed Structural System Estimate

The Sterling And Francine Art Institute Detailed Structural Systems Estimate

Wiiliamstown, MA **01267**

Data Release : Year 2011 Quarter 3, **Unit Cost Estimate**

Quantity	LineNumber	Source	SubContracted Ind.	Description	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment	Total	Ext. Mat.	Ext. Labor	Ext. Equip.	Ext. Total	Mat. O&P	Labor O&P	Equip. O&P	Total O&P	Ext. Mat. O&P	Ext. Labor O&P	Ext. Equip. O&P	Ext. Total O&P	Labor Type	Data Release	Zip Code	Notes
2095.48	033105350400			Building Beams(based on the typical bay selected)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 237,019.74	$ -	$ -	$ 237,019.74	$ 124.32	$ -	$ -	$ 124.32	$ 260,510.07	$ -	$ -	$ 260,510.07	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
2156	033105350400			Slabs (took average and based on the typical bay selected)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 243,865.16	$ -	$ -	$ 243,865.16	$ 124.32	$ -	$ -	$ 124.32	$ 268,033.92	$ -	$ -	$ 268,033.92	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
540.11	033105350400			Columns (took average and based on the typical bay selected)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 61,091.84	$ -	$ -	$ 61,091.84	$ 124.32	$ -	$ -	$ 124.32	$ 67,146.48	$ -	$ -	$ 67,146.48	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
3661.44	033105350400			Mat Slab (calculated the the mat slab area and converted it to CY's)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 414,145.48	$ -	$ -	$ 414,145.48	$ 124.32	$ -	$ -	$ 124.32	$ 455,190.22	$ -	$ -	$ 455,190.22	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
3240	033105350400			Foundation Walls				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 366,476.40	$ -	$ -	$ 366,476.40	$ 124.32	$ -	$ -	$ 124.32	$ 402,796.80	$ -	$ -	$ 402,796.80	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
306	033105350400			Arch. Foundation Walls				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 34,611.66	$ -	$ -	$ 34,611.66	$ 124.32	$ -	$ -	$ 124.32	$ 38,041.92	$ -	$ -	$ 38,041.92	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
697.9	033105350400			Roof Beams (based on typical roof bay selected)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 78,939.47	$ -	$ -	$ 78,939.47	$ 124.32	$ -	$ -	$ 124.32	$ 86,762.93	$ -	$ -	$ 86,762.93	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
1655.65	033105350400			Roof Slabs (based on typical roof bay selected)				C.Y.	$ 113.11	$ -	$ -	$ 113.11	$ 187,270.57	$ -	$ -	$ 187,270.57	$ 124.32	$ -	$ -	$ 124.32	$ 205,830.41	$ -	$ -	$ 205,830.41	RR	Year 2011 Quarter 3	012	Structural concrete, ready mix, normal weight, 5000 psi, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments
2793.38	033105700050			Project Beams Placement	C20	60	1.067	C.Y.	$ -	$ 49.45	$ 13.94	$ 63.39	$ -	$ 138,132.64	$ 38,939.72	$ 177,072.36	$ -	$ 80.52	$ 15.37	$ 95.89	$ -	$ 224,922.96	$ 42,934.25	$ 267,857.21	RR	Year 2011 Quarter 3	012	Structural concrete, placing, beam, small, elevated, pumped, includes strike off & consolidation, excludes material
540.11	033105700600			Columns Placement	C20	90	0.711	C.Y.	$ -	$ 32.97	$ 9.31	$ 42.28	$ -	$ 17,807.43	$ 5,028.42	$ 22,835.85	$ -	$ 53.26	$ 10.21	$ 63.47	$ -	$ 28,766.26	$ 5,514.52	$ 34,280.78	RR	Year 2011 Quarter 3	012	Structural concrete, placing, column, square or round, pumped, 18" thick, includes strike off & consolidation, excludes material
3811.65	033105701500			Slabs Placement	C20	160	0.4	C.Y.	$ -	$ 18.64	$ 5.23	$ 23.87	$ -	$ 71,049.16	$ 19,934.93	$ 90,984.09	$ -	$ 29.80	$ 5.75	$ 35.55	$ -	$ 113,587.17	$ 21,916.99	$ 135,504.16	RR	Year 2011 Quarter 3	012	Structural concrete, placing, elevated slab, pumped, 6" to 10" thick, includes strike off & consolidation, excludes material
3661.44	033105702950			Mat Placement	C20	400	0.16	C.Y.	$ -	$ 7.48	$ 2.10	$ 9.58	$ -	$ 27,387.57	$ 7,689.02	$ 35,076.60	$ -	$ 12.05	$ 2.30	$ 14.35	$ -	$ 44,120.35	$ 8,421.31	$ 52,541.66	RR	Year 2011 Quarter 3	012	Structural concrete, placing, foundation mat, pumped, over 20 C.Y., includes strike off & consolidation, excludes material
68153	033529300125			Conc. finishing (floors)	C10	2000	0.012	S.F.	$ -	$ 0.58	$ -	$ 0.58	$ -	$ 39,528.74	$ -	$ 39,528.74	$ -	$ 0.93	$ -	$ 0.93	$ -	$ 63,382.29	$ -	$ 63,382.29	RR	Year 2011 Quarter 3	012	Concrete finishing, floors, basic finishing for unspecified flatwork, bull float & manual float, excludes placing, striking off & consolidating
24406.56	033529600600			Cast In Place Walls (based on average wall height)	1 Cefi	300	0.027	S.F.	$ 0.30	$ 1.38	$ -	$ 1.68	$ 7,321.97	$ 33,681.05	$ -	$ 41,003.02	$ 0.33	$ 2.16	$ -	$ 2.49	$ 8,054.16	$ 52,718.17	$ -	$ 60,772.33	RR	Year 2011 Quarter 3	012	Concrete finishing, walls, float finish, 1/16" thick

5508	033533500100			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	6400	0.001	S.F.	$ 0.39	$ 0.06	$ -	$ 0.45	$ 2,148.12	$ 330.48	$ -	$ 2,478.60	$ 0.43	$ 0.10	$ -	$ 0.53	$ 2,368.44	$ 550.80	$ -	$ 2,919.24	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 1 - first application of dry shake colored hardener, excludes placing, striking off & consolidating
5508	033533500110			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	6400	0.001	S.F.	$ -	$ 0.06	$ -	$ 0.06	$ -	$ 330.48	$ -	$ 330.48	$ -	$ 0.10	$ -	$ 0.10	$ -	$ 550.80	$ -	$ 550.80	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 2 - bull float, excludes placing, striking off & consolidating
5508	033533500130			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	6400	0.001	S.F.	$ 0.19	$ 0.06	$ -	$ 0.25	$ 1,046.52	$ 330.48	$ -	$ 1,377.00	$ 0.21	$ 0.10	$ -	$ 0.31	$ 1,156.68	$ 550.80	$ -	$ 1,707.48	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 3 - second application of dry shake colored hardener, excludes placing, striking off & consolidating
5508	033533500140			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	3 Cefi	1280	0.019	S.F.	$ -	$ 0.98	$ -	$ 0.98	$ -	$ 5,397.84	$ -	$ 5,397.84	$ -	$ 1.51	$ -	$ 1.51	$ -	$ 8,317.08	$ -	$ 8,317.08	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 4 - bull float, manual float & steel trowel, excludes placing, striking off & consolidating
5508	033533500150			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	6400	0.001	S.F.	$ 0.08	$ 0.06	$ -	$ 0.14	$ 440.64	$ 330.48	$ -	$ 771.12	$ 0.09	$ 0.10	$ -	$ 0.19	$ 495.72	$ 550.80	$ -	$ 1,046.52	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 5 - application of dry shake colored release agent, excludes placing, striking off & consolidating
5508	033533500160			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	3 Cefi	2400	0.01	S.F.	$ 1.44	$ 0.52	$ -	$ 1.96	$ 7,931.52	$ 2,864.16	$ -	$ 10,795.68	$ 1.58	$ 0.81	$ -	$ 2.39	$ 8,702.64	$ 4,461.48	$ -	$ 13,164.12	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 6 - place, tamp & remove mats, excludes placing, striking off & consolidating
5508	033533500170			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	1280	0.006	S.F.	$ -	$ 0.33	$ -	$ 0.33	$ -	$ 1,817.64	$ -	$ 1,817.64	$ -	$ 0.51	$ -	$ 0.51	$ -	$ 2,809.08	$ -	$ 2,809.08	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 7 - touch up edges, mat joints & simulated grout lines, excludes placing, striking off & consolidating
5508	033533500400			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	1600	0.005	S.F.	$ -	$ 0.25	$ -	$ 0.25	$ -	$ 1,377.00	$ -	$ 1,377.00	$ -	$ 0.41	$ -	$ 0.41	$ -	$ 2,258.28	$ -	$ 2,258.28	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 8 - pressure wash @ 3000 psi after 24 hours, excludes placing, striking off & consolidating
5508	033533500500			Line number 033533500100 through 0335335005000 correspond to Arch. walls finishing	1 Cefi	800	0.01	S.F.	$ 0.49	$ 0.52	$ -	$ 1.01	$ 2,698.92	$ 2,864.16	$ -	$ 5,563.08	$ 0.54	$ 0.81	$ -	$ 1.35	$ 2,974.32	$ 4,461.48	$ -	$ 7,435.80	RR		Year 2011 Quarter 3	012	Slab texture stamping, step 9 - roll 2 coats cure/seal compound when dry, excludes placing, striking off & consolidating
91635.8	032110600202			Total rebar lbs in project columns	4 Rodm	3000	0.011	Lb.	$ 0.43	$ 0.57	$ -	$ 1.00	$ 39,403.39	$ 52,232.41	$ -	$ 91,635.80	$ 0.46	$ 0.95	$ -	$ 1.41	$ 42,152.47	$ 87,054.01	$ -	$ 129,206.48	RR		Year 2011 Quarter 3	012	Reinforcing Steel, in place, columns, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories
464858.22	032110600402			All project slabs	4 Rodm	5800	0.006	Lb.	$ 0.45	$ 0.30	$ -	$ 0.75	$ 209,186.20	$ 139,457.47	$ -	$ 348,643.67	$ 0.49	$ 0.50	$ -	$ 0.99	$ 227,780.53	$ 232,429.11	$ -	$ 460,209.64	RR		Year 2011 Quarter 3	012	Reinforcing Steel, in place, elevated slabs, #4 to #7, A615, grade 60, incl labor for accessories, excl material for accessories
168691.68	032110600552			MAT Slab #9 rebars	4 Rodm	7200	0.004	Lb.	$ 0.43	$ 0.23	$ -	$ 0.66	$ 72,537.42	$ 38,799.09	$ -	$ 111,336.51	$ 0.46	$ 0.40	$ -	$ 0.86	$ 77,598.17	$ 67,476.67	$ -	$ 145,074.84	RR		Year 2011 Quarter 3	012	Reinforcing Steel, in place, footings, #8 to #18, A615, grade 60, incl labor for accessories, excl material for accessories
6080.62	032110600102			Total rebar lbs in project beams	4 Rodm	3200	0.01	Lb.	$ 0.43	$ 0.53	$ -	$ 0.96	$ 2,614.67	$ 3,222.73	$ -	$ 5,837.40	$ 0.46	$ 0.89	$ -	$ 1.35	$ 2,797.09	$ 5,411.75	$ -	$ 8,208.84	RR		Year 2011 Quarter 3	012	Reinforcing Steel, in place, beams and girders, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories
125575.53	032110600702			Total rebar lbs in project foundation walls (took most typical found. wall)	4 Rodm	6000	0.005	Lb.	$ 0.43	$ 0.29	$ -	$ 0.72	$ 53,997.48	$ 36,416.90	$ -	$ 90,414.38	$ 0.46	$ 0.47	$ -	$ 0.93	$ 57,764.74	$ 59,020.50	$ -	$ 116,785.24	RR		Year 2011 Quarter 3	012	Reinforcing Steel, in place, walls, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories
15334.425	031113202500			Forms for project beams	C2	320	0.15	SFCA	$ 2.04	$ 6.87	$ -	$ 8.91	$ 31,282.23	$ 105,347.50	$ -	$ 136,629.73	$ 2.25	$ 11.24	$ -	$ 13.49	$ 34,502.46	$ 172,358.94	$ -	$ 206,861.39	RR		Year 2011 Quarter 3	012	C.I.P. concrete forms, beams and girders, interior, plywood, 24" wide, 1 use, includes shoring, erecting, bracing, stripping and cleaning
9711.8	031113256500			Forms for project columns	C1	190	0.168	SFCA	$ 2.43	$ 7.53	$ -	$ 9.96	$ 23,599.67	$ 73,129.85	$ -	$ 96,729.53	$ 2.67	$ 12.27	$ -	$ 14.94	$ 25,930.51	$ 119,163.79	$ -	$ 145,094.29	RR		Year 2011 Quarter 3	012	C.I.P. concrete forms, column, square, plywood, 24" x 24", 1 use, includes erecting, bracing, stripping and cleaning
3542.4	031113850150			Forms for project foundation walls	C2	280	0.171	L.F.	$ 1.94	$ 7.86	$ -	$ 9.80	$ 6,872.26	$ 27,843.26	$ -	$ 34,715.52	$ 2.13	$ 12.82	$ -	$ 14.95	$ 7,545.31	$ 45,413.57	$ -	$ 52,958.88	RR		Year 2011 Quarter 3	012	C.I.P. concrete forms, wall, box out for opening, to 16" thick, over 10 S.F. (use perimeter), includes erecting, bracing, stripping and cleaning
68153	031113351000			Forms for project slabs	C2	470	0.102	S.F.	$ 3.16	$ 4.67	$ -	$ 7.83	$ 215,363.48	$ 318,274.51	$ -	$ 533,637.99	$ 3.48	$ 7.64	$ -	$ 11.12	$ 237,172.44	$ 520,688.92	$ -	$ 757,861.36	RR		Year 2011 Quarter 3	012	C.I.P. concrete forms, elevated slab, flat plate, plywood, to 15' high, 1 use, includes shoring, erecting, bracing, stripping and cleaning
Total													$2299864.81	$1137953.03	$71592.09	$3509409.94					$2521308.43	$1861025.06	$78787.07	$4461120.54					

Appendix F

General Conditions Estimate

Table 2.2: Primary Personnel					
Item	**Quantity**	**Unit**	**HRS/WK**	**Unit Labor**	**Total Labor**
Project Executive	156	WKS	8	$1,128	$175,968
Project Engineer	156	WKS	40	$2,000	$312,000
Project Manager	156	WKS	40	$3,558	$555,048
Superintendent	135	WKS	40	$4,038	$545,130
MEP Coordinator	160	WKS	40	$3,558	$569,280
Project Accountant	156	WKS	8	$1,632	$254,592
				TOTAL	**$2,242,290**

Table 2.3: Field Office Expense & Temporary Facilities					
Item	**Quantity**	**Unit**	**Unit Material Cost**	**Total Material Cost**	**Total Cost**
Field Office Expense					
Office Trailers - Set Up	1	LS	$12,500	$12,500	$12,500
Office Trailers - Rental	36	MOS	$2,400	$86,400	$86,400
Electric - Consumption	36	MOS	$600	$21,600	$21,600
Water & Sanitary Consumption	36	MOS	$250	$9,000	$9,000
Telephones - Monthly	36	MOS	$285	$10,260	$10,260
Furniture	1	LS	$30,000	$30,000	$30,000
Stationary & Supplies	36	MOS	$1,150	$41,400	$41,400
Copier - (purchase)	2	LS	$52,500	$105,000	$105,000
Fax Machine - Purchase	1	LS	$2,500	$2,500	$2,500
Computer Equipment	36	MOS	$3,108	$111,888	$111,888
Progress Photos	34	MOS	$625	$21,250	$21,250
Safety Supplies	36	MOS	$235	$8,460	$8,460
				SUB-TOTAL	**$460,258**
Temporary Facilities					
Porta-Johns	20	MOS	$1,450	$29,000	$29,000
Temp. Storage Trailers	20	MOS	$500	$10,000	$10,000
Project Signs	36	MOS	$1,200	$43,200	$43,200
Tool Rentals	36	MOS	$500	$18,000	$18,000
Housing Expenses	36	MOS	$6,647	$239,292	$239,292
Travel Expenses	36	MOS	$5,996	$215,856	$215,856
Automobile Mileage	36	MOS	$10,125	$364,500	$364,500
Meeting Expenses	36	MOS	$525	$18,900	$18,900
				SUB-TOTAL	**$938,748**
				TOTAL	**$1,399,006**

Appendix G

LEED Scorecard

LEED 2009 for New Construction and Major Renovations

Project Checklist

Sterling and Francine Clark Art Institute VECC+PLANT

11.19.2010

Y	?	N		Sustainable Sites	Possible Points: 26
10	7	9			
Y			Prereq 1	Construction Activity Pollution Prevention	
		1	Credit 1	Site Selection	1
	5		Credit 2	Development Density and Community Connectivity	5
		1	Credit 3	Brownfield Redevelopment	1
		6	Credit 4.1	Alternative Transportation—Public Transportation Access	6
1			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
3			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
1			Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
1			Credit 6.2	Stormwater Design—Quality Control	1
	1		Credit 7.1	Heat Island Effect—Non-roof	1
	1		Credit 7.2	Heat Island Effect—Roof	1
		1	Credit 8	Light Pollution Reduction	1

Y	?	N		Water Efficiency	Possible Points: 10
8					
Y			Prereq 1	Water Use Reduction—20% Reduction	
4			Credit 1	Water Efficient Landscaping	2 to 4
2			Credit 2	Innovative Wastewater Technologies	2
2			Credit 3	Water Use Reduction	2 to 4

Y	?	N		Energy and Atmosphere	Possible Points: 35
7	9	1			
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
5	2		Credit 1	Optimize Energy Performance	1 to 19
		1	Credit 2	On-Site Renewable Energy	1 to 7
2			Credit 3	Enhanced Commissioning	2
	2		Credit 4	Enhanced Refrigerant Management	2
	3		Credit 5	Measurement and Verification	3
	2		Credit 6	Green Power	2

Y	?	N		Materials and Resources	Possible Points: 14
2	5	7			
Y			Prereq 1	Storage and Collection of Recyclables	
		3	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
		1	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
1	1		Credit 2	Construction Waste Management	1 to 2
		2	Credit 3	Materials Reuse	1 to 2

Y	?	N		Materials and Resources, Continued	
	2		Credit 4	Recycled Content	1 to 2
1	1		Credit 5	Regional Materials	1 to 2
		1	Credit 6	Rapidly Renewable Materials	1
	1		Credit 7	Certified Wood	1

Y	?	N		Indoor Environmental Quality	Possible Points: 15
4	3	8			
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
		1	Credit 1	Outdoor Air Delivery Monitoring	1
		1	Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
1			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
	1		Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
	1		Credit 4.3	Low-Emitting Materials—Flooring Systems	1
	1		Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
		1	Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
		1	Credit 6.2	Controllability of Systems—Thermal Comfort	1
		1	Credit 7.1	Thermal Comfort—Design	1
		1	Credit 7.2	Thermal Comfort—Verification	1
		1	Credit 8.1	Daylight and Views—Daylight	1
		1	Credit 8.2	Daylight and Views—Views	1

Y	?	N		Innovation and Design Process	Possible Points: 6
6					
1			Credit 1.1	Innovation in Design: Specific Title	1
1			Credit 1.2	Innovation in Design: Specific Title	1
1			Credit 1.3	Innovation in Design: Specific Title	1
1			Credit 1.4	Innovation in Design: Specific Title	1
1			Credit 1.5	Innovation in Design: Specific Title	1
1			Credit 2	LEED Accredited Professional	1

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

Y	?	N		Total	Possible Points: 110
41	24	25			

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

Appendix H

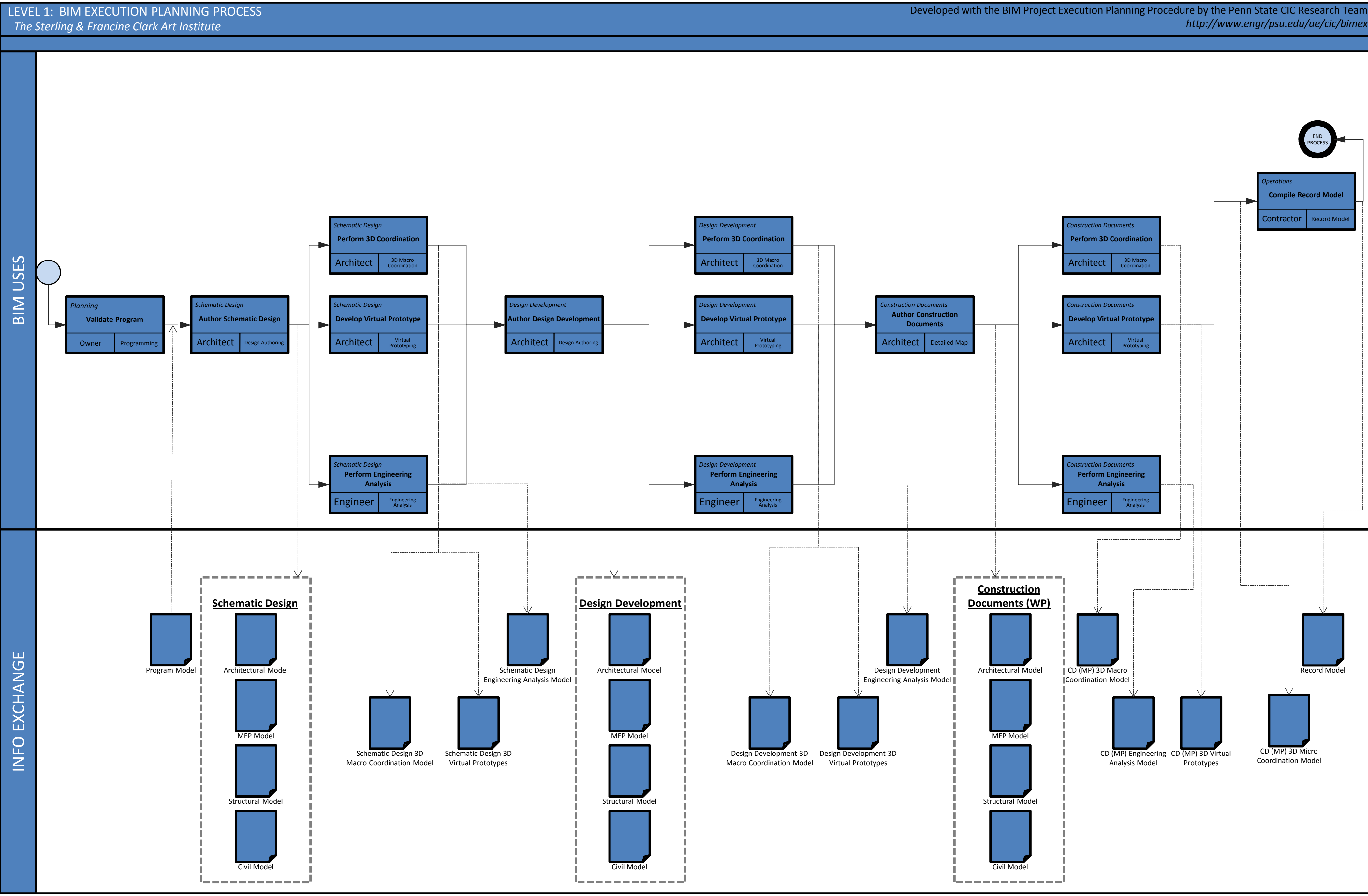
BIM Worksheets and Plans

BIM Goals Worksheet

Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	**Value added objectives**	
1	Aid the the maintenance and operation of the Art Museum and its assets and artifacts.	Asset Management, 3D Coordination
2	Automated systems analysis (Thermal Comfort and Lighting), Efficient Energy Consumption, Improving the quality of the building services.	Engineering Analysis, LEED Evaluation
3	Ensure building is operating to specified design and sustainable standards (Continuing to maintain LEED standards after building occupancy)	Building Systems Analysis, LEED Evaluation
3	Assisting in planning for adding a future restaurant	Space Management and Tracking, 3D Coordination
3	Accelerate design review and LEED certification process and improve communication between project participants in order to achieve LEED credits	LEED Evaluation, 3D Coordination

BIM Use*	Value to	Responsible Party	Value to	Capability Rating			Additio nal	Notes	Procee d with
	High / Med / Low		High / Med / Low	Scale 1-3		(1 = Low)			YES / NO / MAYBE
				Resources	Competency	Experience			
Building Systems Analysis	MED	MEP Engineer	HIGH						**YES**
		Architect	MED						
3D Coordination (Construction)		Contractor	HIGH						**YES**
		Subcontractors	HIGH						
		Designer	MED						
Engineering Analysis	HIGH	MEP Engineer	HIGH						**YES**
		Architect	MED						
		Owner	LOW						
3D Coordination (Design)	HIGH	Architect	HIGH						**YES**
		MEP Engineer	MED						
		Structural Engineer	HIGH						
Asset Management	HIGH	Owner	HIGH						**YES**
		Architect	HIGH						
Sustainability (LEED) Anlysis	MED	Contractor	MED						**YES**
		MEP Engineer	HIGH						
		Architect	HIGH						
Space Management and Tracking	LOW	Architect	HIGH						**MAYBE**
		Owner	MED						
		Contractor	LOW						
4D Modeling									**NO**
Site Utilization Planning									**NO**
Layout Control & Planning									**NO**
Site Analysis									**NO**
Design Reviews									**NO**
Existing Conditions Modeling									**NO**
Design Authoring									**NO**
Programming									**NO**

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



LEVEL 1: BIM EXECUTION PLANNING PROCESS
The Sterling & Francine Clark Art Institute
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team
http://www.engr/psu.edu/ae/cic/bimex
BIM USES
INFO EXCHANGE
Planning
Validate Program
Owner
Programming
Schematic Design
Author Schematic Design
Architect
Design Authoring
Schematic Design
Perform 3D Coordination
Architect
3D Macro Coordination
Schematic Design
Develop Virtual Prototype
Architect
Virtual Prototyping
Schematic Design
Perform Engineering Analysis
Engineer
Engineering Analysis
Design Development
Author Design Development
Architect
Design Authoring
Design Development
Perform 3D Coordination
Architect
3D Macro Coordination
Design Development
Develop Virtual Prototype
Architect
Virtual Prototyping
Design Development
Perform Engineering Analysis
Engineer
Engineering Analysis
Construction Documents
Author Construction Documents
Architect
Detailed Map
Construction Documents
Perform 3D Coordination
Architect
3D Macro Coordination
Construction Documents
Develop Virtual Prototype
Architect
Virtual Prototyping
Construction Documents
Perform Engineering Analysis
Engineer
Engineering Analysis
Operations
Compile Record Model
Contractor
Record Model
END PROCESS
Program Model
Schematic Design
Architectural Model
MEP Model
Structural Model
Civil Model
Schematic Design 3D Macro Coordination Model
Schematic Design 3D Virtual Prototypes
Schematic Design Engineering Analysis Model
Design Development
Architectural Model
MEP Model
Structural Model
Civil Model
Design Development 3D Macro Coordination Model
Design Development 3D Virtual Prototypes
Design Development Engineering Analysis Model
Construction Documents (WP)
Architectural Model
MEP Model
Structural Model
Civil Model
CD (MP) 3D Macro Coordination Model
CD (MP) Engineering Analysis Model
CD (MP) 3D Virtual Prototypes
CD (MP) 3D Micro Coordination Model
Record Model

Appendix I

Precast Plank Specification Sheet

Connection Drawings Can Be Found At:

http://www.nitterhouse.com/DrawingSpecs/DrawingSpecsSub/HollowcoreSpecs.html

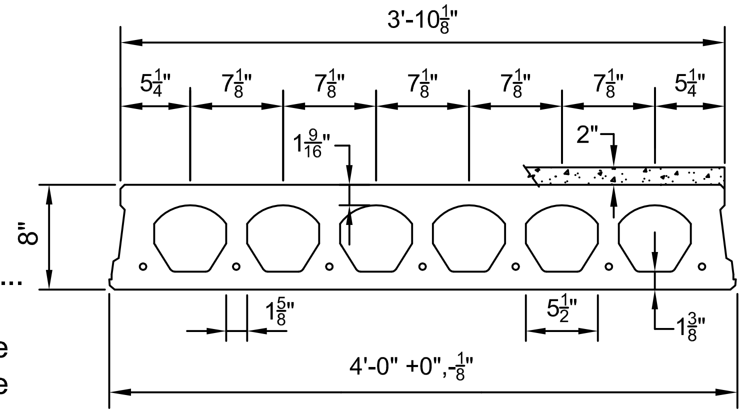
Prestressed Concrete
8"x4'-0" Hollow Core Plank

2 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

A_c = 301 in.^{2}	Precast b_w = 13.13 in.
I_c = 3134 in.^{4}	Precast S_{bcp} = 616 in.^{3}
Y_{bcp} = 5.09 in.	Topping S_{tct} = 902 in.^{3}
Y_{tcp} = 2.91 in.	Precast S_{tcp} = 1076 in.^{3}
Y_{tct} = 4.91 in.	Precast Wt. = 245 PLF
	Precast Wt. = 61.25 PSF

DESIGN DATA



1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI
3. Precast Density = 150 PCF
4. Strand = 1/2"Ø 270K Lo-Relaxation.
5. Strand Height = 1.75 in.
6. Ultimate moment capacity (when fully developed)...
   4-1/2"Ø, 270K = 92.3 k-ft at 60% jacking force
   6-1/2"Ø, 270K = 130.6 k-ft at 60% jacking force
   7-1/2"Ø, 270K = 147.8 k-ft at 60% jacking force
7. Maximum bottom tensile stress is $10\sqrt{f'c}$ = 775 PSI
8. All superimposed load is treated as live load in the strength analysis of flexure and shear.
9. Flexural strength capacity is based on stress/strain strand relationships.
10. Deflection limits were not considered when determining allowable loads in this table.
11. Topping Strength @ 28 days = 3000 PSI. Topping Weight = 25 PSF.
12. These tables are based upon the topping having a uniform 2" thickness over the entire span. A lesser thickness might occur if camber is not taken into account during design, thus reducing the load capacity.
13. Load values to the left of the solid line are controlled by ultimate shear strength.
14. Load values to the right are controlled by ultimate flexural strength or fire endurance limits.
15. Load values may be different for IBC 2000 & ACI 318-99. Load tables are available upon request.
16. Camber is inherent in all prestressed hollow core slabs and is a function of the amount of eccentric prestressing force needed to carry the superimposed design loads along with a number of other variables. Because prediction of camber is based on empirical formulas it is at best an estimate, with the actual camber usually higher than calculated values.

SAFE SUPERIMPOSED SERVICE LOADS												IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)								
Strand Pattern		SPAN (FEET)																		
		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
4 - 1/2"ø	LOAD (PSF)	280	248	214	185	159	138	118	102	87	74	62	52	42						
6 - 1/2"ø	LOAD (PSF)	366	341	318	299	271	239	211	187	165	146	129	114	101	88	77	67	58	50	42
7 - 1/2"ø	LOAD (PSF)	367	342	320	300	282	265	243	221	202	181	161	144	128	114	101	90	79	70	61

NITTERHOUSE
CONCRETE PRODUCTS

2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17202-9203
717-267-4505 Fax 717-267-4518

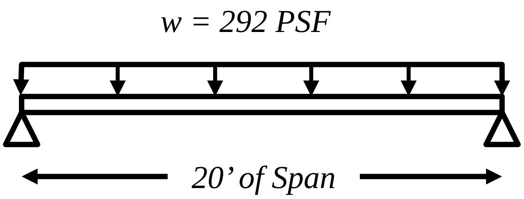
This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths. The allowable loads shown in this table reflect a 2 Hour & 0 Minute fire resistance rating.

Appendix J

Structural Breadth Detailed Calculations

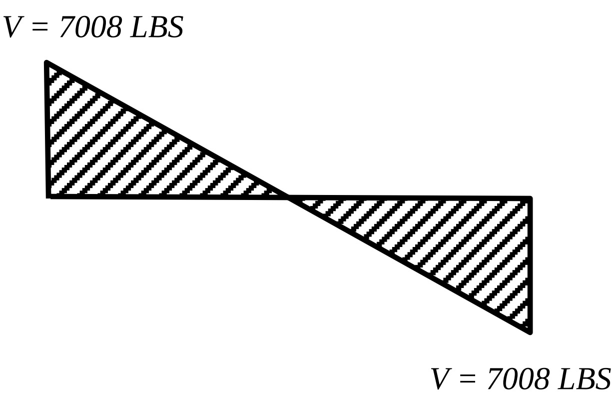
Deflection Calculations for Structural Breadth:-

Simply supported with uniformly distributed load of 292 PSF:

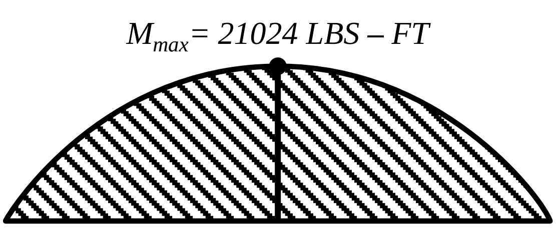


$$w = 292\ PSF\ (4') = 1168\ PLF$$

$4'$ *is the tributary width*



$$V = {}^{wl}/_{2} = {}^{(1168)(12)}/_{2} = 7008\ LBS$$



$$M_{max} = {}^{wl^2}/_{8} = {}^{(1168)(12)^2}/_{8} = 21024\ LBS - FT$$

$$E = 5700 \times \sqrt{f'_c} = 5700 \times \sqrt{6000} = 441520.1\ PSI$$

$$Deflection\text{:}\ \Delta_{actual} = {}^{5wl^4}/_{384\ EIc} = {}^{(5)(282)(1728)(20)^4}/_{(384)(441520.1)(3134)} = 0.76"$$

$$Roof = {}^{L}/_{240} = {}^{(20)(12)}/_{240} = 1 \geq 0.76"\ \therefore \text{OK}$$

Appendix K

PV Panels & Inverter Specification Sheet

Datasheet

Crystalline PV Module CHSM 6610P

220 | 225 | 230 | 235 | 240 | 245 | 250

ELECTRICAL SPECIFICATIONS

STC rated output (P_{mpp})	220 Wp	225 Wp	230 Wp	235 Wp	240 Wp	245 Wp	250 Wp
PTC rated output	199.9 Wp	204.6 Wp	209.2 Wp	213.9 Wp	218.5 Wp	223.2 Wp	227.9 Wp
Standard sorted output	(Pmpp + 2.5 Wp) > P_{flash} ≥ (Pmpp - 2.5 Wp)						
Measurement Tolerance	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%	+/- 3%
Warranted power output STC ($P_{mpp\ min}$)	217.5 Wp	222.5 Wp	227.5 Wp	232.5 Wp	237.5 Wp	242.5 Wp	247.5 Wp
Rated voltage (V_{mpp}) at STC	28.02 V	28.40 V	28.78 V	29.16 V	29.54 V	29.92 V	30.30 V
Rated current (I_{mpp}) at STC	7.86 A	7.92 A	7.99 A	8.06 A	8.13 A	8.20 A	8.27 A
Open circuit voltage (V_{oc}) at STC	36.92 V	37.14 V	37.35 V	37.56 V	37.77 V	37.98 V	38.19 V
Short circuit current (I_{sc}) at STC	8.46 A	8.49 A	8.53 A	8.56 A	8.59 A	8.62 A	8.65 A
Module Efficiency	13.4%	13.7%	14.0%	14.3%	14.6%	14.9%	15.2%
Rated output (P_{mpp}) at NOCT	165.0 Wp	168.8 Wp	172.5 Wp	176.3 Wp	180.0 Wp	183.8 Wp	187.5 Wp
Rated voltage (V_{mpp}) at NOCT	25.36 V	25.74 V	26.08 V	26.42 V	26.75 V	27.06 V	27.37 V
Rated current (I_{mpp}) at NOCT	6.51 A	6.56 A	6.61 A	6.67 A	6.73 A	6.79 A	6.85 A
Open circuit voltage (V_{oc}) at NOCT	33.73 V	33.93 V	34.12 V	34.31 V	34.50 V	34.70 V	34.89 V
Short circuit current (I_{sc}) at NOCT	7.12 A	7.15 A	7.18 A	7.21 A	7.23 A	7.26 A	7.28A

Temperature coefficient α (P_{mpp})	- 0.469%/K
Termperature coefficient β (I_{sc})	+ 0.052%/K
Temperature coefficient δ (I_{mpp})	- 0.008%/K
Temperature coefficient ε (V_{mpp})	- 0.463 %/K
Termperature coefficient χ (V_{oc})	- 0.344%/K
Normal Operating Cell Temperature (NOCT)	43℃

Maximum system voltage SCII	1000 V_{DC}
Maximum system voltage NEC	600 V_{DC}
Number of Diodes	6
Max. series fuse rating	15 A

APPROVED PRODUCT

ISO 9001 | ISO 14001 | GB/T 28001

A CHINT COMPANY

ASTRONERGY

ASTRONERGY

QUALIFICATION AND WARRANTIES

Product standard	IEC 61215, 61730 / UL 1703
Extended product warranty	5 years
Output warranty of 90% performance P_{mpp} (STC)	10 years
Output warranty of 80% performance P_{mpp} (STC)	25 years

CELL TECHNOLOGY

Cell type	polycrystalline
Number of cells / cell arrangement	60 / 6 x 10
Cells Dimension	6"

MECHANICAL SPECIFICATIONS

Outer dimensions (L x W x H)	1652 x 994 x 45 mm 65.04 x 39.13 x 1.77 inch
Frame technology	Aluminum, silver anodized
Module compound	Glass / EVA / Backsheet (white)
Weight (module only)	20 kg / 44.0 lbs
Front glass thickness	3.2 mm / 0.13 inch
Junction Box IP rating	IP 65
Cable length / diameter (UL)	1000 mm / 39.37 inch / 12 AWG
Cable length / diameter (IEC)	1000 mm / 39.37 inch / 4 mm^2
Maximum load capacity	5400 Pa
Fire Class	C
Connector type (UL)	Multi Contact Type 4
Connector type (TUV)	MC Type 4 compatible

MISCELLANEOUS

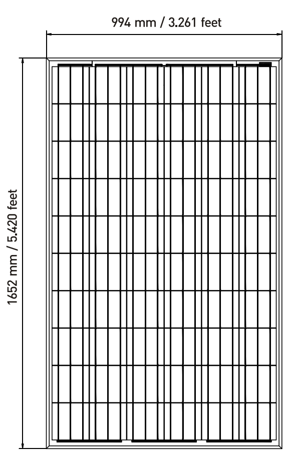
Packing unit	22 modules
Weight of packing unit	480 kg / 1056 lbs

ARTICLE NUMBER (per panel)

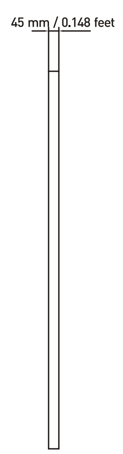
Power Class	Article No.(IEC)	Article No.(UL)
220 Wp	200016	200023
225 Wp	200017	200024
230 Wp	200018	200025
235 Wp	200019	200026
240 Wp	200020	200027
245 Wp	200021	200028
250 Wp	200022	200029

MODULE DIMENSION DETAILS

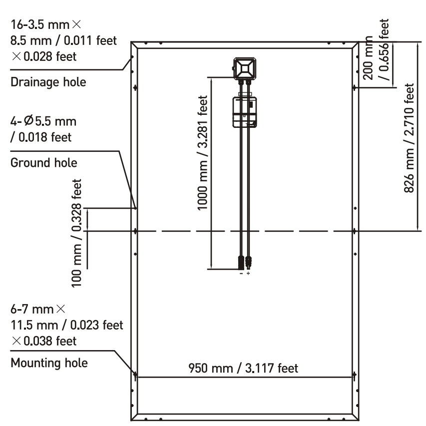
Front View



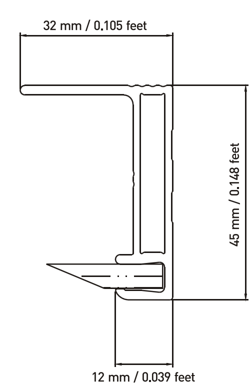
Side View



Back View



Frame Cross Section



SOLECTRIA RENEWABLES

COMMERCIAL INVERTERS

PVI 60KW
PVI 82KW
PVI 95KW

FEATURES
- Fully-integrated design
- Transformer isolated
- 208 VAC, 240 VAC, 480 VAC or 600 VAC
- MODBUS communications
- User-interactive LCD display

OPTIONS
- Fused subcombiners
- Forward facing disconnects
- Stainless steel enclosure
- Web-based monitoring
- Sub-array monitoring
- Built-in celullar connectivity

OPTIONS FOR UTILITIES
- Low voltage ride through
- VAR support
- Controlled ramp rate
- Remote power control

COMMERCIAL INVERTERS

The most fully customizable line of commercial grid-tied PV inverters available today, the PVI 60KW, PVI 82KW, and PVI 95KW series of Solectria Renewables inverters has been utilized in projects ranging from 50kW to multi-megawatt solar farms. This series of inverters is capable of operating at 208 VAC, 240 VAC, 480 VAC, and 600 VAC and comes standard with AC and DC disconnects, isolation transformer, LCD display and monitoring gateway. Options include an integrated fused subcombiner, forward facing disconnects, stainless steel enclosure and web-based monitoring. AC voltage and frequency settings may be customized according to utility specifications.

INTERTEK ETL LISTED C US

Built for the real world

SPECIFICATIONS		PVI 60KW	PVI 82KW	PVI 95KW
DC Input				
Absolute Maximum Input Voltage		600 VDC		
MPPT Input Voltage Range		312-500 VDC		
MPPT Input Voltage Range - Low Voltage Option		296-500 VDC		
Maximum Operating Input Current		201 A	278 A	320 A
Maximum Operating Input Current - Low Voltage Option		212 A	293 A	337 A
AC Output				
Nominal Output Voltage		208, 240, 480 or 600 VAC, 3-Ph		
AC Voltage Range (Standard)		-12%/+10%		
Continuous Output Power		60 kW	82 kW	95 kW
Continuous Output Current	208 VAC	167 A	228 A	264 A
	240 VAC	145 A	198 A	229 A
	480 VAC	73 A	100 A	115 A
	600 VAC	58 A	80 A	92 A
Maximum Backfeed Current		0 A		
Nominal Output Frequency		60 Hz		
Output Frequency Range		59.3-60.5 Hz		
Power Factor		Unity, >0.99		
Total Harmonic Distortion (THD)		<3%		
Efficiency				
Peak Efficiency	208/240 VAC	95.7%	95.6%	95.3%
	480/600 VAC	96.5%	96.5%	96.5%
CEC Efficiency	208 VAC	94.0%	94.5%	94.5%
	480 VAC	95.5%	95.5%	95.5%
Tare Loss	208 VAC	4 W		
	240 VAC	4 W		
	480 VAC	5 W		
	600 VAC	7 W		
Subcombiner Options				
		2-8 positions, 40-275 A		
Temperature				
Ambient Temperature Range (full power)		-13°F to +122°F (-25°C to +50°C)		
Storage Temperature Range		-13°F to +122°F (-25°C to +50°C)		
Relative Humidity (non-condensing)		5-95%		
Monitoring Options				
Web-based Monitoring (Inverter Direct)		SolrenView		
Revenue Grade Monitoring		External		
Sub-Array Monitoring (SolZone)		2-8 zones		
Cellular Communication		SolrenView AIR		
Third Party Compatibility		Standard via MODBUS		
Testing & Certifications				
Safety Listings & Certifications		UL 1741/IEEE 1547, IEEE 1547.1, IEEE 62.41.2, IEEE 62.45, IEEE C37.90.2, CSA C22.2#107.1, FCC part 15 B		
Testing Agency		ETL		
Warranty				
Standard		5 year		
Optional		10, 15, 20 year; extended service agreement; uptime guarantee		
Enclosure				
Transformer		Standard, fully-integrated (internal)		
AC/DC Disconnects		Standard, fully-integrated		
Dimensions 208/240 VAC (H x W x D) Dimensions 480/600 VAC (H x W x D)		76 in. x 56 in. x 29.3 in. (1930 mm x 1422 mm x 744 mm) 76 in. x 54 in. x 25.3 in. (1930 mm x 1372 mm x 643 mm)		
Weight		1526 lbs (694 kg)	1615 lbs (734 kg)	1748 lbs (794 kg)
Enclosure Rating		NEMA 3R		
Enclosure Finish		Polyester powder coated steel; Optional stainless steel		

Appendix L

NEC Tables

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

**Refer to 240.4(D) for conductor overcurrent protection limitations.

Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors[a] (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum[b]
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors[a] (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum[b]
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	750
5000	700	1200
6000	800	1200

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120.

Table C.1(A) Maximum Number of Compact Conductors in Electrical Metallic Tubing (EMT) *(Based on Table 1, Chapter 9)*

COMPACT CONDUCTORS											
	Conductor Size	Metric Designator (Trade Size)									
Type	(AWG/ kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
THW, THW-2, THHW	8	2	4	6	11	16	26	46	69	90	115
	6	1	3	5	9	12	20	35	53	70	89
	4	1	2	4	6	9	15	26	40	52	67
	2	1	1	3	5	7	11	19	29	38	49
	1	1	1	1	3	4	8	13	21	27	34
	1/0	1	1	1	3	4	7	12	18	23	30
	2/0	0	1	1	2	3	5	10	15	20	25
	3/0	0	1	1	1	3	5	8	13	17	21
	4/0	0	1	1	1	2	4	7	11	14	18
	250	0	0	1	1	1	3	5	8	11	14
	300	0	0	1	1	1	3	5	7	9	12
	350	0	0	1	1	1	2	4	6	8	11
	400	0	0	0	1	1	1	4	6	8	10
	500	0	0	0	1	1	1	3	5	6	8
	600	0	0	0	1	1	1	2	4	5	7
	700	0	0	0	1	1	1	2	3	4	6
	750	0	0	0	0	1	1	1	3	4	5
	900	0	0	0	0	1	1	2	3	4	5
	1000	0	0	0	0	1	1	1	2	3	4
THHN	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table C.1 *Continued*

		CONDUCTORS									
	Conductor Size	Metric Designator (Trade Size)									
Type	(AWG kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH*, RHW*, RHW-2*, TW, THW, THHW, THW-2	6	1	3	4	8	11	18	32	48	63	81
	4	1	1	3	6	8	13	24	36	47	60
	3	1	1	3	5	7	12	20	31	40	52
	2	1	1	2	4	6	10	17	26	34	44
	1	1	1	1	3	4	7	12	18	24	31
	1/0	0	1	1	2	3	6	10	16	20	26
	2/0	0	1	1	1	3	5	9	13	17	22
	3/0	0	1	1	1	2	4	7	11	15	19
	4/0	0	0	1	1	1	3	6	9	12	16
	250	0	0	1	1	1	3	5	7	10	13
	300	0	0	1	1	1	2	4	6	8	11
	350	0	0	0	1	1	1	4	6	7	10
	400	0	0	0	1	1	1	3	5	7	9
	500	0	0	0	1	1	1	3	4	6	7
	600	0	0	0	1	1	1	2	3	4	6
	700	0	0	0	0	1	1	1	3	4	5
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	3	5
	900	0	0	0	0	0	1	1	2	3	4
	1000	0	0	0	0	0	1	1	2	3	4
	1250	0	0	0	0	0	1	1	1	2	3
	1500	0	0	0	0	0	1	1	1	1	2
	1750	0	0	0	0	0	0	1	1	1	2
	2000	0	0	0	0	0	0	1	1	1	1
THHN, THWN, THWN-2	14	12	22	35	61	84	138	241	364	476	608
	12	9	16	26	45	61	101	176	266	347	443
	10	5	10	16	28	38	63	111	167	219	279
	8	3	6	9	16	22	36	64	96	126	161
	6	2	4	7	12	16	26	46	69	91	116
	4	1	2	4	7	10	16	28	43	56	71
	3	1	1	3	6	8	13	24	36	47	60
	2	1	1	3	5	7	11	20	30	40	51
	1	1	1	1	4	5	8	15	22	29	37
	1/0	1	1	1	3	4	7	12	19	25	32
	2/0	0	1	1	2	3	6	10	16	20	26
	3/0	0	1	1	1	3	5	8	13	17	22
	4/0	0	1	1	1	2	4	7	11	14	18
	250	0	0	1	1	1	3	6	9	11	15
	300	0	0	1	1	1	3	5	7	10	13
	350	0	0	1	1	1	2	4	6	9	11
	400	0	0	0	1	1	1	4	6	8	10
	500	0	0	0	1	1	1	3	5	6	8
	600	0	0	0	1	1	1	2	4	5	7
	700	0	0	0	1	1	1	2	3	4	6
	750	0	0	0	0	1	1	1	3	4	5
	800	0	0	0	0	1	1	1	3	4	5
	900	0	0	0	0	1	1	1	3	3	4
	1000	0	0	0	0	1	1	1	2	3	4
FEP, FEPB, PFA, PFAH, TFE	14	12	21	34	60	81	134	234	354	462	590
	12	9	15	25	43	59	98	171	258	337	430
	10	6	11	18	31	42	70	122	185	241	309
	8	3	6	10	18	24	40	70	106	138	177
	6	2	4	7	12	17	28	50	75	98	126
	4	1	3	5	9	12	20	35	53	69	88
	3	1	2	4	7	10	16	29	44	57	73
	2	1	1	3	6	8	13	24	36	47	60

Appendix M

Cash Flow Table

Year	Cumulative payback
0	-$820,658.00
1	-$469,370.00
2	-$336,054.00
3	-$230,924.00
4	-$142,153.00
5	-$52,010.80
6	$23,754.70
7	$92,673.40
8	$160,551.00
9	$229,917.00
10	$300,804.00
11	$311,700.00
12	$323,265.00
13	$335,519.00
14	$348,483.00
15	$362,179.00
16	$376,628.00
17	$391,852.00
18	$407,876.00
19	$424,723.00
20	$442,417.00
21	$460,985.00
22	$480,452.00
23	$500,845.00
24	$522,191.00
25	$544,520.00