Research Facility Core and Shell| Southern California

THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ARCHITECTURAL ENGINEERING

Research Facility Core and Shell- Prefabrication of Exterior Façade, Solar Panel Implementation, and Integration of Mobile Technology in Construction

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Abstract

This report details three technical analysis areas that investigate the means and methods of construction utilized for the construction of the facility titled "Research Facility Core and Shell (RFCS)" which is located in Southern California. The building is a 130,000 SF, 4-story with underground parking garage, mixed use laboratory and office space. The three areas of analysis aim to provide a better final product by decreasing cost and schedule duration, increasing sustainable solutions, and utilizing technology to save time and increase construction quality.

Technical Analysis 1: Application of Prefabricated Wall Panels with Detailed Sequencing

The original exterior façade of RFCS utilizes stick-built construction where the walls are constructed in place. In this analysis two forms of prefabrication techniques are investigated in the effort to decrease cost and schedule of the exterior facade. These two forms of prefabrication include a fully prefabricated Clark Pacific architectural precast concrete panel system and a partially prefabricated system where the metal studs and sheathing are built on site as panels, raised into place, and then completed as if stick-built. After cost, schedule, constructability concerns, and project requirements were addressed; the system chosen was the partially prefabricated system. When compared to the original stick-built construction, this system saves $5,953 in costs and reduces the overall project schedule by three weeks.

Accompanying this analysis is a detailed schedule report demonstrating the specifics of the modularization breakdown, the panel construction, and the erection sequence of the panels. Diagrams and virtual mockups are provided to help demonstrate this process.

Technical Analysis 2: Solar Panel Installation at Roof Level

Owner interest in installing solar panels at the roof level of RFCS to achieve LEED Gold Certification drove the analysis and design of this 47,000 kWh, 143 module, TrinaSolar array system. This system has an initial direct cost of $180,534 and a lifecycle payback term of 14 years once incentives and annual energy cost gains were accumulated. Installation of this system is scheduled to take approximately four weeks if implemented.

Technical Analysis 3: Mobile Technology Integration- Tablet Computers

Tablet computer technology is beginning to provide a platform which enables processes required for construction management to be made more efficient. This analysis examines case studies of mobile technology integration on various projects in an effort to apply the appropriate implementation to RFCS. The uses of mobile technology appropriate to RFCS are: accessibility to drawings in the field, coordination in the field, documenting field issues, email and correspondence, safety evaluations, and daily forms and checklists. Based on the case studies and rates specific to RFCS, the project stands to save $1,668 per week or $116,272 over the span of the entire project in on-site management costs while increasing quality, efficiency and customer service.

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Table of Contents

Index of Figures

Index of Tables

Chapter 1: Project Overview

1.1 Project Description

Figure 1.1: Exterior View of Research Facility Core and Shell

Research Facility Core and Shell (RFCS) was designed and built to serve the growth demands of the tenant, Faction, on their existing campus located in Southern California. Faction's main business involves research into new tools that can be used to study the human genome.

The building is four stories above grade with an underground parking garage. The gross square footage of the building is 130,000 SF and will operate as a mixed use facility comprised of both laboratory and office space. To find detailed descriptions of the systems used at RFCS please reference Appendix C-System Descriptions.

1.1.1 General Information

The construction of this project is planned to be completed in two phases under two contracts: a core and shell portion and a tenant improvement portion to follow. The General Contractor for the project is DPR construction contracted under a GMP and delivered as a design-bid-build. The area of study for this thesis proposal is the core and shell portion of the project which includes the structural system, the building enclosure, heavy mechanical and electrical equipment, and site work. Under current plans Research Facility Core and Shell is estimated to cost $20 M and take 18 months to complete from design through substantial completion. The breakdown of the main costs and schedule durations can be found in *Table 1: Major Project Costs* and *Table 2: Major Schedule Durations*.

Table 1.1: Major Project Costs

Major Costs for Research Facility Core and Shell		
	Construction Cost	Cost/SF
Actual Building Construction	$16,031,402	$125.86
Total Project	$20,035,000	$157.29
Mechanical System	$1,574,261	$12.36
Electrical System	$1,014,666	$7.97
Plumbing System	$662,250	$5.20
Fire Protection	$298,462	$2.34
Structural System	$5,238,945	$41.13
Exterior Skin	$4,089,261	$32.10

Table 1.2: Major Schedule Durations

Schedule Overview	
Phase	Timeframe
Notice to Proceed	January 24, 2011
Design/Preconstruction	January 24, 2011 – June 26, 2011
Substructure	June 27, 2011 – September 30, 2011
Superstructure	October 12, 2011 – November 30, 2011
Exterior Envelope	December 15, 2011 – June 29, 2012
Core MEP Rough-in	March 20th 2012 – April 30, 2012
Core Interior Finishes	May 1, 2012 – June 21, 2012
Commissioning	March 20, 2012 – August 27, 2012
Substantial Completion	August 28, 2012

1.1.2 Planned Facility Use at RFCS

As previously noted, Research Facility Core and Shell was designed and built to serve the research and office growth demands of the client, Faction. *Table 3: Building Use Description* gives a breakdown of the planned use for each floor at RFCS. The garage will house the main electrical and elevator machine rooms as well as parking while floors 1-4 will serve the main office and laboratory needs. The roof will house the large mechanical equipment necessary to serve the HVAC needs of the building.

Table 1.3: Building Use Description

Building Use Description		
Level	**Size**	**Use**
Underground Parking Garage	31,197 SF	Parking; UPS, Electrical & Elevator Machine Rooms
First Floor	31,850 SF	Lobby, Laboratory Space
Second Floor	31,850 SF	Offices, Laboratory Rooms
Third Floor	31,850 SF	Offices, Laboratory Rooms
Fourth Floor	31,850 SF	Offices
Roof	31,850 SF	Large Mechanical Equipment

1.2 Local Conditions

The conditions of this Southern California site are quite favorable for construction. Owners and contractors benefit from the almost always sunny weather with almost no rainy days (10 inches per year on average). The Faction campus is also very spacious allowing for a large site with gracious lay down space and tie-ins to an existing central utility plant. Adding to these conveniences is an existing parking lot that is next to the site which allows space for trailers as well as parking for employees, craftsman and labors. This clears the actual site, opening it even further for the trades to efficiently work.

Figure 1.2: Aerial View of Site

An existing fire lane that passes the site allows for easy entrance and exit for vehicles such as dump trucks, concrete trucks, and delivery trucks. As one might expect, the soil in the area remains dry which was a benefit to the project team as they did not have to pump water during excavation. The consistently sandy soil of the area also gave ease to the excavation process as well as the predictability of avoiding unforeseen conditions.

The area where RFCS is located has both steel and concrete structures spread throughout. While both exist, steel construction is by far the most preferred method of construction; especially on the Faction campus. The low building height of surrounding buildings as well as the large spacing of the campus allows for safe and more efficient crane picks during steel erection. One would be hard pressed to find a site to construct their new building on as favorable as this one and the team certainly used this to their advantage.

1.3 Client Information

Faction is a company with highly vested interests into the study of genes and the biologic functions resulting from genetics. Their line of products that will be under investigation in the new RFCS does not deal with the actual study of genetics but rather- the study of *the tools* that are needed to closely examine genetics. The campus is dedicated to providing a space for ingenuity and contains buildings such as a gym, a café, and an amphitheater that is currently under construction on the north side of RFCS. Faction not only incorporates this attitude into specialized buildings on campus but also tries to work that feeling into their research labs. Because of this, they want the spaces to be detailed and pleasant to be in. They have worked with the designer to allow for large open spaces for research as well as architecturally pleasing finishes such as an intricate lobby space that evokes a feeling of compression and expansion immediately upon entry.

The need for the RFCS arose mainly out of company growth but the extraordinarily speedy pace of the technology industry contributed as well. Faction has held specific construction needs throughout the building process. Schedule has been a driving factor for the project because of the amount of money that can be generated by the scientists once occupied. This has contributed to a very hectic core and shell schedule pushing for a very quick turn-around. Along with schedule, safety is a very important component of what the owner/tenant would call a successful project. The company exists to find new products that will help other scientists look closer at our genome which consequently leads to saving lives. Having a death during construction would be an enormous tragedy and the contractor would certainly see the repercussions.

Sequencing has become a large part of this project as well. The owner continues to push for phased occupancy to allow for research to start as soon as possible. Because of this, the project was split into core and shell and tenant improvement. The reasoning behind this was to reach a contractual agreement with DPR on scopes that could be properly bought, managed, and released in a speedy manor while still holding a design-bid-build contract. While DPR builds the CS, the TI scope and contract are negotiated. If one were to look at both the CS and TI together as one contract it would look very similar to a fast-track construction method. This is not the case though and seems to have been done so intentionally by the owner.

1.4 Project Delivery System

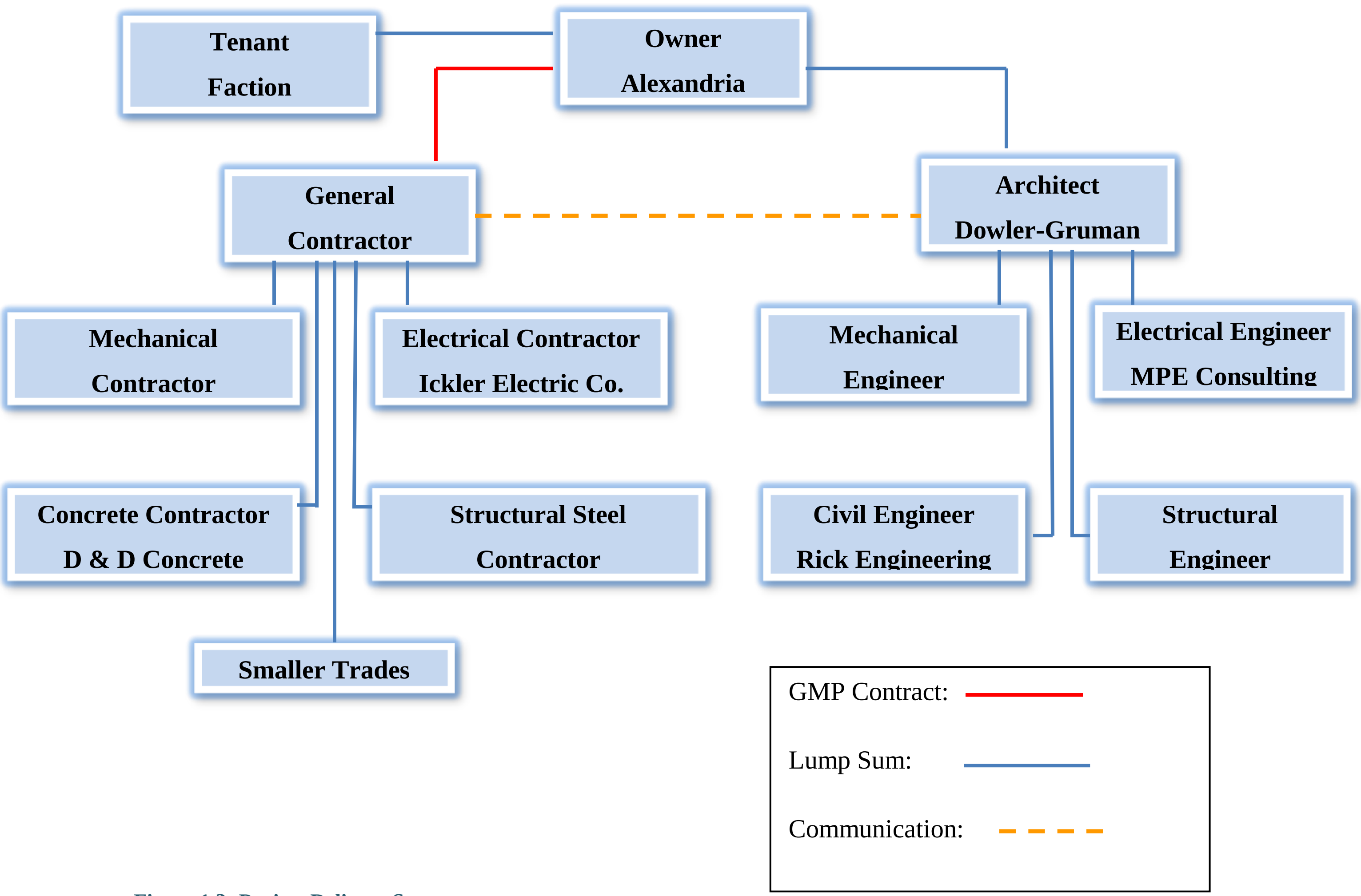


Figure 1.3: Project Delivery System

The Research Facility Core and Shell is being delivered as a “design-bid-build”. Faction uses this delivery method because it is a familiar approach used by the organization and has proven to be successful for other buildings on their campus. DPR has built a strong relationship with the Client and has built many of the existing buildings on the campus. The trust factor, DPR’s presence on campus, and a fair bid, allowed DPR to win the job.

DPR has been contracted under a GMP by Alexandria. DPR then contracts the subcontractors based on a lump sum. Dowler-Gruman, the Architect, has been contracted under a lump sum and holds its engineering consultants under lump sum contracts as well. DPR is in constant communication with Dowler-Gruman exchanging RFI’s, submittals, and working out some of the issues in constructability.

Subcontractors were chosen based on lowest bid, safety plans, and their ability to build the project. DPR is concerned with more than just the lowest bid. Safety is of utmost concern as well as the promise to complete the work and the need for complete bonds and insurance to cover any failure to do so.

1.5 Project Team Staffing Plan

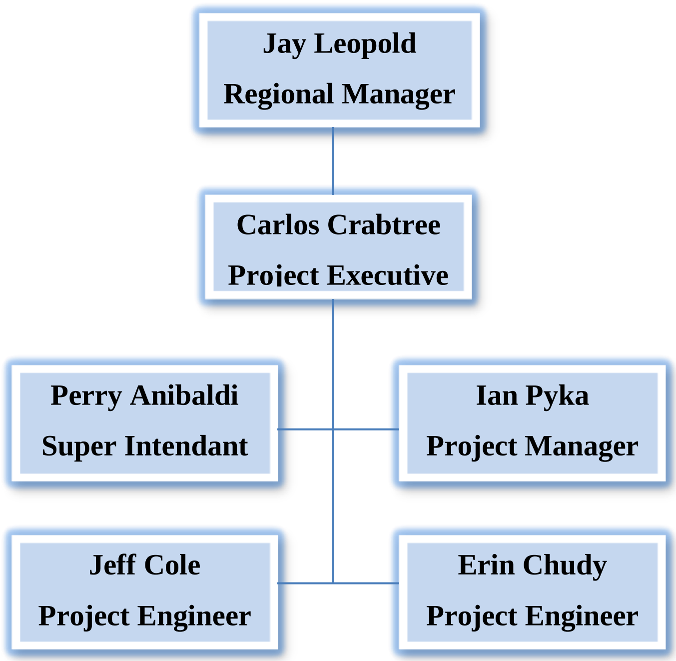


Figure 1.4: Staffing Plan

DPR operates as a flat organization relying on the team to "break down the silos". To do so they chose not to have formal titles or formal bosses. The titles listed above have been used to represent the main role of the individual but in reality each individual on the DPR team is responsible for answering to one another and being informed on all areas of expertise. For purposes of this thesis, and the requests of Dr. Messner, a hierarchy has been shown to form a chain of command.

Jay Leopold is the Regional Manager of the San Diego office and oversees all of the projects that are going on in the greater San Diego region. Managing the entire campus of buildings for the Owner is Carlos Crabtree. The project manager for the entire campus and more specifically the Research Facility Core and Shell is Ian Pyka. Ian is in charge of the finances on the project and also holds a very "in touch" relationship with the owner. Erin Chudy and Jeff Cole are the Project Engineers responsible for the day to day management that takes place while Perry Anibaldi leads the charge as Super Intendant responsible for managing the crews on site. Erin Chudy has taken a lead on the core and shell as project engineer and Jeff Cole has assumed the responsibility of the MEP systems.

1.6 Building Systems Summary

The following section discusses the main building systems at RFCS. To begin, an initial checklist was completed to understand which systems were implemented as well as what questions needed to be answered on how they were constructed. Below is a table showing this initial check-up. Also contained in this section is a summary of the sustainability features that were incorporated to achieve a LEED Silver certification.

Table 1.4 Building System Summaries

Yes	No	Work Scope	Issues addressed
	x	Demolition	N/A
x		Structural Steel Frame	Type of bracing, member sizes, construction type
x		Cast in Place Concrete	Horiz. And Vert. Formwork types, concrete placement methods
	x	Precast Concrete	N/A
x		Mechanical System	Mech. Room locations, system type, types of distribution, types of fire suppression
x		Electrical System	Size/ capacity, redundancy
x		Masonry	Load bearing or veneer, connection details, scaffolding
x		Curtain Wall	Materials included, construction methods, design responsibility
x		Support of Excavation	Type of excavation support system, dewatering system, permanent vs. temporary
x		LEED Certification	Sustainability features

1.6.1 Structural Steel Frame

The main superstructure at RFCS consists of structural steel. It rests on 42 spread footings sized mainly at 11'x11' supporting the structure with a CMU wall running the perimeter of the basement bearing the load from the soil. The design is straight forward following a redundant bay scheme. Composite metal deck rests on the steel beams topped with 3 ½" normal-weight concrete. A relatively new form of lateral bracing was used on this building. It is called a "side-plate" system and involves using steel side plates to horizontally brace and connect the perimeter columns to one another. An image taken from the manufacturer's website can be seen below. The most common beam used throughout the building is a W21x44 spanning 42 ½ feet and running N-S. The girders that these beams rest on are typically W27x84 and run E-W. Columns are spaced in a typical pattern with the largest being W12x120.

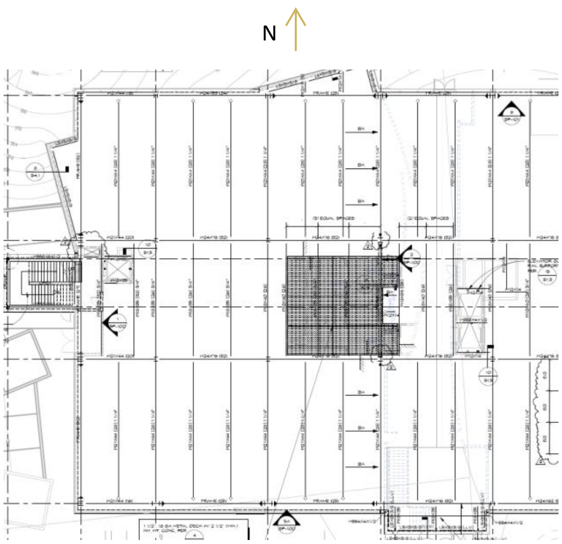


Figure 1.5: Typical Steel Bays

Figure 1.6: Side Plate System

www.sideplate.com

1.6.2 Cast in Place Concrete

Cast in Place concrete was utilized for the foundation, slab on grade, and floor slabs. Classic wooden formwork was used for the foundation and SOG while an edge plate was built into the structure to allow for the pours onto metal deck. Trucks delivered the concrete to site allowing for direct pours for the foundation and SOG. A pump was utilized for floors 1-4 due to the elevations.

1.6.3 Mechanical System

The portion of RFCS that is being studied incorporates only the main "core" of the mechanical system which entails large rooftop units with large ducts that travel down the main vertical chase of the building. While the scope of work is small, at this phase in the project is when the main drivers of what the mechanical system will be are installed. The core portion of the HVAC system is comprised of 4 rooftop air handling units utilizing central chilled water via a main plant on the Faction campus and will service hot water via two 4-ton rooftop boilers. A smaller mechanical/utility room is located at the garage level but most of the service will occur at the rooftop level. A large vertical chase runs from the rooftop to the garage allowing for an organized flow of ductwork and piping. This chase is located at the center of the building next to the restrooms.

1.6.4 Electrical System

Five hundred feet of newly installed high voltage lines connect three transformers (3000KVA, (2) 1500KVA) to the existing Faction campus power; this can be seen in the figure below. Two newly constructed man holes on the south end of the building serve as this tie in. The power travels from the transformers to a 4000 A switchgear and a 2500 A switchgear that serve the power needs of the building. The electrical scope for the core and shell portion of the building was kept to the main power components. Further installations for the smaller distribution have been built into the Tenant Improvement contract.

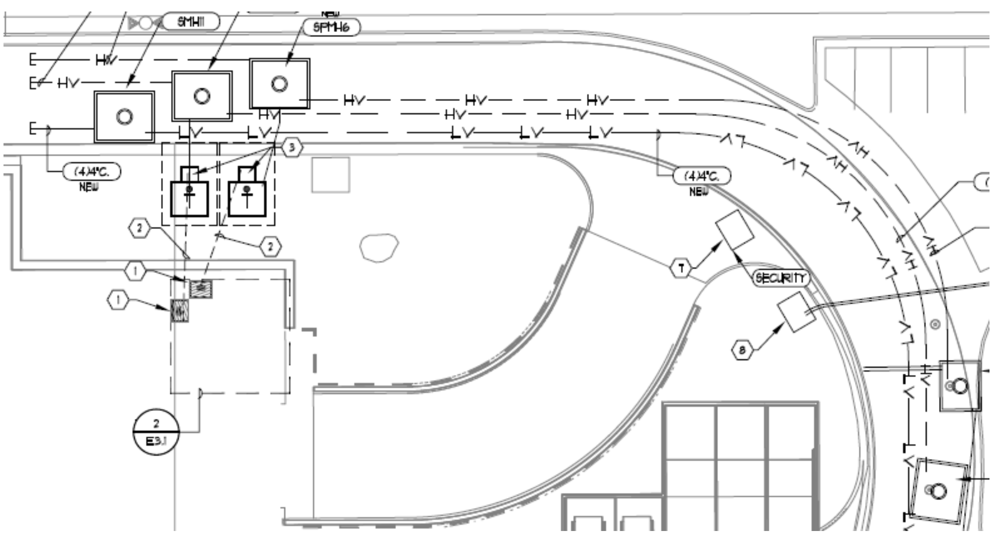


Figure 1.7: New High Voltage Lines

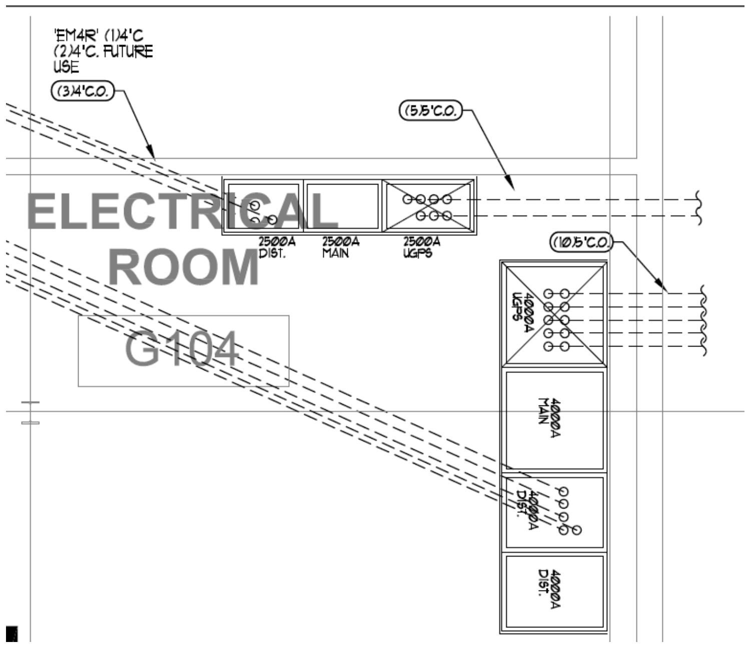


Figure 1.8: Main Electrical Room

1.6.5 Masonry

RFCS is heavily characterized by its masonry components. Concrete Masonry Units are used to support the soil loads in the basement and run the perimeter of the building below grade. Various types of masonry veneer were used on the enclosure of the building which can be seen in the figure below. All of which were about 6"x12"x 1" pieces of stone attached one by one to the metal stud wall assembly. Stick built scaffolding was used and all four sides of the building went up simultaneously.


Figure 1.9: Masonry Walls

1.6.6 Curtain Wall

Aside from the masonry that was used for the enclosure, curtain walls constituted a large portion as well. These curtain walls consisted of steel mullions that supported windows that were mainly 4'x8' and were composed of clear blue "vision" glass. The curtain walls were built on the ground and raised as panels. Once raised, they were tied into the structure at connection points on each floor.

Figure 1.10: Curtain Wall

1.6.7 Support of Excavation

RFCS has one level below grade that will eventually be a parking garage. This requires excavation which could be a potential hazard if not addressed appropriately. To prevent from any cave-ins, the construction team set back the perimeter of the excavation where space permitted and used sheathing and shoring in areas that were more restrictive on space. Dewatering was unnecessary during construction both permanently and temporarily.

1.6.8 LEED Goals

From the very start of the project it was important to the owner to be as sustainable as possible and meet LEED standards. The core and shell is on track for attaining LEED silver certification. Recycled insulation boards are used on the roof and layered twice which saves materials as well as increases the thermal properties of the building. Along with this, white EPDM membrane is used on the roof to decrease the heat island effect. The thermal properties of the enclosure also prove to be proficient and will save energy through time when compared to a normal system. Adding to the sustainability features mentioned above was a rigorous recycling program implemented throughout construction to eliminate waste from construction.

1.7 Project Cost Evaluation

The following section outlines the actual construction costs for Research Facility Core and Shell and compares them to both a square foot estimate and an assemblies estimate. The estimates were performed by Tim Maffett on September 15th 2012 using RS Means construction cost data. A more detailed estimate breakdown can be found in Appendix A: Preliminary Project Cost Evaluation.

1.7.1 Actual Construction Costs

Table 1.5: Actual Project Costs

Major Costs for Research Facility Core and Shell		
	Construction Cost	**Cost/SF**
Actual Building Construction	$16,031,402	$125.86
Total Project	$20,035,000	$157.29
Mechanical System	$1,574,261	$12.36
Electrical System	$1,014,666	$7.97
Plumbing System	$662,250	$5.20
Fire Protection	$298,462	$2.34
Structural System	$5,238,945	$41.13
Exterior Skin	$4,089,261	$32.10

*Actual Building Construction pricing does not include land costs, site work, permitting, insurance, general conditions or fee.

*Total Project includes land costs, site work, permitting, insurance, general conditions, and fee.

1.7.2 Square Foot Estimate

Table 1.6: Square Foot Estimate

Square Foot Costs for Research Facility Core and Shell		
	Construction Cost	**Cost/SF**
Total Project	$19,857,928	$194.88

1.7.3 Assemblies Estimate

Table 1.7: Assemblies Estimate

Assemblies Costs for Research Facility Core and Shell		
	Construction Cost	**Cost/SF**
Mechanical System	$2,496,510.80	$19.60
Electrical System	$203,504.10	$1.60
Plumbing System	$146,924.22	$1.15
Fire Sprinkler System	$415,235.98	$3.26

The Research Facility Core and Shell costs are mostly associated with the superstructure and exterior skin rather than the typically large MEP budgets. This is due to the owner's decision to split the project up into two phases, a Core and Shell and a Tenant Improvement. Because of this split, estimates besides a detailed estimate prove to be very difficult to quantify.

The square foot estimate was based on a typical Office Building 2-4 stories. This is due to the Superstructure being very similar to that of an office building. Once adjustments were made and calculated for things like story height, location, and wall types, the estimated percentage of mechanical and electrical systems that are not included in the CS were removed allowing for a very close match SF estimate.

On the other hand, the assemblies estimate proved to be unreliable. The estimate varies from actual costs due to the split in MEP scopes. This semi-unorthodox split caused difficulties when trying to pick an appropriate assembly system from RS Means. The assemblies estimate accounted for items that were not included in the Core and Shell package in some instances and did not account for things in other instances. A detailed estimate would prove to be very effective for a building of this nature as the amount of items to count in the MEP system is minimal. Another issue associated with the assemblies estimate is that it does not include the piping, conduit, and duct work that is needed in the building; this certainly causes a difference between the estimate and the actual costs.

1.8 General Conditions Estimate

The General Conditions cost for Research Facility Core and Shell is estimated to be $754,705 over the 63 week schedule. This works out to cost $11,831.97 per week in General Conditions. These costs seem considerably low but unique factors come into play for this project allowing the DPR team to offer competitive prices.

DPR is in an advantageous position for keeping their General Conditions cost low and thus competitive on the RFCS project. The team has an established base on Faction's campus because another DPR team is working on the fitness center next to RFCS and started work at about the same time. Because of this, general requirement costs such as the cost of the office trailer can be distributed between the projects thus driving the cost down. The two projects also share some key supervision personnel which allows DPR to bill less for jobsite management. These factors contribute to a relatively low GC cost and help to explain why values are lower than industry averages.

Temporary utilities costs become an important factor when calculating General Condition's costs for projects. Fortunately on the RFCS project, temporary utilities costs were minimal because the team was immediately able to tie into the existing utilities made available by Faction from the central plant on campus. These tie-ins were covered in the MEP scopes because their contracts included running the underground utilities to the new RFCS as well as connection to the trailer.

The following tables give a detailed breakdown of the General Condition's costs mentioned above. By itemizing the individual costs, readers can see where DPR was able to keep costs low and therefore competitive for RFCS. These costs are essential for future studies that will analyze the effects of schedule increases and reductions on total project cost.

Table 1.8: General Conditions Summary

RFCS General Conditions Summary		
General Breakdown	**Cost/Week**	**Total Cost**
Management	$10,701	$674,133
Jobsite Requirements	$1131	$80,572
Total	**$11,832**	**$754,705**

Table 1.9: Jobsite Management

RFCS Jobsite Management					
Title	**Weeks**	**Total Hours**	**Rate ($/hr)**	**Cost/Week**	**Total Cost**
Project Executive	-	-	-	$1,032	$64,994
Project Manager	-	-	-	$1,237	$77,922
Project Superintendent	-	-	-	$4,150	$261,469
Project Engineer	-	-	-	$2,698	$169,955
Field Office Coordinator	-	-	-	$889	$56,029
Accounting	-	-	-	$250	$15,771
MEP Coordinator	-	-	-	$257	$16,165
Safety Engineer	-	-	-	$188	$11,828
Total	**63**	**7955**	**$84.74**	**$10,701**	**$674,133**

Table 1.10: General Requirements

RFCS Jobsite General Requirements		
Item	**Cost/Week**	**Total Cost**
Trailer Setup/Mobilization	(--)	$6,493
Trailer Demobilization	(--)	$2,828
Office Trailer Complex	$155.37	$9,788
ISP/IT Setup	$25.87	$1,630
Computers	$325.87	$20,530
Monthly Network & Server	$27.16	$1,711
Office Supplies	$54.32	$3,422
Printer/ Fax	$13.59	$856
Copy Machine	$59.76	$3,765
Janitorial Service	$43.46	$2,738
Postage	$16.30	$1,027
Office Drinking Water	$5.43	$342
Cell Phones	$130.35	$8,212
Trucks	$170.86	$10,764
Fuel	$102.63	$6,466
Total	**$1131**	**$80,572**

*(--) indicates that the item is a one-time cost and has been removed from the Cost/Week total for purposes of analyzing effects of scheduled increase/decrease in future reports.

1.9 Existing Conditions and Site Layout Planning

Please reference Appendix B – Existing Conditions Plan and Phasing Plans for detailed schematic layout plans.

1.9.1 Existing Conditions

The existing conditions of this site did not provide too many obstacles for the construction team. Of necessary items to focus on though include the need to address pedestrian traffic and the need for finding exact utility tie-in point locations. It is important that pedestrians on campus are informed and kept as far away from the construction as possible. The fence location and associated walking paths create a boundary for this which should manage walking traffic as best as possible. Existing utility tie-in points must be found in order to connect the new lines to the RFCS. Often times the As-Built drawings are imprecise so it is imperative that the team does proper investigation and takes caution when digging for these.

1.9.2 Site Layout Planning

1.9.2.1 Excavation

Critical items that must be addressed during the excavation process include vehicular traffic such as dump trucks, disturbing underground utilities, and on site caution from heavy equipment. Dump trucks must be coordinated to follow a one way pattern from the north side of site travelling around and southward as can be seen on the Building Excavation Plan. When digging the excavators must exercise caution near utilities and workers must also be conscientious of one another while the heavy equipment is in operation.

1.9.2.2 Superstructure

The site allows for a relatively safe erection of the superstructure. Again, trucks must enter from the north and exit on the south side. Space is available for concrete trucks to back in from the fire lane and make the appropriate pours for the foundations and SOG. Crews can erect the structure from north to south using a crawler crane with a swing radius of 75’. Steel laydown areas are ample and can even move with the crane as it works its way south. The crane operator must be cautious when erecting the south end of the building as Existing Building A is close enough that it could be threatened if a control mistake was made.

1.9.2.3 Enclosure

The logistics plan for the enclosure is quite similar to that of the superstructure. The crane will still need to be in operation to raise the north side curtain wall. Stick built scaffolding surrounds the remaining walls to allow the entire enclosure to be erected as speedily as possible. Materials for the masons and other crews can be placed where the steel had been or next to it if steel materials are still left. At this point in the project crews must be especially cautious of one another. Multiple trades are on site and will be working in close vicinity of one another.

1.10 Project Schedule

From conception to completion, RFCS was built in 20 months. Design began January 24th, 2011 and the project attained substantial completion August 28th, 2012. Over this 20 month period the project underwent many different phases which were all heavily coordinated to ensure on-time completion. The following table gives a general breakdown of the phases and their associated time frames:

Table 1.11: Schedule Overview

Schedule Overview	
Phase	**Timeframe**
Notice to Proceed	January 24, 2011
Design/Preconstruction	January 24, 2011 – June 26, 2011
Substructure	June 27, 2011 – September 30, 2011
Superstructure	October 12, 2011 – November 30, 2011
Exterior Envelope	December 15, 2011 – June 29, 2012
Core MEP Rough-in	March 20th 2012 – April 30, 2012
Core Interior Finishes	May 1, 2012 – June 21, 2012
Commissioning	March 20, 2012 – August 27, 2012
Substantial Completion	August 28, 2012

Many of the phases of RFCS overlapped and often followed a logical pattern. Design was followed by BIM-clash detection which occurred simultaneously with procurement and fabrication. Once the team mobilized, the site work and basement excavation began which followed closely by foundations, slab on grade, and basement structures. The steel structure was then erected which was phased according to floor level. Levels 1 and 2 were raised first followed by 2 and 4 and then finally the roof level. Once a level was raised, crews began welding and metal decking the associated floor. The process followed vertically until the entire structure was raised, welded, and metal deck installed. Concrete crews followed, lagging slightly behind the steel detailers, pouring the slab on deck one level at a time from Level 1 to 4. Once all of the concrete pours were complete the exterior skin was built. The skin was raised from the ground up on all four major sides of the building concurrently. Lagging the exterior skin by a few months, the interior work began on all floors almost simultaneously. This is most likely due to the majority of the interior work being done on the main vertical chase of the building which runs through all levels. As systems were installed they were commissioned which saved the team time at the end from figuring each system out last minute. Final commissioning allowed for substantial completion which marked the end of the Core and Shell effort and signaled the beginning of the next contract- Tenant Improvement.

A more detailed version of the project schedule can be found in Appendix C: Overall Project Schedule. This researcher chose to go into greater detail on the substructure, superstructure, and facade than that of interior work. This decision is based on the uniquely minimal amount of MEP and interior work that lies within the scope of the Core and Shell when compared to the structure and exterior facades. The scheduling of the structure was the main key to success for DPR so this also gives merit to analyzing this portion more extensively.

Chapter 2: Application of Prefabricated Wall Panels

2.1 Problem Identification

A primary concern for the exterior enclosure at RFCS was the stick-built metal stud wall with sheathing and masonry veneer that accounted for the majority of the enclosure. This portion of the exterior enclosure drove the schedule as a critical path item for 6 months of the 18 month total schedule and created the majority of congestion on the site. With scaffolding erected on entire sides of the building at a time and crews and materials creating confusion on the ground, the on-site stick-built nature of the design proved to be expensive and time consuming for the team at RFCS.

Adding to the on-site troubles was the reliance the exterior enclosure had on the steel structure. Work on the exterior enclosure could not begin until the steel contractor had finished erecting “Sequence 1” which consisted of levels 1 and 2 steel framing. This meant that the exterior skin contractor was completely reliant on predecessor activities which give greater opportunity for project completion delay. Keeping this reliance in the schedule gives greater opportunity for problems.

With alternative options available and knowledgeable subcontractors in the market, the stick-built approach to the exterior façade denied the project team the opportunity to begin working on the exterior façade at an earlier date and created heavy reliance on prior critical path activities.

2.2 Research Goals

1. To explore the effects of implementing a prefabricated panel system for the exterior façade at RFCS as opposed to the stick-built system.
2. To analyze the costs, schedule, constructability, manufacturing, delivery, and erection concerns associated with a prefabricated exterior panel system.
3. To analyze the rigging system necessary to erect the prefabricated wall panel system focusing on structural concerns.
4. To produce a cost and schedule comparison between stick-built exterior façade and prefabricated panel exterior façade.

2.3 Application Methodology

(1) Consult Project Manager of DPR Construction and determine most appropriate way of paneling the building.
(2) Document actual construction values and rates at RFCS using the stick-built method of construction.
(3) Design 2 alternative approaches to prefabricate panels for exterior enclosure.
(4) Locate area on site appropriate for prefabrication and staging.
(5) Investigate off-site prefabrication and staging.
(6) Determine sequencing of panel erection.
(7) Attain values and rates of prefabricated wall panel erection from case study: Temecula Valley Hospital located in Temecula Valley, CA.
(8) Run comparisons on cost, schedule, quality, and safety between proposed prefabricated wall panels and original stick-built system.
(9) Propose the most appropriate solution.

2.4 Preliminary Analysis

Prefabricated wall panels are becoming more and more prevalent as prefabrication efforts are increasingly standardized; the design and installation of prefabricated panels are better understood; and the safety, quality, and logistical benefits are further brought to light. Suiting prefabrication to the correct situation is essential to success. According to a member of Forester Construction who spoke during a discussion at the Penn State University- PACE Roundtable; prefabrication is best suited for projects that do not have many variations in the design. The enclosure at RFCS appears to be fitting for such efforts in principle.

According to an interview with a Project Manager at DPR Construction, many ways of prefabrication would be possible for this building. The Project Manager prescribed that the best way to prefabricate these wall panels would be to panelize the walls in long, 16’ sections (height of one story) and then infill between them with smaller panels. His knowledge will be valuable to this analysis topic.

Another source for study is present at a recently built hospital located in Temecula Valley, CA. On this job DPR Construction and DPR Drywall were able to work together to prefabricate the exterior panels on site and install them using a crane in a matter of days. This case study will be valuable to this analysis as the job is located in a similar area and will provide durations and cost data. This raw data was tracked throughout the entire process which offers valuable comparison information.

2.5 Background Information

The construction of the stick-built exterior façade at RFCS was allotted a large amount of time in the overall schedule duration of RFCS; specifically 6 months. Some of this time overlaps with other trades but a large portion of the activity lies on the critical path. By instituting a prefabricated panel system, the project could enclose the building sooner, reduce the overall schedule duration and reduce costs through more efficient means and methods as well as general conditions overhead.

Prefabrication methods and panel sizes vary significantly depending on the constraints of the project. The following figure details the many constraints and variables that exist during the planning stage of prefabricating an exterior enclosure. These factors were considered during the selection of the appropriate prefabricated façade scheme at RFCS.

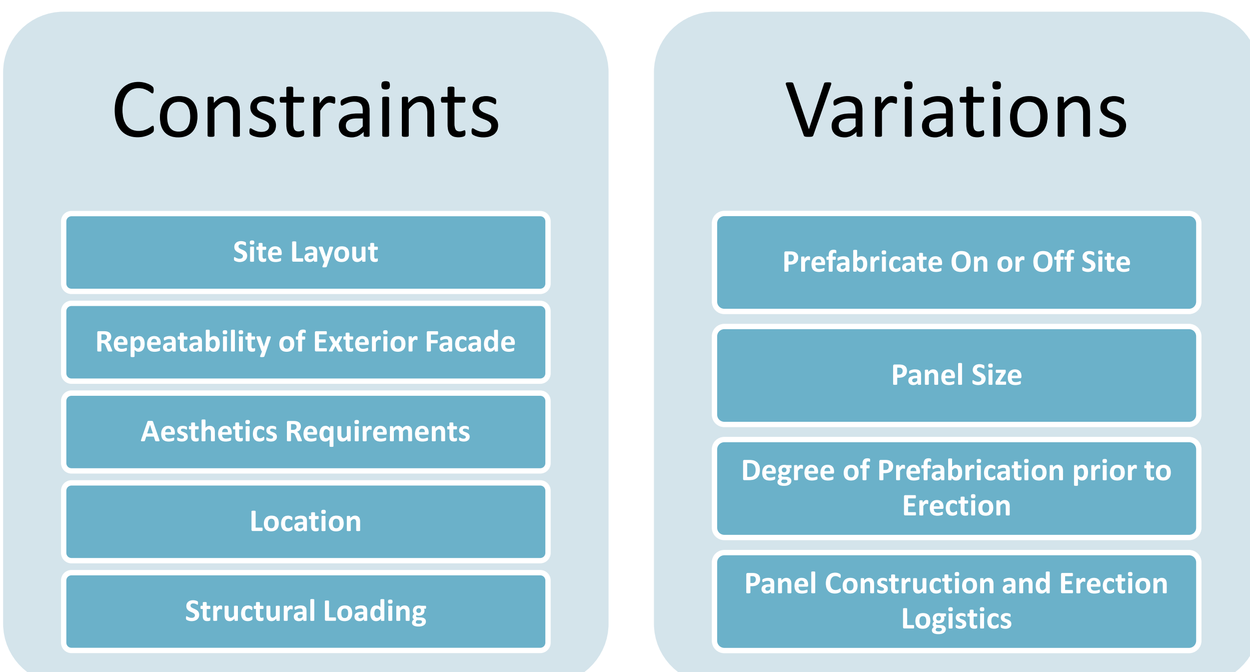


Figure 2.1: Prefabrication Constraints and Variations of RFCS

2.6 Current Façade Assembly

The portion of the exterior façade at RFCS that is under study consists of stone tile set on 1/8" mortar bed on ¾" plaster with metal lath on a felt vapor barrier on spray applied vapor barrier on 5/8" dens-glass sheathing framed on metal studs. A typical section of this wall is shown in Figure 2.2: Typical Wall Section RFCS.

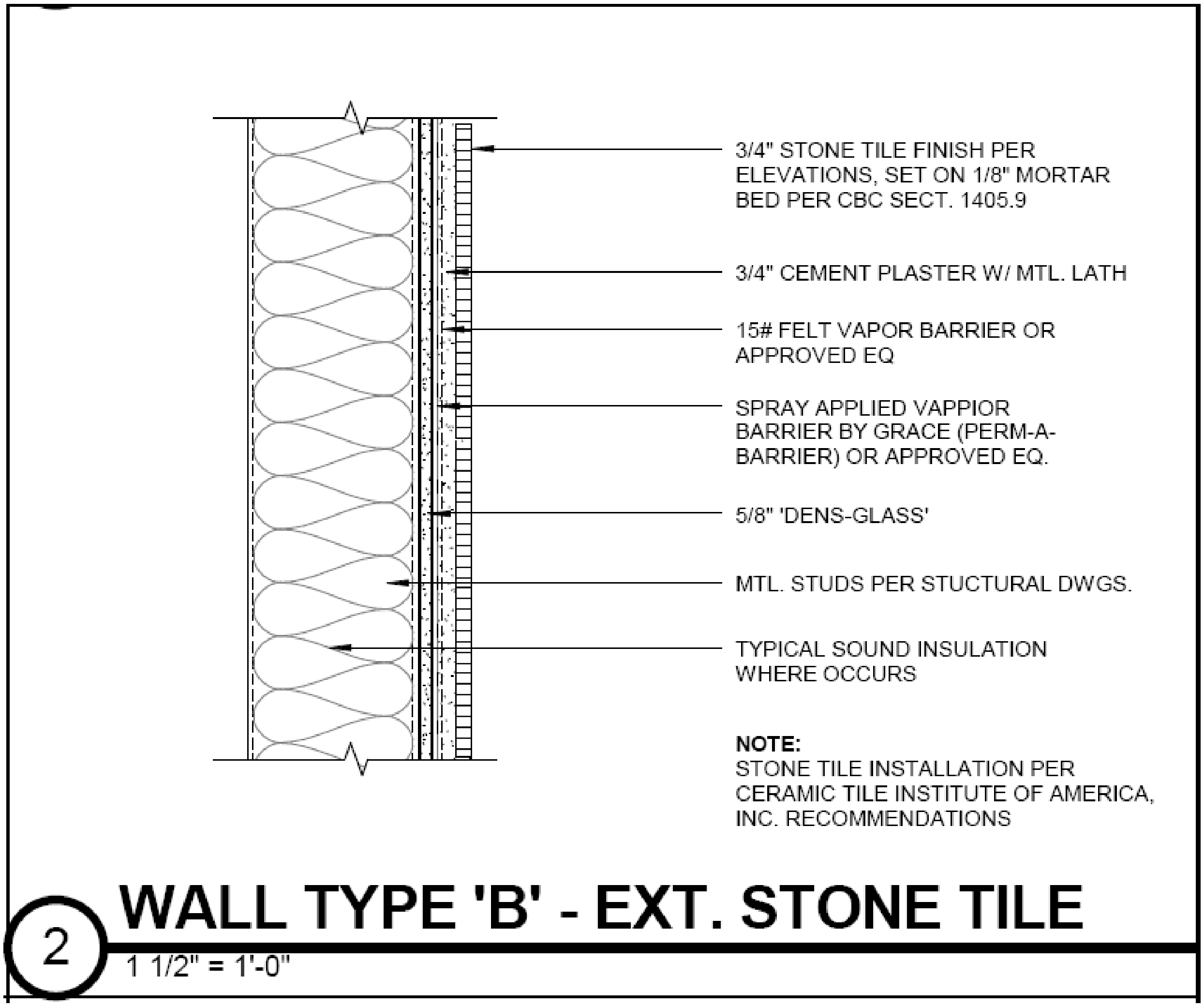


Figure 2.2: Typical Wall Section RFCS

The façade assembly under focus was originally built using a typical stick-built construction where the structure was erected and then the metal stud walls and associated components were installed using scaffolding. The construction of the façade lasted 24 weeks and cost $1,507,959.00 to complete.

2.7 Prefabricated Alternatives

2.7.1 Alternative 1: C-CAPP Prefabricated Panel System from Clark Pacific

The first alternative under investigation is an architectural, lightweight, precast concrete panel system. The system is produced by Clark Pacific and it is called C-CAPP (Clark Composite Architectural Precast Panel). The panel is comprised of a 2" thick concrete skin that is attached to a steel frame for mounting. Clark Pacific describes this system as "a durable, low maintenance, fire resistant, weatherproof, light weight system" (C-CAPP). The following figure is an excerpt from the Clark Pacific C-CAPP Catalog showing a typical panel in section.

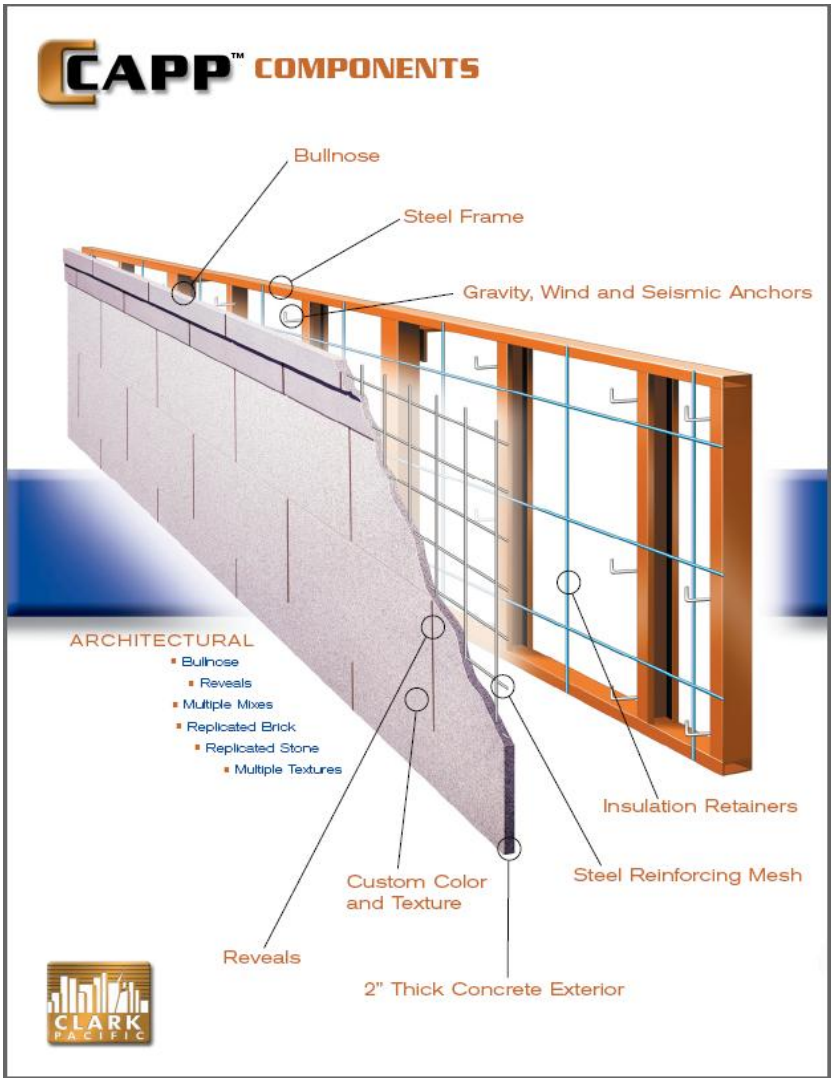


Figure 2.3: Typical C-CAPP Panel Section

The following images were provided by Clark Pacific and give a better idea of what this system looks like on a finished building.

Figure 2.3: Completed Project 1

Figure 2.5: Completed Project 2

Figure 2.6: Completed Project 3

The C-CAPP system was chosen as the appropriate prefabricated alternative based on industry references in the Southern California region. During an interview, a project manager from DPR Construction informed me that Clark Pacific was very knowledgeable with prefabricated exteriors and that he was willing to put me in contact with a representative from Clark Pacific. The representative that helped to guide the panel decision is the Business Development Manager for Clark Pacific. After speaking with the representative of Clark Pacific, the C-CAPP system was recommended based on its durability, lightweight, and the architectural need to mimic the stone tile of the façade.

Under this system, the panels would be prefabricated off-site at Clark Pacific's precast plant and sent to site on 18-wheel tractor trailers. The panel sizes are limited in this sense as they must be transported safely and effectively to site. The most repetitive panel size that would be implemented is a 12' x 22' unit. The 12' is a limitation that is based on transportation constraints while the 22' corresponds to the length of a typical two window unit. The two window unit proved to be the most repetitive and transportable unit for the exterior of RFCS.

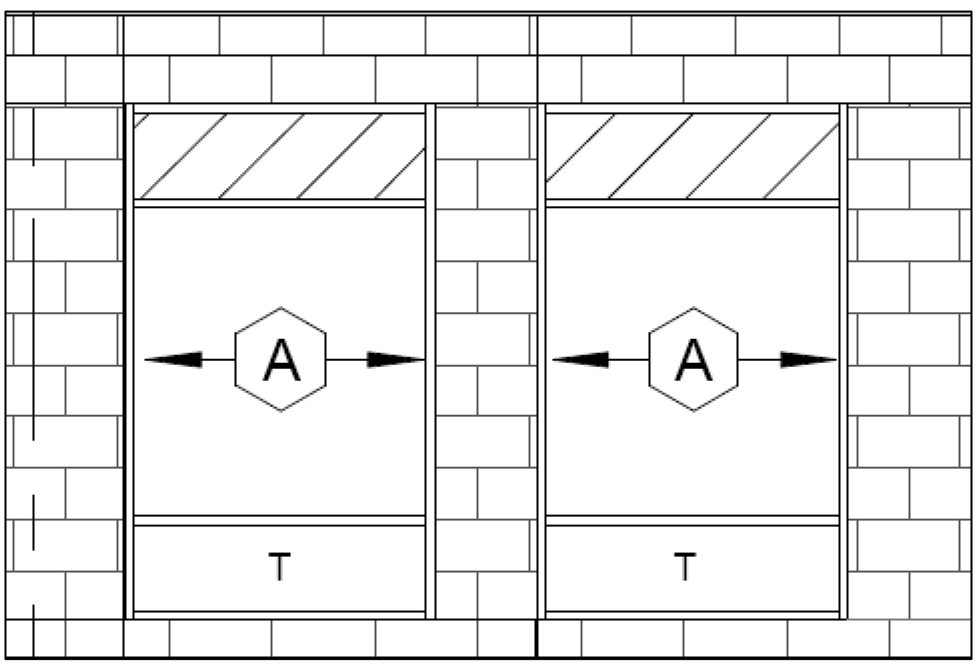


Figure 2.7: Module Example Size for C-CAPP

The representative of Clark Pacific put together a preliminary cost and schedule estimate based on the details of RFCS. This professional estimate will be utilized for comparison purposes. *It is important to note that all rates and durations given by Clark Pacific are for the purposes of study in this thesis document and are not to be used or referenced for professional practice. Table 2.1: Quote on C-CAPP Prefabricated Panel System breaks down the costs and schedule impacts of Clark Pacific's estimate on installing the C-CAPP system at RFCS.

Table 2.1: Quote on C-CAPP Prefabricated Panel System

<table>
<tr><th colspan="4">Quote on C-CAPP Prefabricated Panel System</th></tr>
<tr><th colspan="2">Cost Breakdown ($)</th><th colspan="2">Schedule (Duration)</th></tr>
<tr><td>Base Budget</td><td>$907,500</td><td rowspan="2">Preliminary</td><td rowspan="2">Variable</td></tr>
<tr><td>Staining Panels</td><td>$99,500</td></tr>
<tr><td>Preweld Connections to Steel Structure</td><td>$75,000</td><td>Layout and Preweld</td><td>3 weeks</td></tr>
<tr><td>Caulking</td><td>$33,000</td><td>Hanging Panels</td><td>1 week</td></tr>
<tr><td>--</td><td>-------------</td><td>Final Aligning and Welding</td><td>3 weeks</td></tr>
<tr><td>Total Cost of System</td><td>$1,115,000</td><td>Total Duration on site</td><td>7 weeks</td></tr>
</table>

The C-CAPP system is estimated to cost $1,115,000 and take approximately 7 weeks on-site to install. Both the cost and duration for this system are significantly lower than the façade utilized at RFCS. These values will be considered when choosing the appropriate alternative.

2.7.2 Alternative 2: On-Site Partial Panel Prefabrication

The second alternative to stick-building the façade is a prefabricated panel system that carries the same architectural and structural properties of the current façade. The difference that this alternative would offer compared to the actual construction is that the panel wall section would be partially built at ground level, erected, and then completed once installed. The portion of the wall that is prefabricated at ground level consists of the metal stud framing and sheathing.

Figure 2.8: Partial Panel Prefabrication at Hospital in Temecula Valley, CA

The idea for this alternative came from a consultation with a project manager at DPR who has 20 years of experience panelizing buildings and who recently completed an almost identical, panelized construction at a hospital in Temecula Valley, Ca. The partial prefabrication was successful at this hospital creating a safer work space, a lower final cost, and most impacting, shorter activity duration. To gain a better understanding of this method please reference Appendix D: Case Study- Hospital in Temecula Valley, Ca.

To make the prefabrication process most efficient, the panels must be as modular as possible while still maintaining a manageable size for erection. After repeated attempts at determining the most appropriate way of panelizing the exterior at RFCS, this researcher found that the most repetitive and thus most efficient means of panelization were to breakdown the façade into three different panel modules. These modules, as well as the overall building divisions, can be found in the second portion of this analysis: *Chapter 3: Detailed Sequencing of Prefabricated Wall Panels.*

Once module sizes were determined, this researcher consulted with a senior estimator at DPR Construction who has past experience with estimating this type of panel prefabrication. He informed me that forming this estimate can be done relatively accurately since most of the values from the original stick-built estimate are still applicable. The differences that exist by switching to a panelized method such as this involve the metal stud and sheathing cost, scaffolding cost, crane cost, and schedule duration.

To calculate the estimate and schedule, values were taken from RFCS's GMP and combined with values from previous projects DPR completed which followed this prefabricated panel approach. The following table and figure show a generalized cost report and overall schedule timeline for this process. To find a more detailed estimate please reference Appendix E: Partial Prefabricated Panel Estimate.

Table 2.2: Prefabricated Panel Estimate Summary

Prefabricated Panel Estimate	
Description	**Cost**
Scaffolding	$59,800
Stone	$278,080
Framing and Sheathing	$330,027
Thermal Insulation	$58,743
Fire Safing	$41,500
Preformed Metal Paneling	$181,146
Metal Flashing	$130,031
Sealants	$31,050
Doors, Frames, Hardware	$4,969
Wall Louvers/ Coiling Doors	$44,972
Lath and Plaster, Painting	$341,689
Total	**$1,502,007**

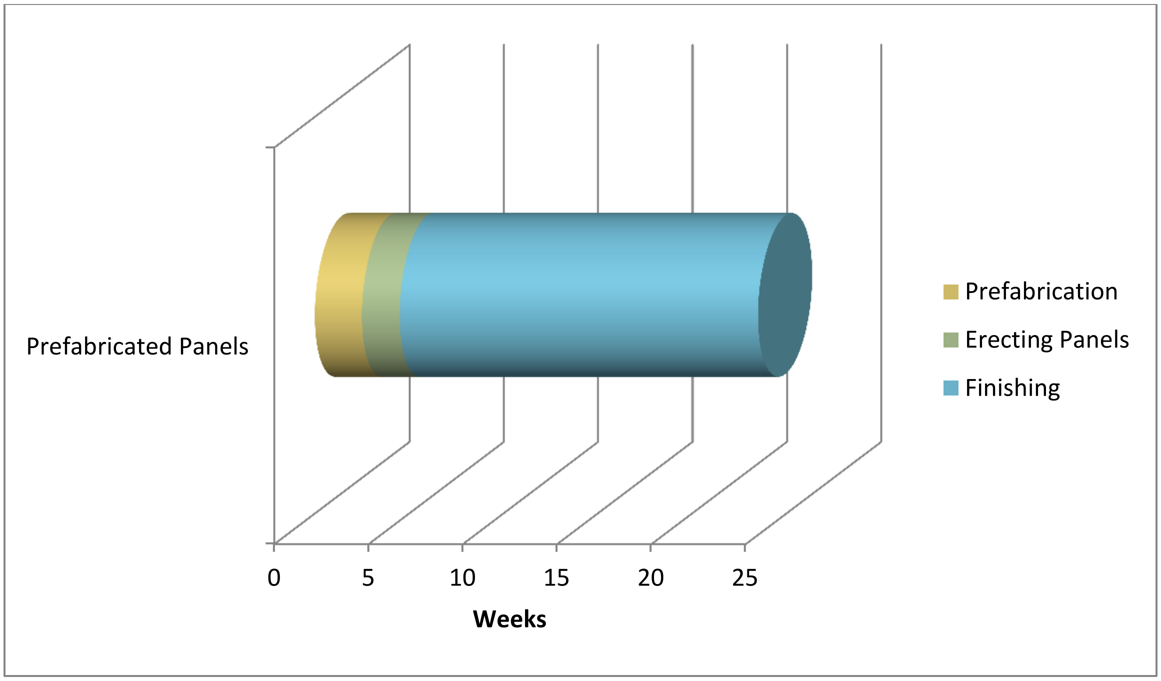


Figure 2.9: Prefabricated Panel Schedule Summary

The cost estimate for partially prefabricating the panels is $1,502,007 compared to the original stick-built amount of $1,507,960 and offers a total completion in 23 weeks. The total duration of 23 weeks does not reflect overall schedule savings as 2 of these weeks can be completed at ground level and do not have any predecessor activities. This means this activity will be critical for 21 weeks as opposed to the 24 weeks the stick-built method was critical for.

The weeks of time savings here essentially exist because in the original construction framing and sheathing is scheduled to take just over five weeks. With the partially prefabricated panel method the framing and sheathing can be erected into place in just 2 weeks.

2.8 Chosen Alternative

Both alternatives that were identified and investigated in this report prove to be successful substitutes to the current approach in relation to cost and schedule. "Alternative 1: C-CAPP Prefabricated Panel System from Clark Pacific" proves to be the cheapest and demonstrates the shortest duration of on-site installation. "Alternative 2: On-site Partial Panel Prefabrication" produces a reduced schedule and a slight cost saving but also produces the same architectural appeal that the architect and owner requested and also allows for an easy integration into the project. Figure 2.10: C-CAPP System vs. Partial Prefabrication compares the two alternatives listing pros and cons of each compared to one another.

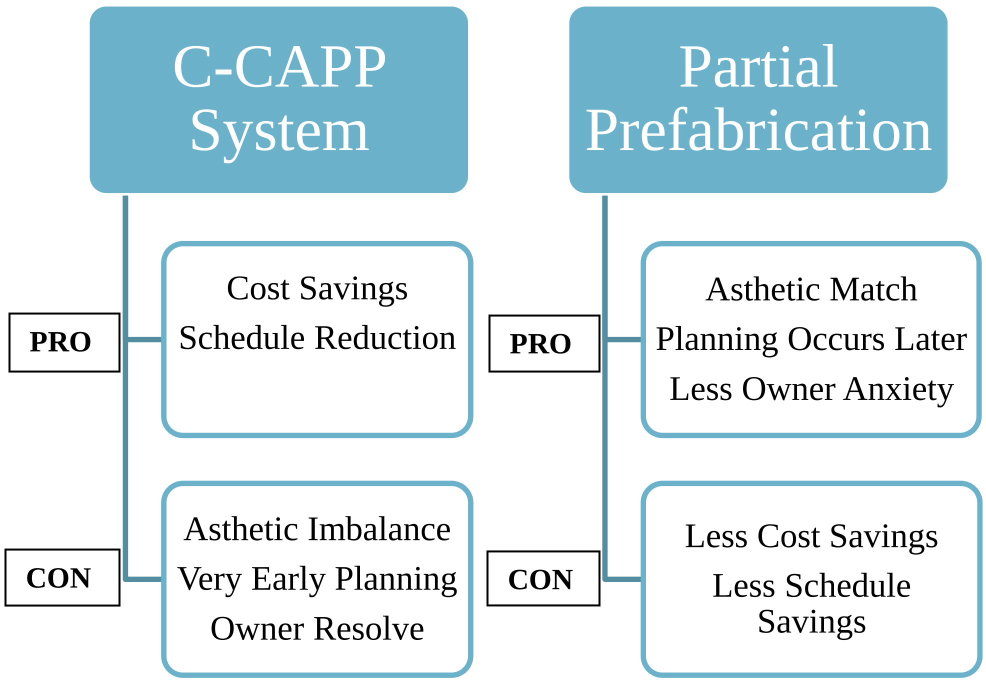


Figure 2.10: C-CAPP System vs. Partial Prefabrication

Based on the researched information, and the comparison between the systems, this researcher chooses "Alternative 2: On-site Partial Panel Prefabrication" as the best option between the two alternatives. Alternative 2 is the best choice based on the requirements set forth by the owner as well as the project delivery type. The owner of RFCS required the team to match the aesthetics of buildings on site. While the C-CAPP system produces an architecturally pleasant appearance, it does not offer the aesthetics that the owner has required on this project. It is this researcher's opinion that the owner would not see the value in changing the aesthetics of this exterior to save around $.5M.

The project delivery type also adds challenges to this situation. Since this building is Design-Bid-Build, the process is very linear and allows for little early collaboration from the GC offering a precast system of this nature. If the idea of completely prefabricated panels like the C-CAPP system is not pursued very early, architects and engineers will be too far in design by the time the idea is brought to their attention.

On the contrary to the C-CAPP system the Partial Panel Prefabrication matches the aesthetics of the stick-built façade, can be implemented after design is complete, and is much less of a commitment for the owner to make. It achieves all of the owner's requests and project delivery constraints while still offering a lower cost and decreased schedule duration compared to the stick-built façade.

2.9 Investigation into Chosen Alternative: On-Site Partial Panel Prefabrication

2.9.1 Cost and Schedule Comparison

The chosen alternative produces a lower cost and shorter schedule duration than the stick-built construction. The main cost savings is accrued from the decrease in general conditions costs based on the 3-week overall project schedule reduction. Another item that saves costs is a decrease in scaffolding needs. The need for a crane to erect the panels adds additional costs. Table 2.3: Partial Prefabrication vs. Stick-Built Estimate shows the portion of the estimate that differs between the two approaches.

Table 2.3: Partial Prefabrication vs. Stick-Built Estimate

Framing and Sheathing						
Engineering	1	LS	$	19,000.00	$	19,000.00
Exterior Framing Mock-up	1	LS	$	15,000.00	$	15,000.00
Crane Rental	1	LS	$	35,000.00	$	35,000.00
Onsite Panel Shop	1	LS	$	5,000.00	$	5,000.00
Build Panels	26943	SF	$	6.95	$	187,253.85
Install Panels	26943	SF	$	1.35	$	36,373.05
Complete screwoff of panels	26943	SF	$	2.15	$	57,927.45
Patch in Densglass sheathing form pick points	26943	SF	$	0.40	$	10,777.20
Sheath backside of parapets	1300	SF	$	2.15	$	2,795.00
Deduct of scaffold time usage (-3 weeks rent)	1	LS	$	(7,000.00)	$	(7,000.00)
Schedule savings general conditions cost (-3 weeks)	3	weeks	$	(10,700.00)	$	(32,100.00)
Subtotal					**$**	**330,027**

The overall amount of time that the prefabricated panel system and the stick-built construction will take place only differs by one week. Though the overall duration is similar, the prefabricated panel system can begin prior to fully erecting the structure. Under this system crews can begin framing and sheathing at ground level in the on-site panel shop as opposed to waiting to begin this until the structure is complete. This will provide an overall project schedule savings of three weeks based on the ability to erect the framed and sheathed panels in two weeks vs. the original stick-built framing and sheathing duration of five weeks. The following table outlines the cost and schedule comparisons between the stick-built façade and the partially prefabricated panel alternative.

Table 2.4: Cost and Schedule Comparison

Partially Prefabricated Panel Alternative vs. Original Stick Built Design		
Description	Partially Prefabricated Panels	Original Stick-Built Design
Overall Cost	**$1,502,007**	**$1,507,960**
Difference +/-	**$5,953 Savings**	
Overall Schedule	**21 Weeks**	**24 Weeks**
Difference +/-	**3 Week Schedule Reduction**	

2.9.2 Constructability

Framing and sheathing the panels at ground level presents unique challenges. In order for this implementation to be successful, planning must be of utmost importance. Items that would be considered in this scenario range from the most detailed component all the way to the grand scheme.

The panel sizes and repetition must be determined and spool sheets must be developed for the crew to use to accurately produce the panels. This is especially critical as all of the panels must eventually fit together once erected. In relation to the crane, a very precise erection plan must be designed to ensure a safe construction site as well as to minimize the time the crane will be on site. Designating the appropriate crews to the construction, erection, and tie-ins of the panels is also essential. Finally, the materials but be quantified allowing the team to have the appropriate supplies on-site and on-time.

In order to manage these constructability concerns that are present with this alternative technique, the second portion of this analysis will delve deeper into the specifics of scheduling and planning for a partially prefabricated exterior wall system at RFCS. This will be completed by performing a technical demonstration of the planning process necessary for RFCS.

2.9.3 Conclusion

It is this researcher's opinion that the project team at RFCS would benefit from implementing the partially prefabricated panels as opposed to the original stick-built construction. The prefabricated panel plan is estimated to save $5,953 and more importantly, reduce the overall schedule duration by three weeks. This schedule reduction allows the project to be in use by the owner sooner which will in turn generate profits. This schedule reduction also can allow for a buffer period in the schedule as protection in case a different activity falls behind.

Chapter 3: Detailed Sequencing of Prefabricated Wall Panels

3.1 Introduction

Based on the constructability concerns addressed earlier in this section, the following items must be considered and managed in order to have a successful application of the prefabricated wall panel scheme:

- Choose Location of Prefabrication Tent and Panel Staging Area
- Determine Panel Construction Plan and Schedule
- Generate Report with Necessary Materials and Quantities
- Determine Erection Plan and Schedule

The purpose of this section is to outline the constructability concerns of implementing this alternative.

3.2 Choosing a Location to Prefabricate the Panels

The first step in planning the partial prefabrication of the wall panels is choosing a location on site which is most suitable for construction. Based on the available space, the parking lot adjacent to the contractor trailer was deemed most suitable for the prefabrication tent and staging area for the completed panels. Figure 3.1 demonstrates this building zone highlighting the area in the color yellow. 3,600 SF will be dedicated to the prefabrication tent and 3,600 SF will be dedicated to the panel staging area. The parking lot is large enough that if more space should be needed, expansion is quickly feasible.

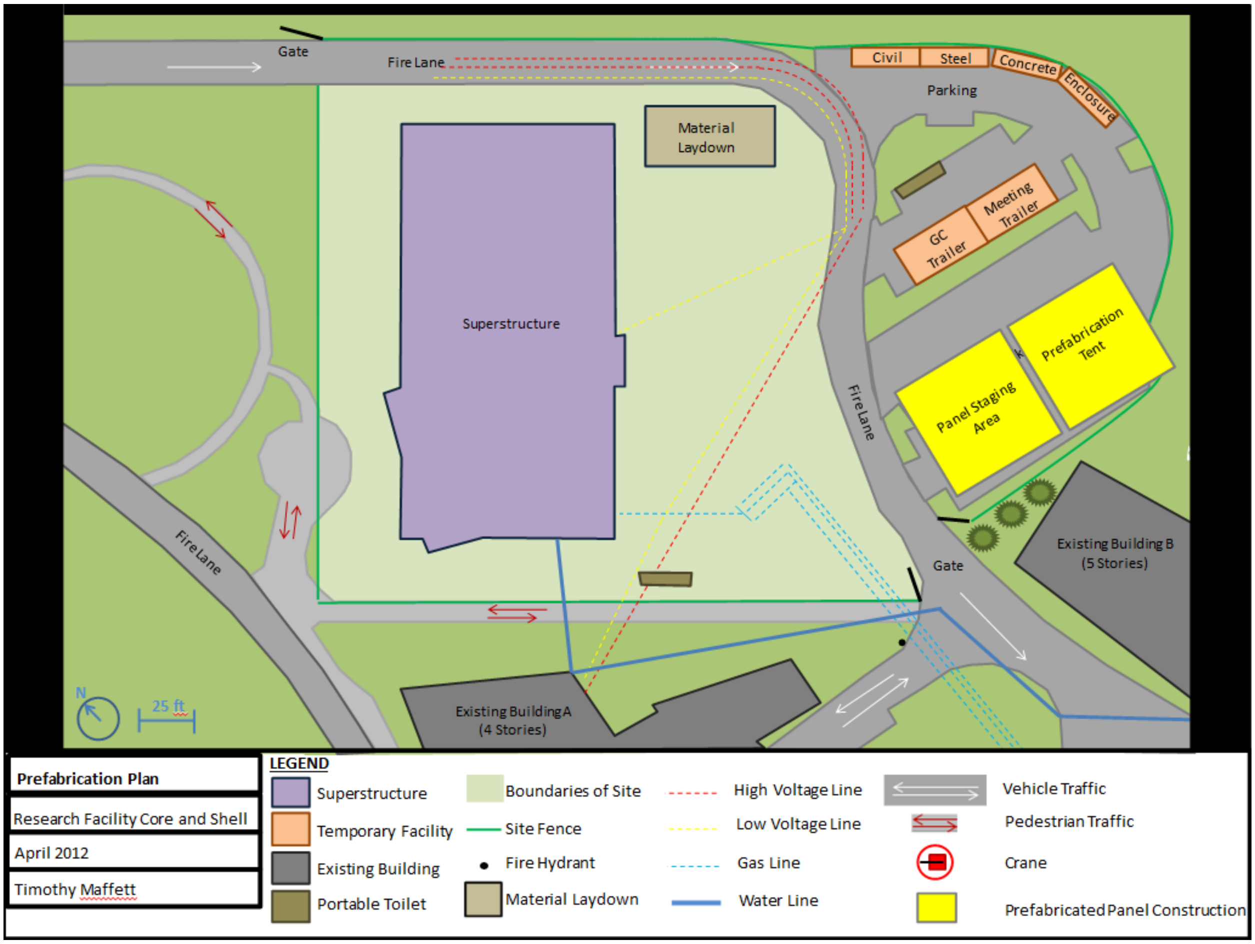


Figure 3.1: Prefabrication Tent and Staging Area

3.3 Module Breakdown

The most efficient and feasible way this researcher found to panelize the exterior of RFCS was through the application of three different module types. These three module sizes are demonstrated in the following figures: Figure 3.2, Figure 3.3, and Figure 3.4. These module sizes were chosen because they resulted in the fewest amount of modules while maintaining manageable size for erection thus causing the most ease and repeatability for which workers at ground level will build the panels. Table 3.1 gives the overall quantity of panels for production.

Table 3.1: Module Take-Off

Panel Module Take-Off	
Description	**Amount**
Module Type #1	28
Module Type #2	21
Module Type #3	3
Total	**52 Panels**

Module Type #1

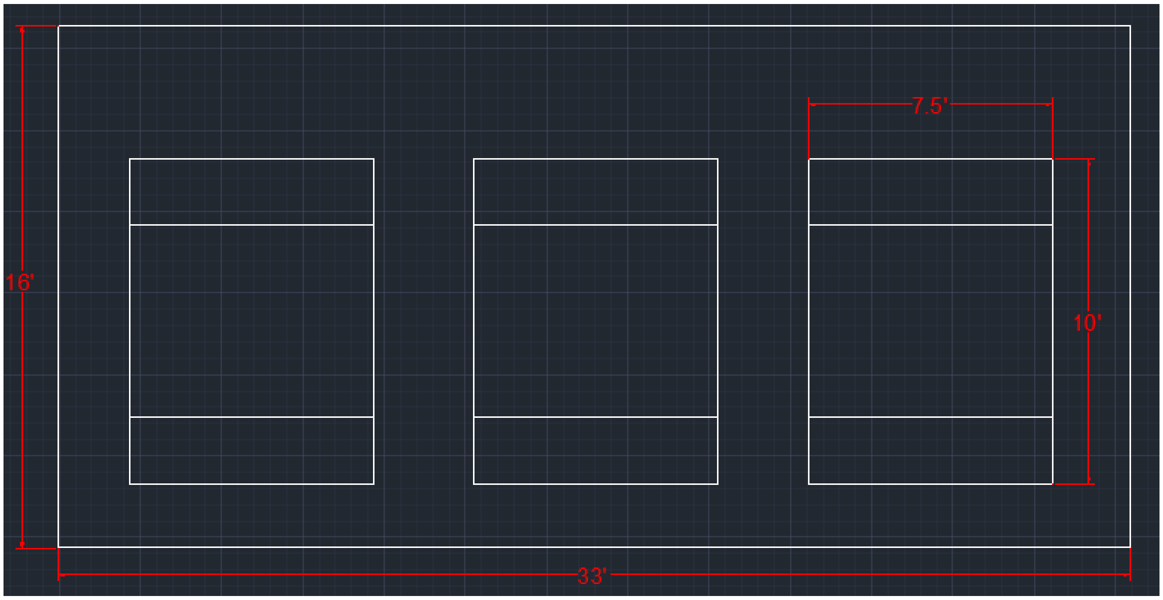


Figure 3.2: Module Type #1

Module Type #2

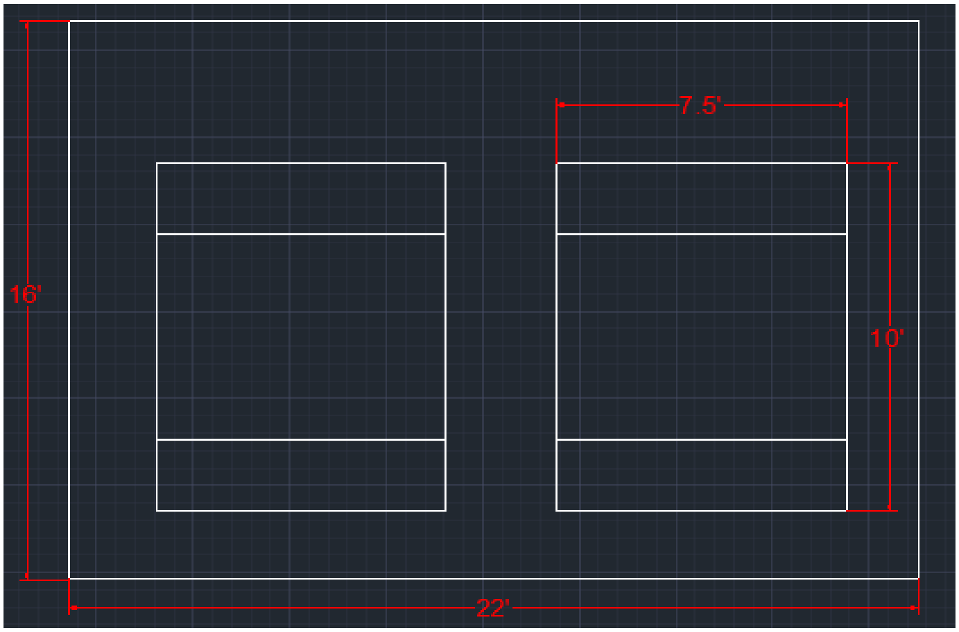


Figure 3.3: Module Type #2

Module Type #3

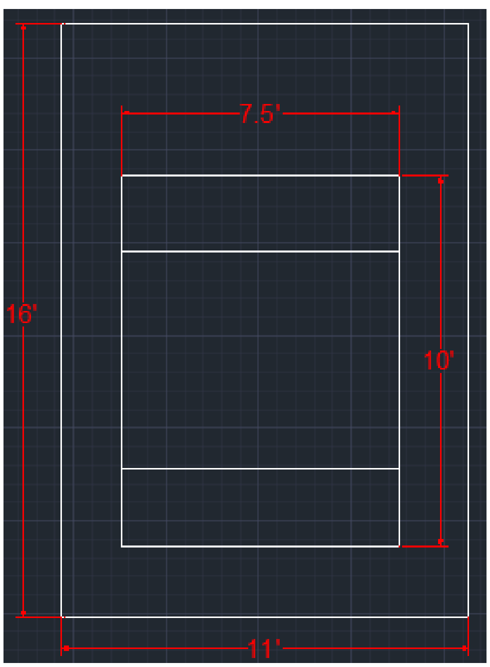


Figure 3.4: Module Type #3

3.4 Detailed Panel Construction Plan with Virtual Mock-up

Dimensioning and sizing the modules, as well as giving an overall count of how many of each type must be built, gives the team a broad overview of the panel construction. While this is an essential portion of the prefabrication process, a more detailed breakdown is necessary to give an exact estimate as to how long it will take to build each panel and to quantify the materials that will need to be ordered. The following sequence of figures demonstrates the construction of Module Type #1 giving a visualization of the process to help understanding in the field as well as quantification for estimate purposes (Module Type #1 was chosen because it is the largest and provides comparison values necessary for the remaining two panel types).

3.4.1 Constructing Module Type #1

Step 1: Build Outer Framing

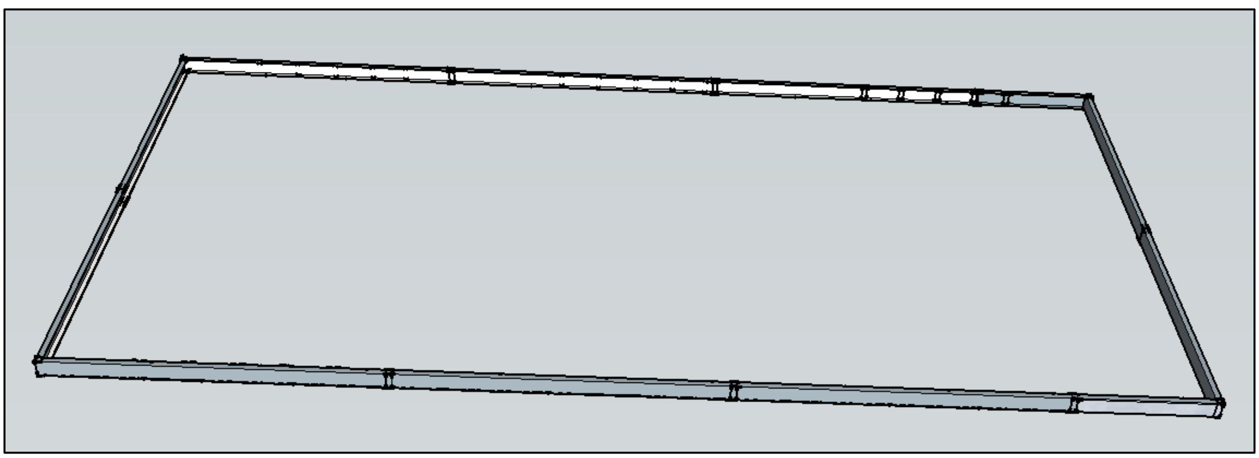


Figure 3.5: Step 1- Build Outer Framing

Step 2: Frame Full Length Studs

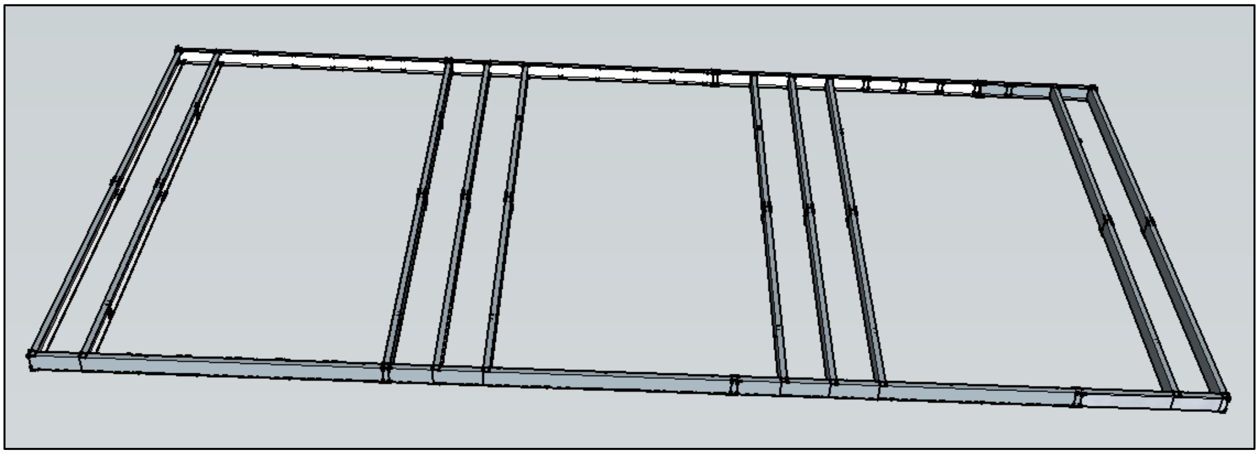


Figure 3.6: Step 2- Frame Full Length Studs

Step 3: Frame Window Opening 1

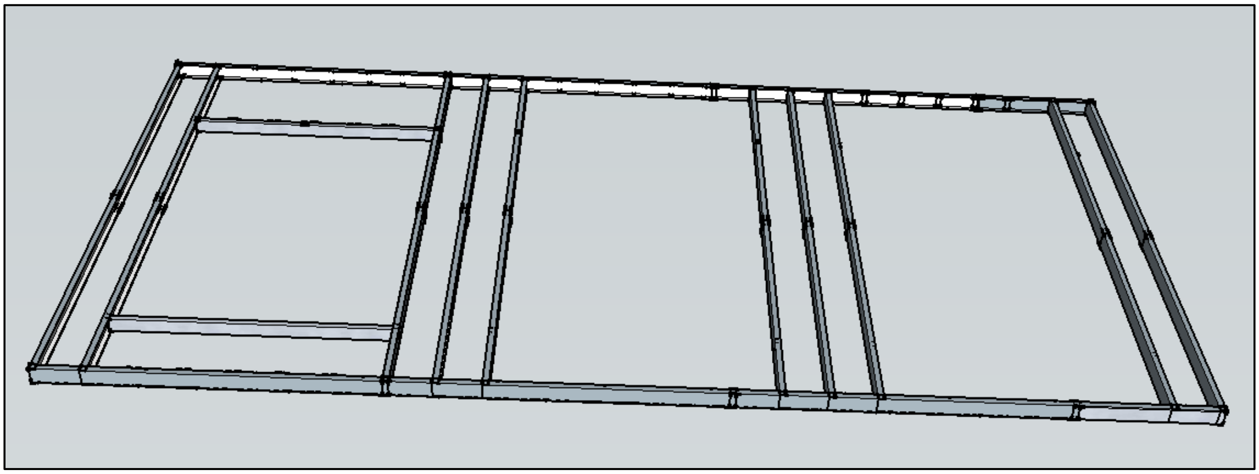


Figure 3.7: Step 3- Frame Window Opening 1

Step 4: Frame Window Opening 2

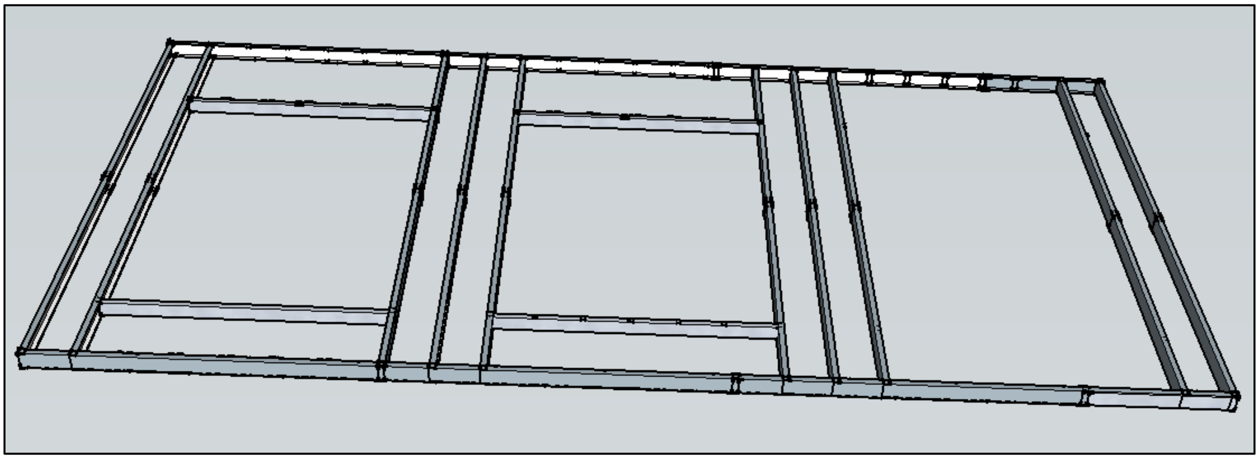


Figure 3.8: Step 4-Frame Window Opening 2

Step 5: Frame Window Opening 3

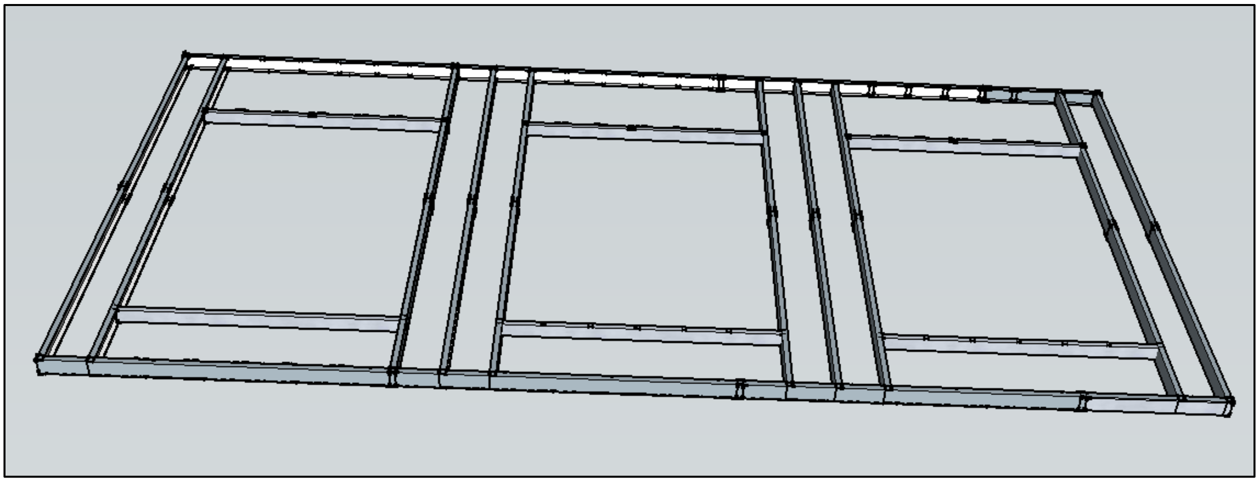


Figure 3.9: Step 5 Frame Window Opening 3

Step 6: Install Small Studs Supporting Window Framing

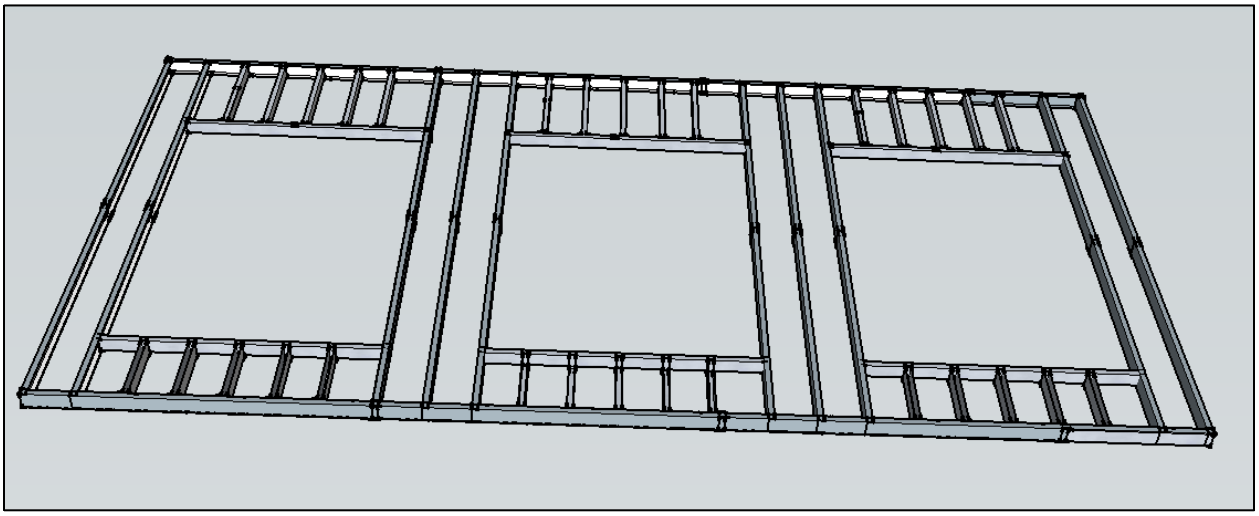


Figure 3.10: Step 6- Install Small Studs

Step 7: Screw-in Sheathing to Panel

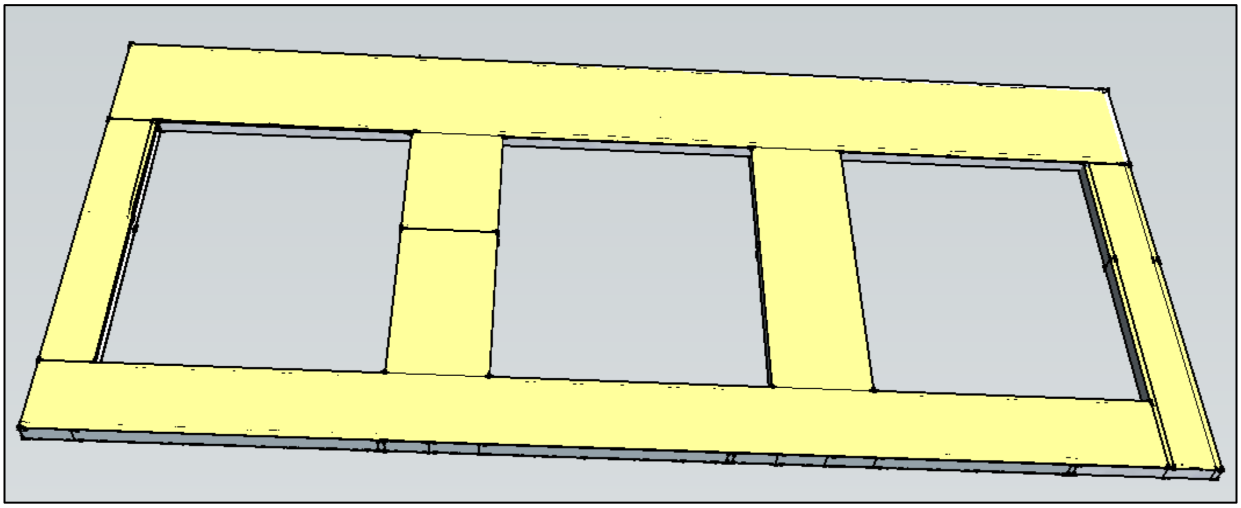


Figure3.11: Step 7-Sheath Panel

3.4.2 Quantifying and Summarizing the Detailed Panel Construction Sequence

Table 3.2 summarizes the breakdown of the duration and material estimate for the partial prefabrication of Module Type #1. A comprehensive breakdown of the entire panel prefabrication schedule and material estimate can be found in Appendix F: Detailed Partial Panel Prefabrication Schedule and Estimate showing the overall grand total values as well as the individual panel breakdowns for each module type.

Table 3.2: Module Type #1 Estimate Summary

Detailed Panel Prefabrication Schedule and Material Estimate				
Prefabricating 33' x 10' Panels on Ground				
Task	**Quantity (LF of Metal Stud)**	**Quantity (LF of Track)**	**Quantity (SF of Sheathing)**	**Duration (Minutes)**
Build Outer Framing	32	66	-	30
Install Full Length Studs	128	-	-	30
Frame Window Opening 1	35	-	-	20
Frame Window Opening 2	35	-	-	20
Frame Window Opening 3	35	-	-	20
Install Small Studs Supporting Window Framing	80	-	-	40
Sheath Panel	-	-	303	50
Move to Staging Area	-	-	-	20
Subtotal	345	66	303	230
(28) Panels- Total:	**9660**	**1848**	**8484**	**6440**

The overall duration for ground level panel construction totals 10,985 minutes, or 183 hours. The overall estimate of this alternative assumed 3 crew members allocated to building the panels for labor costs which results in about 9 days of ground level construction.

The sequence summary, schedule estimate, and material tracking estimate will allow the team to prepare and plan this process as best as possible. Preconstruction can offer an educated cost and schedule estimate to the owner and they can account for the appropriate materials to be ordered and delivered to site based on this analysis.

Not only will this analysis be valuable to preconstruction and supply logistics, but a model of this nature will serve to educate crew members responsible for the panel construction as well as the management on-site that will oversee the entire process. By analyzing the panel construction process to this detail, the team will be able to figure out if they are on schedule down to almost the exact minute. Assembly crews will be able to practice the process with the model first, pre-educating themselves to the challenges they will see in the field. Management will be able to create tutorials and analyze possible ways to expedite the process.

Once ground level panel construction is complete, crews must have a plan and be ready to erect the panels and complete tie-in and patching. The next section outlines the erection plan for the prefabricated exterior panels at RFCS.

3.5 Prefabricated Exterior Panel Erection Plan

Crane involvement is a top safety concern for most general contractors. It also has the ability to accrue serious costs if the crane is kept on-site for extended periods of time. Because of this, as well as the uniqueness of this prefabrication, it is necessary to complete an erection plan for the prefabricated panels at RFCS. This erection plan will allow management and crew members to visualize the erection process as well as calculate the schedule and timing the crane will need to be on-site.

The following figures demonstrate the sequential order in which the panels will be placed. The numbers indicate the order in which the panels will be placed and the letters represent the different crane relocations. The order was chosen to minimize the amount of motion the crane arm must swing which minimizes the time each pick takes. Another factor was the effort to minimize the amount of times the crane would have to mobilize to a new location and reposition.

According to this plan, panel erection will begin at the westward side of the south façade moving to the east. Once phase A of the south façade is complete, the crane will move to the position for phase B on the eastward side of the south façade. This process continues from the south façade, to the east façade, to the north façade, to the west façade, essentially circling the building completing phases A-E.

Overall View of Sequence

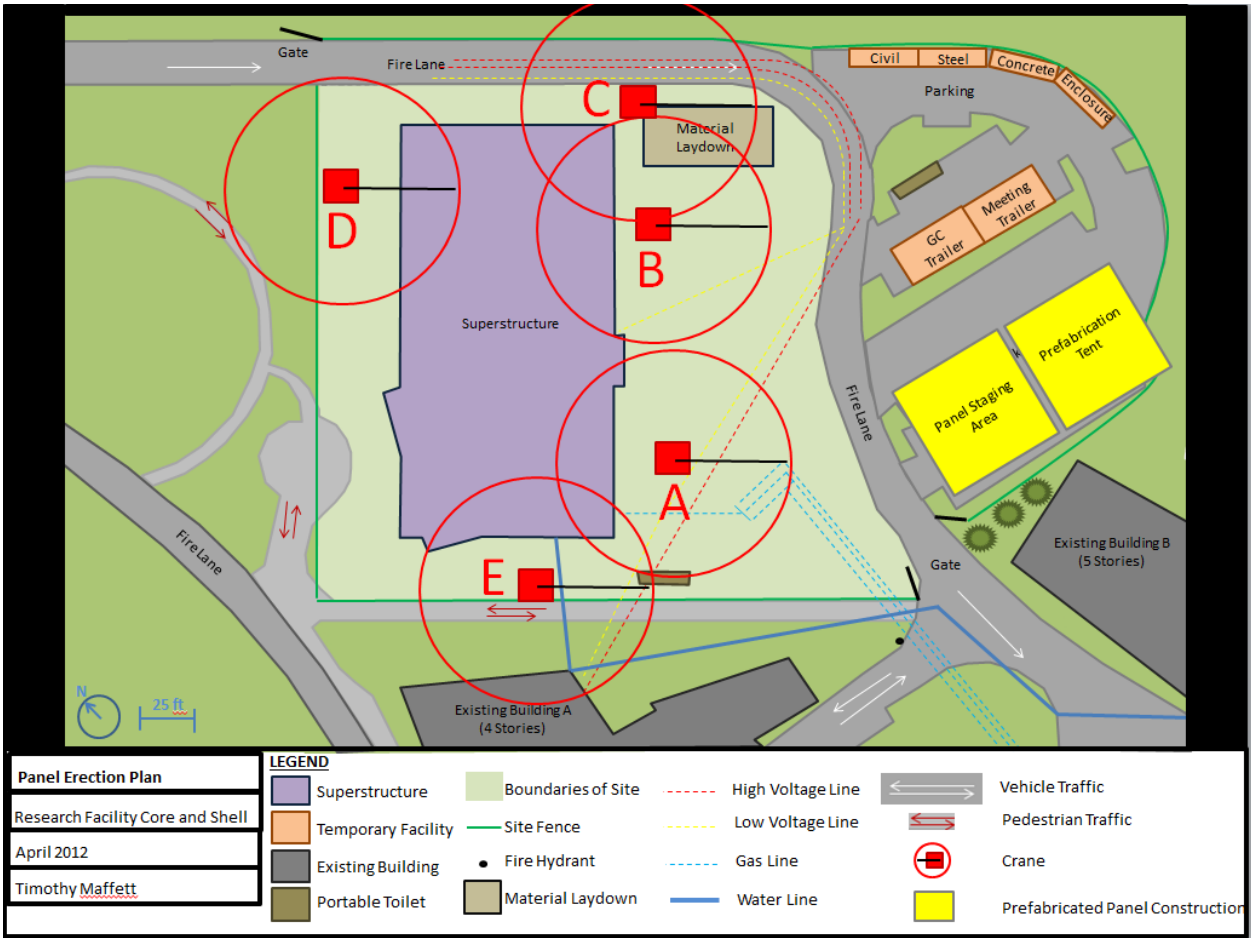


Figure 3.12: Erection Sequence

Step 1: South Facade Phase A and B

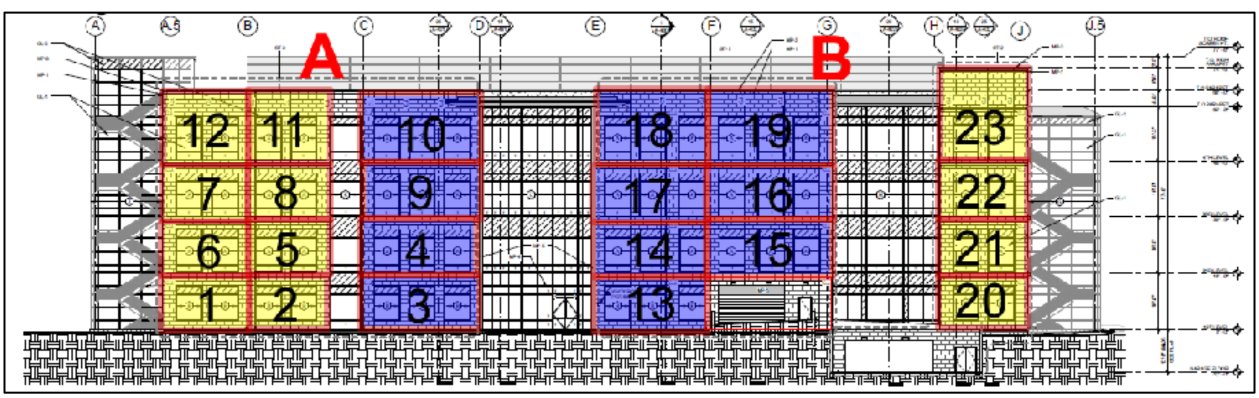


Figure 3.13: Phase A and B

Step 2: East Facade Phase C

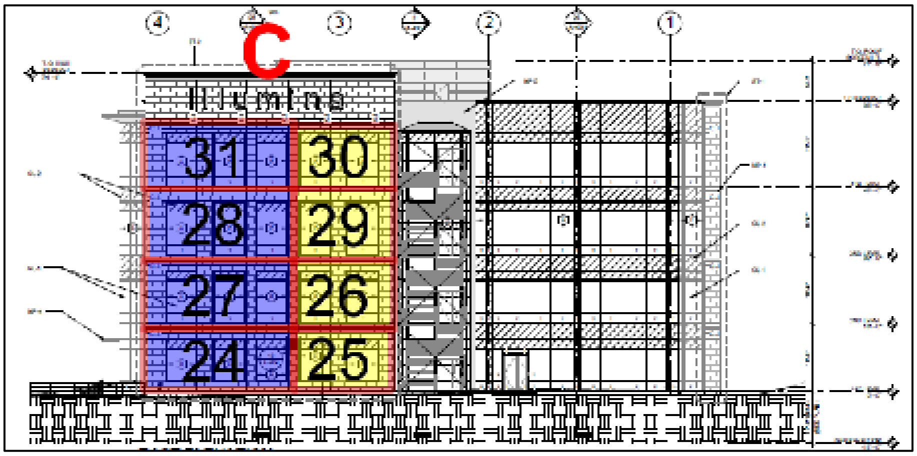


Figure 3.14: Phase C

Step 3: North Facade Phase D

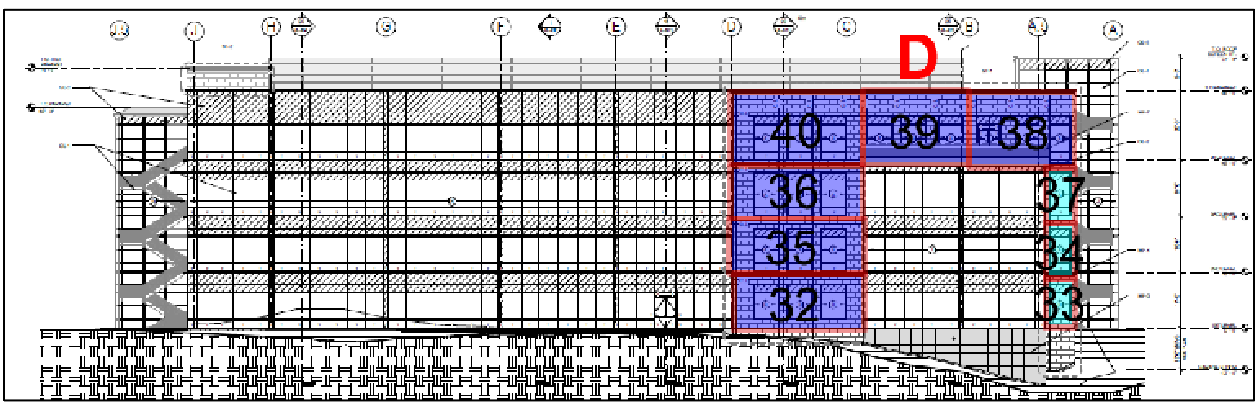


Figure 3.15: Phase D

Step 4: West Façade Phase E

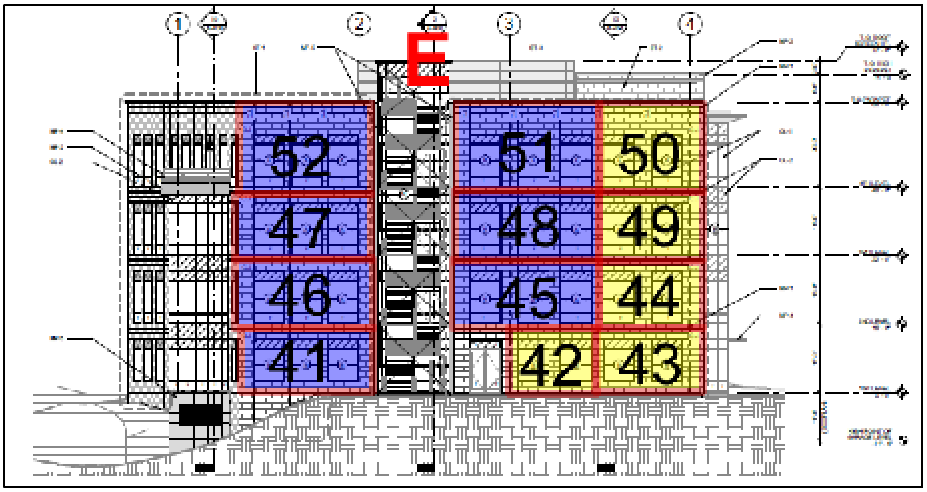


Figure 3.16: Phase E

Allocating 30 minutes to each panel pick and erection, the erection process will take approximately 10 days, or two weeks. There is a significant opportunity for the team to decrease the amount of time necessary to erect each panel based on the repetitive nature of the activity and the learning curve that is associated with it. This could result in a decreased activity duration which would decrease the overall schedule duration of the exterior facade.

3.6 Conclusion

The sequencing provided in this section allows the team at RFCS to properly plan for both the construction and erection process that will be necessary to achieve a successful implementation of the partial prefabricated exterior panels. Through a detailed on-ground panel construction sequence, the preconstruction team is able to precisely schedule and estimate materials for the activity. They can ensure accurate values providing a smooth transition to the construction phase. The construction team can then use these plans to train the crew responsible for construction as well as properly oversee the activity.

Accompanying the benefits of the sequence created for the ground construction of the panels is the panel erection plan. This plan will help to safeguard against the injuries that could result during the erection process as well as the possibility of keeping the crane on-site for an unwarranted, extended period of time.

Chapter 4: Breadth #1- Sizing the Rigging Beam Necessary to Lift and Erect Panels

Partially prefabricating the panels at RFCS requires the need for a picking attachment on the crane to safely swing the panels into place while supporting the load of the panel. As a reference, the dimensions and type of rigging setup that was utilized in the Temecula Valley Hospital Prefabrication Case Study will be used as a basis for the design of the rigging setup for RFCS. The following image gives a general idea of this setup.

Figure 4.1: Rigging Setup at Temecula Valley Hospital

The purpose of this breadth will be to size the beam necessary to hang and support the panel from during placement. The following figure shows the setup and dimensions of the rigging that is assumed for RFCS. The red beam is the steel beam under consideration. This breadth will analyze the shear and moment forces on the steel rigging beam and then reference the AISC Steel Manual to indicate the size of steel beam required for this rigging.

This breadth will consider the largest of the panel sizes which creates the most load out of the three panel modules. It is assumed that if the beam is designed to the maximum load of panel sizes that it will be sufficient to lift the smaller panels as well.

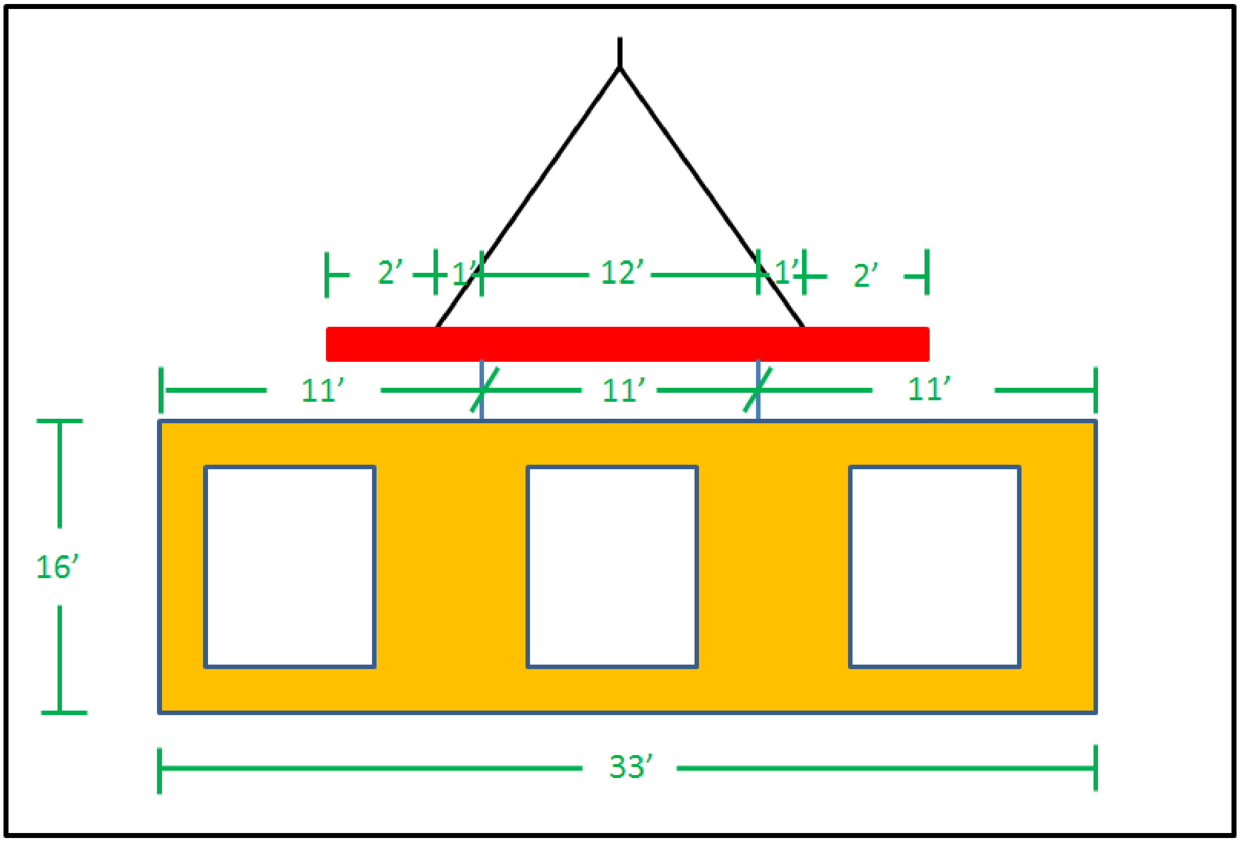


Figure 4.2: Diagram of Rigging Setup

The following table describes the results of this breadth; to view the detailed calculations and diagrams please reference Appendix G: Structural Breadth Calculations.

Table 4.1: Structural Calculations Summary

Results of Structural Calculations on Steel Beam in Rigging	
Description	**Value**
Dead Weight of Panel	1580 lb.
Maximum Shear	.790 kip
Maximum Moment	.790 kip-ft.
Rigging Beam Necessary for RFCS	W 8x10

4.1 Conclusion

The self-weight of the partially prefabricated panel resulted in a much smaller value than expected. The 33’ by 16’ panel will weigh 1,580 lbs. producing a maximum shear force on the rigging beam of 0.790 kip and a maximum moment of 0.790 kip-ft. After referencing the AISC steel manual, the smallest beam in the manual, a W 8x10, is designed to handle a maximum shear force of 26.8 kip and a maximum moment of 21.9 kip-ft. The W 8x10 is more than sufficient to handle the loads created by the panels during erection. This researcher recommends a W 8x10 beam to use as the rigging beam for erection.

Chapter 5: Solar Panel Installation at Roof Level

5.1 Problem Identification

Recent calculations on LEED credits have left the team at RFCS quite happy with their performance but have also given rise to a question of how they can do better. The owner's original request was for RFCS to receive LEED Silver Certification. As time progressed, the team found out that the building met LEED Silver by a large margin and was actually only a few credits short of achieving LEED Gold. They met with the owner to inform them of the results and were surprised when the owner told them to find a way to get the building to LEED Gold standards.

This left the team with an important question; how do we gain the necessary credits for LEED Gold without simply point chasing? They did not want to add bike racks or items of this nature which would gain credits but would ignore the actual desires of the owner to improve sustainability. Currently the project team is looking into the appropriate solution to this problem and has voiced strong opinions that rooftop solar panels could be the best choice.

Rooftop solar panels may be an appropriate choice for RFCS considering the ample amount of direct sunlight that the Southern California area receives. A problem that could hinder the scale in which solar panels could be implemented is the layout of the roof plan. Centrally located is the large mechanical equipment, as well as a 13 ½' rooftop wall screen that surrounds it on all sides. This could prove to be significantly detrimental to the available sunlight on the surface of the roof. Other items that will increase shading include the 4' parapet walls and in some eastern plan locations 10' parapet walls. These factors will take a major role in the decision whether to implement solar panels to attain the necessary LEED credits or find other means of attaining the necessary LEED credits to achieve LEED Gold Certification.

5.2 Research Goals

1. To determine the shading situation at RFCS rooftop.
2. To analyze photovoltaic panel modules and determine most appropriate for RFCS.
3. To calculate and size the modules, equipment, racking, and electrics runs necessary to install such system.

4. To determine cost, schedule, and constructability impacts of installing solar panels.

5.3 Application Methodology

(1) Interview Project Manager on bi-weekly basis during spring semester to report on project specific gains and losses due to owner's desire for solar panels.
(2) Conduct project specific research regarding the contract ties, relationships, benefactors of the installation, constraints, and supports for the solar panels.
(3) Perform shading analysis
(4) Determine location of panels
(5) Choose system- module, inverter, string sizes, combiner boxes, roof attachments
(6) Calculate lifecycle costs and energy use.
(7) Document construction issues such as schedule impacts, purchasing requirements, and sequencing.
(8) Complete electrical analysis to determine installation requirements.
(9) Conclude whether system is appropriate using constraints of project

5.4 Preliminary Analysis

To gain a better understanding of the impacts that rooftop solar panels would have at RFCS, I contacted members of the team on site, specifically the Project Manager. The Project Manager informed me of the requests of the owner and said that the team is currently looking into using solar panels as their solution too. They are in the planning and design phase but have already been given the initial "ok" by the design teams as far as feasibility. The Project Manager will be a valuable resource to interview regarding the impacts the solar panels will have on construction, relationships between the trades, purchasing, and the business model that should be used.

Other resources that will complement the interviews with the Project Manager at RFCS, and the project specific relationships, include research into solar panel cost and lifecycle modeling as well as reaching out to companies that specialize in the design and installation of photovoltaic panels.

5.5 Background Information

The rooftop of RFCS is rectangular in shape measuring 125' by 242'. This gives a GSF of 30,250. The mechanical equipment area on the roof occupies a considerable portion of the space limiting the area in which solar panels can be placed. Figure 5.1 shows the centrally planned mechanical space (50' x 198') which is surrounded by 13 1/2' metal screen walls.

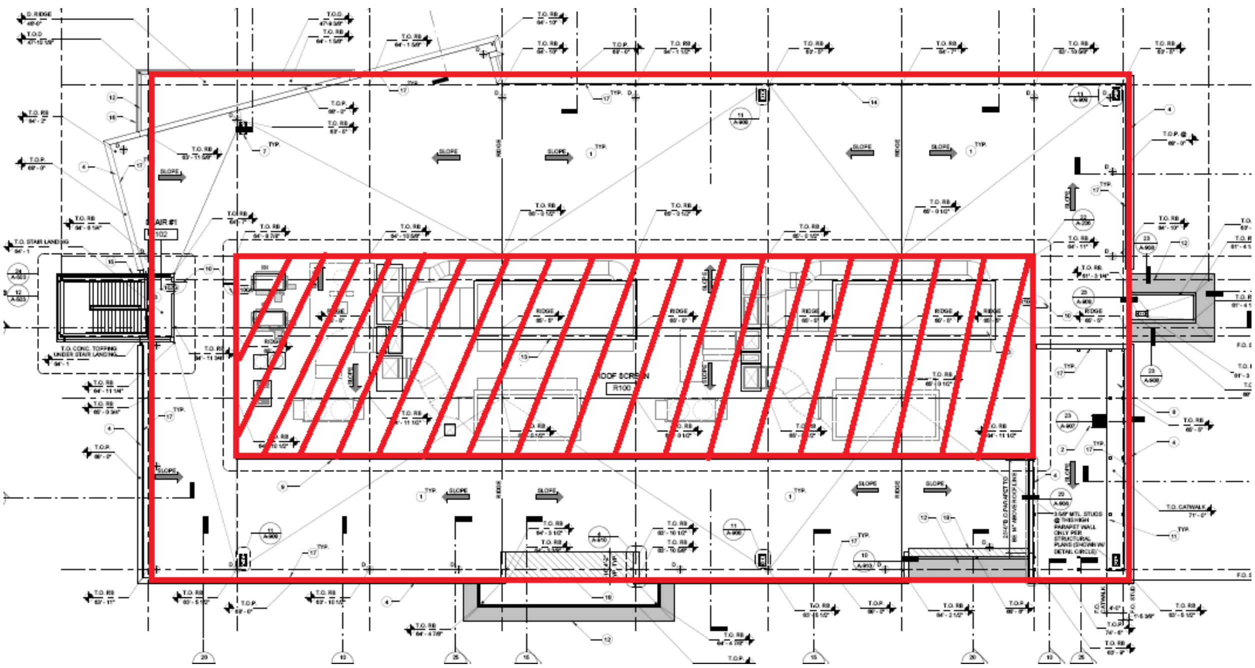


Figure 5.1: Available Space on Rooftop of RFCS

Once the unusable mechanical space is eliminated from the gross square footage, the total space for solar panel installation is 20,350 SF.

Two main types of photovoltaic systems exist: Off-Grid Systems and Grid Direct Systems. With an Off-Grid System the connection is not tied into the utility power connection and directly powers components of the building most often as DC power. In a Grid Direct System the connection is tied into the utility power grid and requires the power to be changed from DC to AC prior to tie-in to the utilities. The system that will be pursued in this analysis is a Grid Direct System.

The Grid Direct System exists of a few main components: the photovoltaic panels to collect the energy, the inverter to transform the power, and the final connections to the circuit breaker and utility connection. Referencing RFCS, the design will focus on placing the panels on the rooftop, the inverter in the rooftop main mechanical zone, and the circuit breaker and utility connection in the main electrical room in the basement. The inverter will be placed at the east side of the rooftop mechanical zone to minimize the run for DC power. This run is minimized compared to the AC run because the energy loss is significantly greater with DC power over long runs than that of AC power. The circuit breakers and utility tie in will be placed in the basement main electrical room because that is where all power currently enters the building.

Chapter 6: Breadth #2- Solar Panel Design and Electrical Analysis

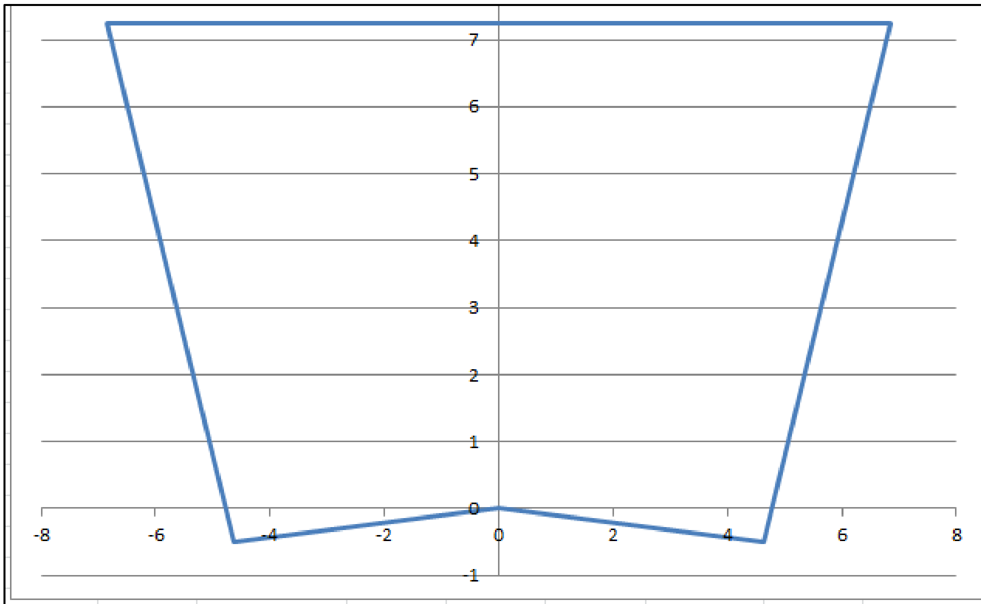
6.1 Design

This chapter will outline the design decisions made for the photovoltaic system at RFCS. The section begins by calculating the shading created by elements on the roof of RFCS; followed by selecting the panel modules to be used, the racking system to be implemented, the array placement of the panels, the appropriate inverter, and sizing the conductors necessary to connect the system.

6.2 Shading Calculations

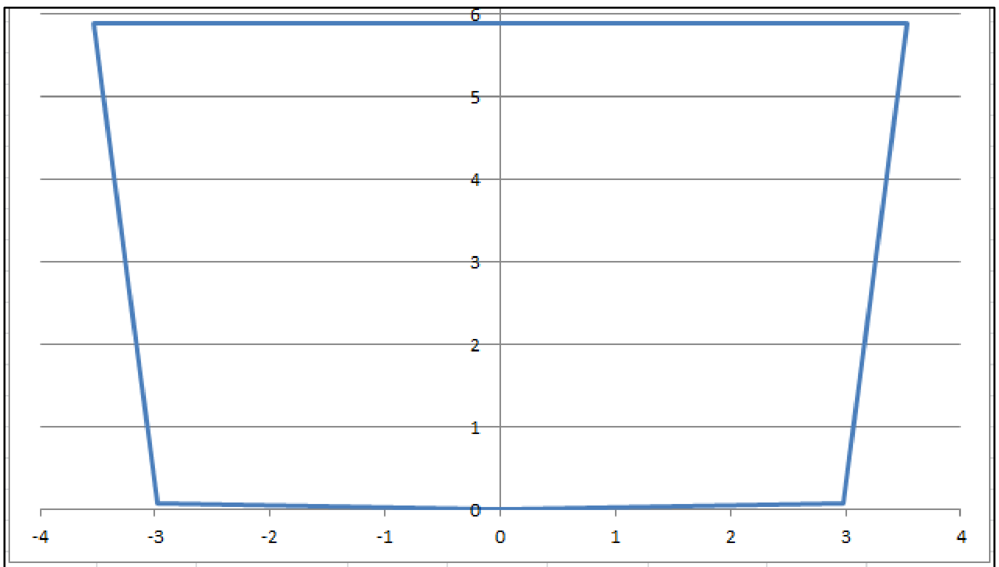
As stated in the *Background Information* section, the space available for solar panel installation totals 20,350 SF. This number represents available space but does not accurately reflect the usable space for solar panels as it does not consider the effects of the shading from other objects on the roof, namely the 4' parapet wall and the 13 ½' mechanical screen wall.

After speaking with a member of the Penn State AE department and Center for Sustainability, I received a model they developed for shading calculations. The following figures, Figure 6.1 and Figure 6.2, model the average shading created by an object of height "H" for the Southern California Region considering two solar gain "windows of time"; an 8hr summer/ 6hr winter window and a 6hr summer/ 4 hr winter window.



Sun Angles: 8hr Summer/ 6hr Winter		
Final result		
Lower line:	H x 1.5	-5 deg from east-west
East-most line:	2.25 x H	75 deg from east-west

Figure 6.1: Shading Window 8hr Summer/6hr Winter



Sun Angles: 6hr Summer/ 4hr Winter		
Final result		
Lower line:	H / 1	0 deg from east-west
East-most line:	1.75 x H	85 deg from east-west

Figure 6.2: Shading Window 6hr Summer/4hr Winter

The model represents the shading that occurs from a source with height "H" that has an orientation of South coinciding with the bottom of the page. To use these models one takes the height of the obstruction to find the length of the shadow and combines that information with the angles that have been determined when creating the diagrams above. These diagrams then show the average area the source casts a shadow on throughout the year.

By applying this model to RFCS, the usable area for solar panels was determined to better inform the design as to which panel module and array is best suited to this scenario. The following shading diagrams show the shading created on the roof of RFCS with the assumed panel height of 0' during the two "windows of time" described above. The red lines indicate the objects on the roof, the green represent the modeled shade diagram of the obstructions, and the yellow indicated the area of the roof that is affected by shade and thus unusable.

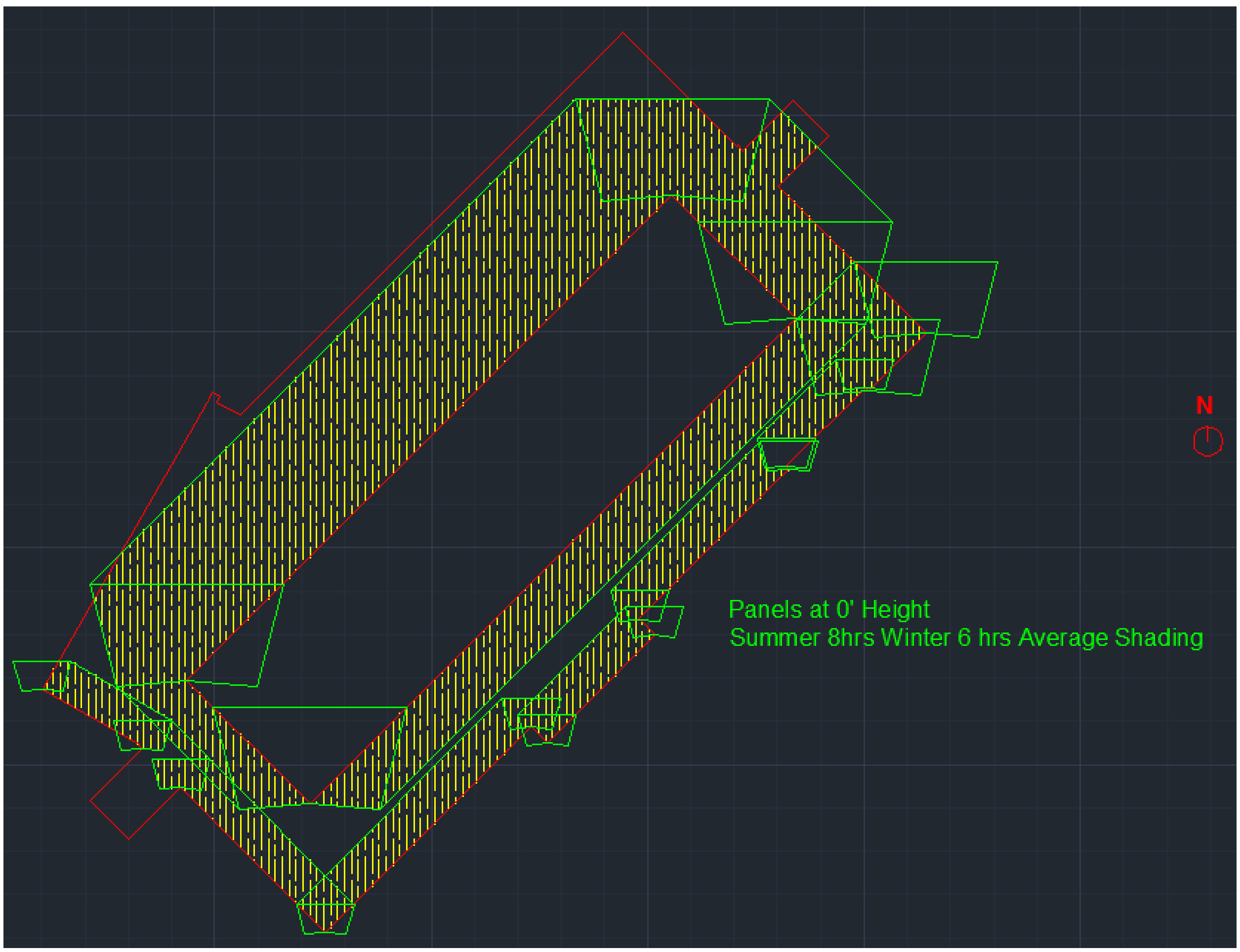


Figure 6.3: Shading at RFCS 8hr Summer/6hr Winter Window

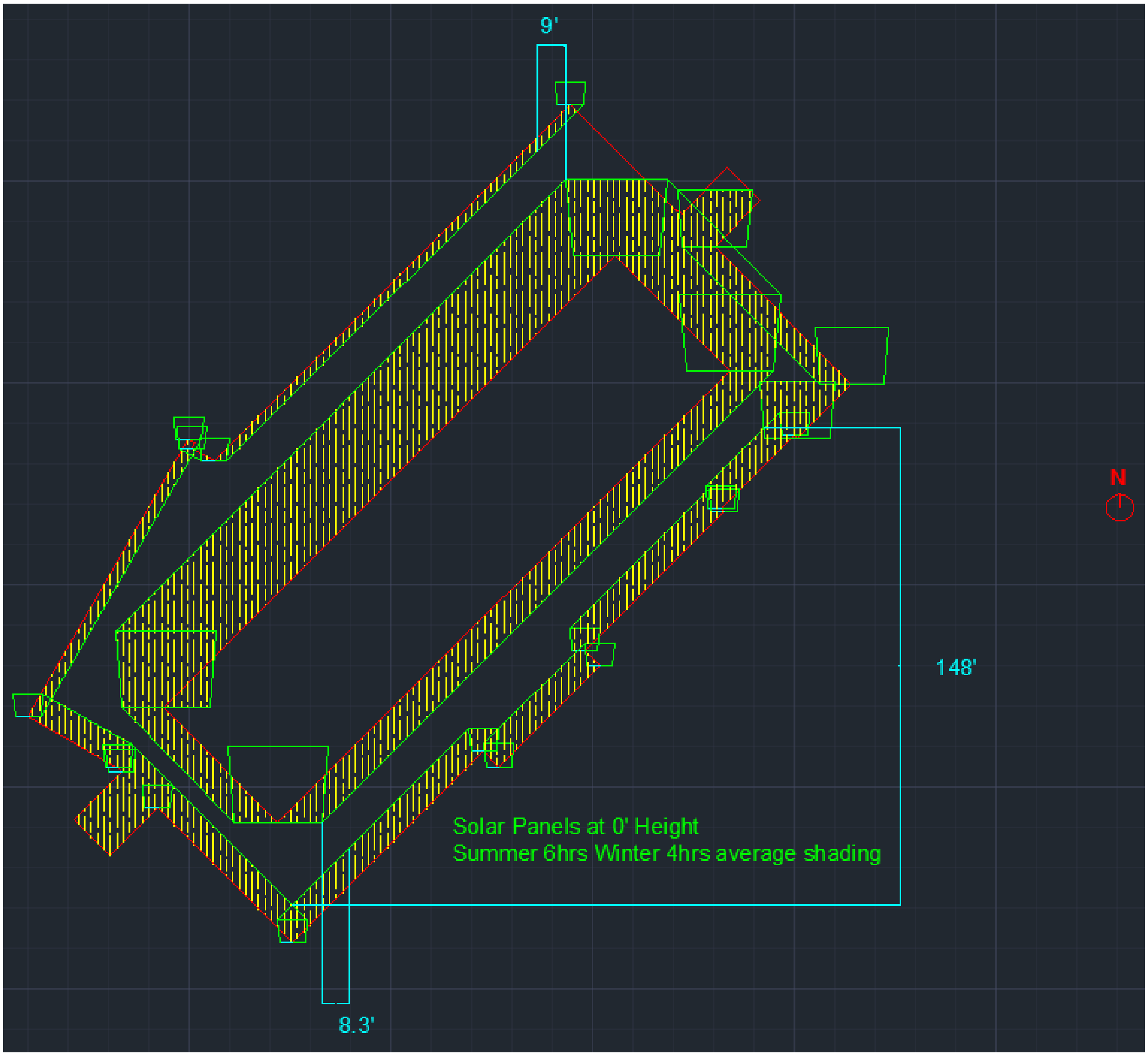


Figure 6.4: Shading at RFCS 6hr Summer/ 4hr Winter Window

Based on these shading diagrams, one can see that the usable space for solar panel installation diminishes significantly once shadows are accounted for. Also, based on this analysis and the obstructions that exist, it is clear that the appropriate "window of time" to plan for at RFCS is 6 hours of sunlight in the summer and 4 hours of sunlight in the winter. This is due to the extreme shading that exists in the 8 hours summer/ 6 hours winter diagram.

6.3 Module Selection

Choosing the correct module for the appropriate situation is critical according to members from the Center for Sustainability at Penn State University. To find the most fitting modules for RFCS, this researcher contacted the key account manager from SunWize Technologies and received a recommendation on which panels would be best suited to RFCS. This recommendation was utilized as SunWize Technologies is a prominent solar panel dealer on the west coast and has great experience with commercial solar projects. The account manager recommended the Trinasolar TSM-250PA05 module for use at RFCS based on the shading diagrams for RFCS, the available usable space, and the current market. According to the recommendation, this module provides the best efficiency for the cost in this specific situation. To view the specifications for this module please reference Appendix H- Solar Module, Inverter, and Ballast Racking Specifications. This module has a maximum efficiency of 15.3%, a maximum power output of 250W, and dimensions measure 3 ¼' by 5 ½'. The next step in this analysis is to select the appropriate racking system.

6.4 Racking Selection

Two popular types of racking systems exist when mounting solar panels; a direct roof mount system and a ballast system. In the direct roof mount system the panels are held up by supports which are directly tied into the roof structure. In contrast, the ballast system is laid on top of the existing roof and is held down by heavy stone weights. This researcher chose to select the ballast system of racking for this situation based on the retrofit nature of the installation. Since the roof at RFCS is complete, a directly tied system would require numerous penetrations into the roof membrane to tie into the structure. The ballast system requires fewer penetrations into the roof membrane because of the stone weights that are used for structural support thus minimizing the chance for leaks in the roof system.

The ballast system that the Trina TSM-250PA05 module is specified for is the Trinamount III by Trinasolar. This racking system is meant for commercial, flat roofs and gains its structural integrity from the high weight stone ballasts placed at its base. The fixed tilt angle for this mounting system is 11^0. Ballast racking systems typically offer the 11^0 tilt to minimize the effects of wind loads on the panels. While the 11^0 angle does not offer optimal energy collection, it offers the benefit that the panel will not create as large of a shadow as say a 30^0 tilt angle. This allows for more panels to be placed which will make up for the small energy loss per panel. Specifications for the Trinamount III ballast mounting system can be found in Appendix H- Solar Module, Inverter, and Ballast Racking Specifications.

6.5 Array Placement

Utilizing the sizes and specifications of the modules and racking system, this researcher developed a solar panel array for the rooftop of RFCS. The array was developed using the solar shading diagram for RFCS, considering the shading created by the panel itself, and in consideration of receiving the highest amount of direct energy while placing the greatest amount of panels. The panels were aligned so the array was facing due South with an azimuth of 180 degrees to obtain the most direct solar gain. The following figure, Figure 6.5, shows the determined array for RFCS. The purple rectangles represent the modules.

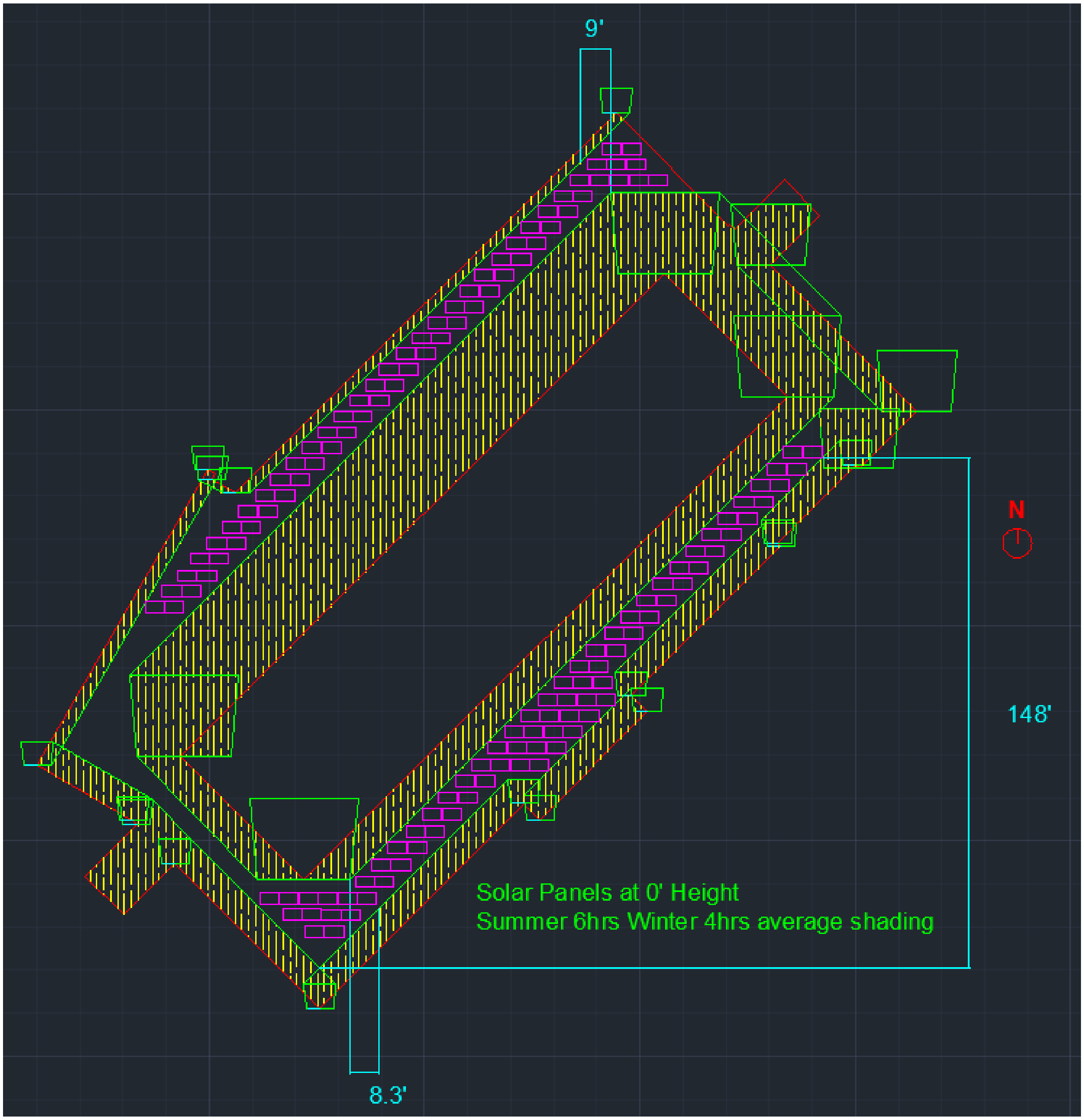


Figure 6.5: Array Placement at RFCS Rooftop

Based on this array, the rooftop of RFCS can hold **143** Trinasolar TSM-250PA05 modules racked on the Trinamount III ballast system.

6.6 Inverter Selection

Selecting the correct inverter for the photovoltaic system is important since the power produced by the panels is in the form of direct current and must be converted into alternating current to match the electricity grid. The inverter must be chosen and sized correctly to efficiently and safely convert the power.

Critical to the inverter selection, as well as the performance and financial modeling of the solar panel system at RFCS, is the System Advisor Model (SAM) which has been produced by the National Renewable Energy Laboratory of the US Department of Energy. This system is programmed to respond to the parameters input by the user and account for the many variables that exist in solar design to output the appropriate component that suits ones specific system. The system has been recommended for use by the Center for Sustainability at Penn State.

Figure 6.6: Inverter Selection

SAM was used to determine which inverter could handle the 36kWdc maximum load produced by the PV-array at RFCS. The inverter that was selected is the Sunny Tower by SMA which is capable of supporting 42 kWdc power. The inverter will run at 80% of its threshold which makes this design conservative. Aside from the Sunny Tower by SMA meeting the designed load requirements, it also offers the lowest specific cost and the highest efficiency of the inverters of this nature. The Sunny Tower combines smaller string inverters into a system which is one unit and can be installed centrally. The Sunny Tower also incorporates combiner boxes which eliminates the need and costs associated with additional combiner boxes that most inverters would require. Specifications for the Sunny Tower by SMA inverter can be found in Appendix H- Solar Module, Inverter, and Ballast Racking Specifications.

6.7 Electrical Sizing and Design

The following electrical wire sizing design abides by NEC 2011 requirements and references a wire sizing example for PV Source Circuits taken from the text *Solar Electric Handbook- Photovoltaic Fundamentals and Applications* to make the appropriate wire sizing analysis for RFCS. Please reference Appendix I- References Used for Conductor Sizing to view tables and references used in this design.

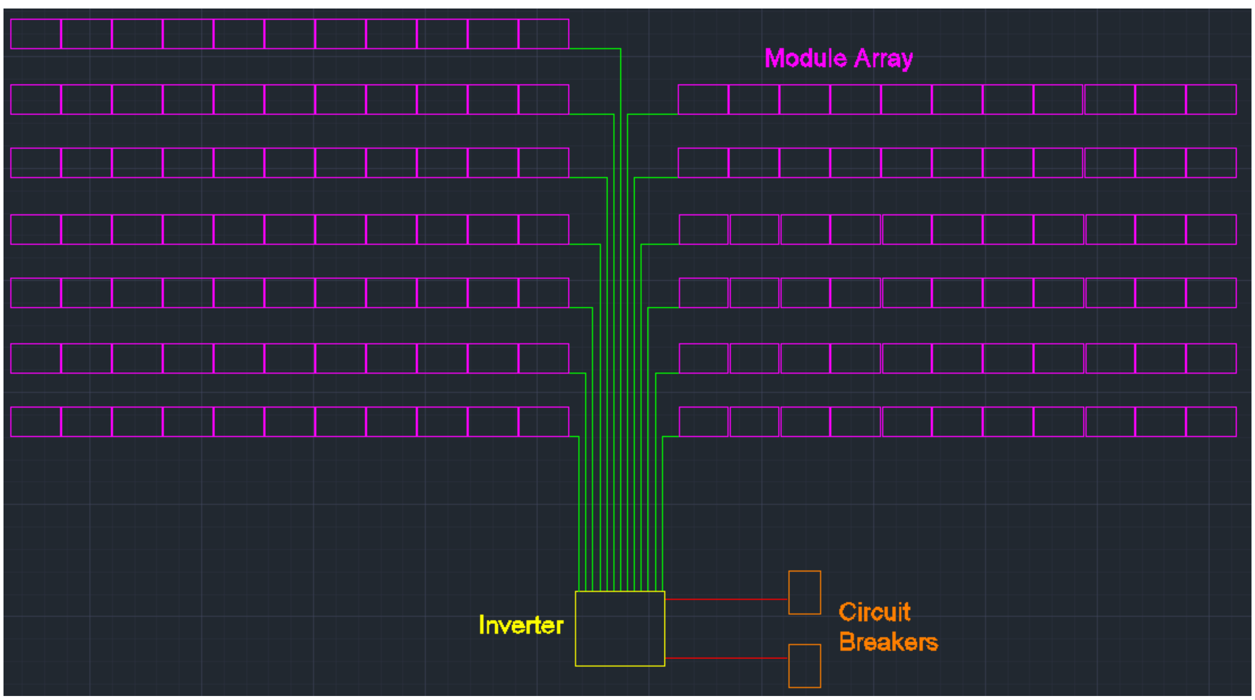


Figure 6.7: Riser Diagram for RFCS Photovoltaic System

6.7.1 Design Summary

The following table, Table 6.1, outlines the results of the conductor sizing analysis. Based on the analysis, (5) #12 AWG conductors will be required per PV Output Circuit String in each direction (+/-) and (3) #4 AWG conductors to connect the inverter to each (2) 80-amp circuit breaker. Following this summary table are the calculations that were made to attain the sizing results.

Table 6.1: Conductor Sizing Summary

Conductor Sizing Summary		
Connection	Description	Legend
Panels String to Inverter (DC Side)		
Conductor Sizing (One Way)	(5) #12 AWG's per PV Output Circuit String	
Maximum Run Length	187 ft. one way for 2% Voltage Drop	
Inverter to Circuit Breakers (AC Side)		
Conductor Sizing (One Way)	(3) #4 AWG conductors per 80-amp breaker	
Maximum Run Length	85 ft. one way for 1.5% Voltage Drop	
Circuit Breaker Sizing	(2) 80-amp circuit breakers	

<u>Assumptions</u>

- 48^{o} C Max. Ambient Temperature; 0.5 – 3.5" above roof surface
- 90^{o} C Terminals
- DC-side desired voltage drop = 2%
- AC-side desired voltage drop = 1.5%
- Inverter placed on rooftop, utility tie-in locate in basement electrical room

6.7.2 Part 1: DC Conductor Sizing

Table 6.2: Module Specifications

Trinasolar TSM-250PA05 Specifications	
Description	**Specification**
Voc	37.6 V
Vmp	30.3 V
Isc	8.85 A
Imp	8.27 A
W	250 W

<u>Conductor Sizing</u>

Isc Module = 8.85 A

Total Isc of PV Output Circuit = 97.35 A

STC Array Isc = 9.6 A

Reference: Appendix I, PV Source and Output Circuits Figure

Minimum Conductor Size: **(5) #12 AWG's per PV Output Circuit**

<u>Voltage Drop</u>

Vmp = 30.3 V x 11 modules in series = 333.3 V system operating voltage

Imp = 8.27 A, 12 AWG wire

Circuit one-way length = 140' (longest run taken from AutoCad array layout)

Maximum Conductor Length

1. 12 AWG wire, 8.27 A = .2806 (multiplier found on voltage drop chart)

2. 0.2806 x 333.3 V system operating voltage x 2 (desired voltage drop %) = **187 feet maximum conductor one-way length**

Actual Voltage Drop

3. Actual length 140 ft/ Maximum length 187 feet = .749

4. Actual Imp = 8.27 A / Current used on chart column 9 A = .919

5. (Desired voltage drop %) 2 x .749 x .919 = **1.38% voltage drop for 140' maximum run**

6. Is voltage drop acceptable? YES

6.7.3 Part 2: AC Conductor Sizing

Table 6.3: Inverter Specifications

Inverter: Sunny Tower by SMA Specifications	
Description	**Specification**
Maximum Continuous Output Power	42 kW
Nominal AC Output Voltage	208 V
Continuous Output Current	117A
Maximum AC Voltage Drop	1.5%

Maximum Continuous Current = 117A

Reference: Appendix I, Inverter Output Circuit Conductor Size Figure

Use: **(3) #4 AWG conductors per 80-amp circuit breaker. (2) 80-amp circuit breakers**

Voltage Drop for AC Side

From Specs: V= 208 V, Imp = 58.5 A, 4 AWG wire, Circuit one-way length = 76’ (Rooftop to Electrical Room in Basement)

1. 4 AWG wire with 58.5 A = 0.2706 (multiplier found on voltage drop chart)

2. 0.2706 x 208V x 1.5 (% max Vdrop) = **84 feet max conductor length**

3. 76’ / 84’ = 0.91

4. 58.5 A / 60 A = 0.975

5. (% max Vdrop) 1.5 x 0.91 x 0.975 = **1.33% Voltage Drop**

6. Is Voltage Drop Acceptable? YES

Chapter 7: Construction Analysis of Solar Panel Installation at Roof Level

Based on the designed PV system for RFCS, the following section will outline the cost, schedule, constructability, and remaining concerns of implementing such a system on the rooftop of RFCS.

7.1 Cost Summary

When determining the costs of an energy production system it is important to evaluate and consider more than just the bottom line direct costs. One must understand the direct costs while also considering the utility savings over the systems lifecycle. Once both values are attained a lifecycle payback analysis can be completed to determine whether the system is feasible. Something that is unique to alternative energy systems, including solar panel systems, is that the US government has offered incentives for pursuing such systems. The government will often reduce the taxes on the alternative energy project and in certain situations will give tax credits to mitigate the large initial cost of installation.

The following table summarizes the direct costs of installing the photovoltaic system at RFCS. According to this estimate, the system will cost $180,534 to install.

Table 7.1: Direct Costs for Solar Panel Installation

Direct Costs for Solar Panel Installation				
Description	**Cost/Unit**	**Quantity**	**Total Cost**	**Reference**
Modules	$190/Module	144	$27,360	Sunwize Quote
Ballast Racking System	$0.30/Watt	35730	$10,720	Rocky Mountain Institute
Inverter	$19553/Unit	1	$19,553	Affordable Solar Quote
DC Wiring #12 AWG	$0.74/LF	12400	$9,176	RSMEANS
DC Conduit 3/4"	$10.50/LF	2480	$26,040	RSMEANS
AC Wiring #4 AWG	$2.29/LF	250	$573	RSMEANS
AC Conduit 1"	$12.45/LF	250	$3,113	RSMEANS
Circuit Breakers 80 AMP	$1025/Ea	2	$2,050	RSMEANS
Crane Rental (Truck Crane 4,000 lb. Capacity)	$4200/day	2	$8,400	RSMEANS
Shipping	$190/Pallet	11	$2,090	Sunwize Quote
Labor	$3/Watt	35730	$107,190	Sunwize Rec.
Total	-	-	**$180,534**	

As a means of determining the yearly cash flow produced by the photovoltaic system, this researcher utilized the System Advisory Model (SAM) produced by the US Department of Energy. The module type, inverter, ballast racking system, and array placement specifications explicit to RFCS were input into the model. Along with these specifications, Southern California specific values for energy costs and incentives were used. In addition to this material, the following variables and assumptions were used to build this model:

- Analysis Period: 25 years
- Purchase as lump sum
- Federal Income Tax Rate: 28%/year
- State Income Tax Rate: 7%/year
- Nominal Discount Rate: 7.83%
- Sales Tax: %5 of installed costs
- Incentives based on San Diego Renewable Energy Incentives: 30% Federal Tax Credit, State Credit: .05 $/kWh
- Salvage Value at 30% of initial cost (conservative)

- Utility rates based on San Diego Gas and Electric Company rates
- Property tax: 0% based on state incentives for renewables and efficiency

Based on the specifics of the system at RFCS, the system will produce 47,000 kWh of power/ year on average over the 25 year span. At a utility rate of $.13/kWh this averages approximately $6,110 worth of power production each year. Paired with this yearly energy production income are the initial government incentives that are offered from the state of California. The following figure shows the lifecycle cost analysis of implementing a photovoltaic system at RFCS. The green bars represent the yearly monetary gains while the red bar represents the overall cost of the system through time accounting for the direct costs and the financial gains produced by the system each year.

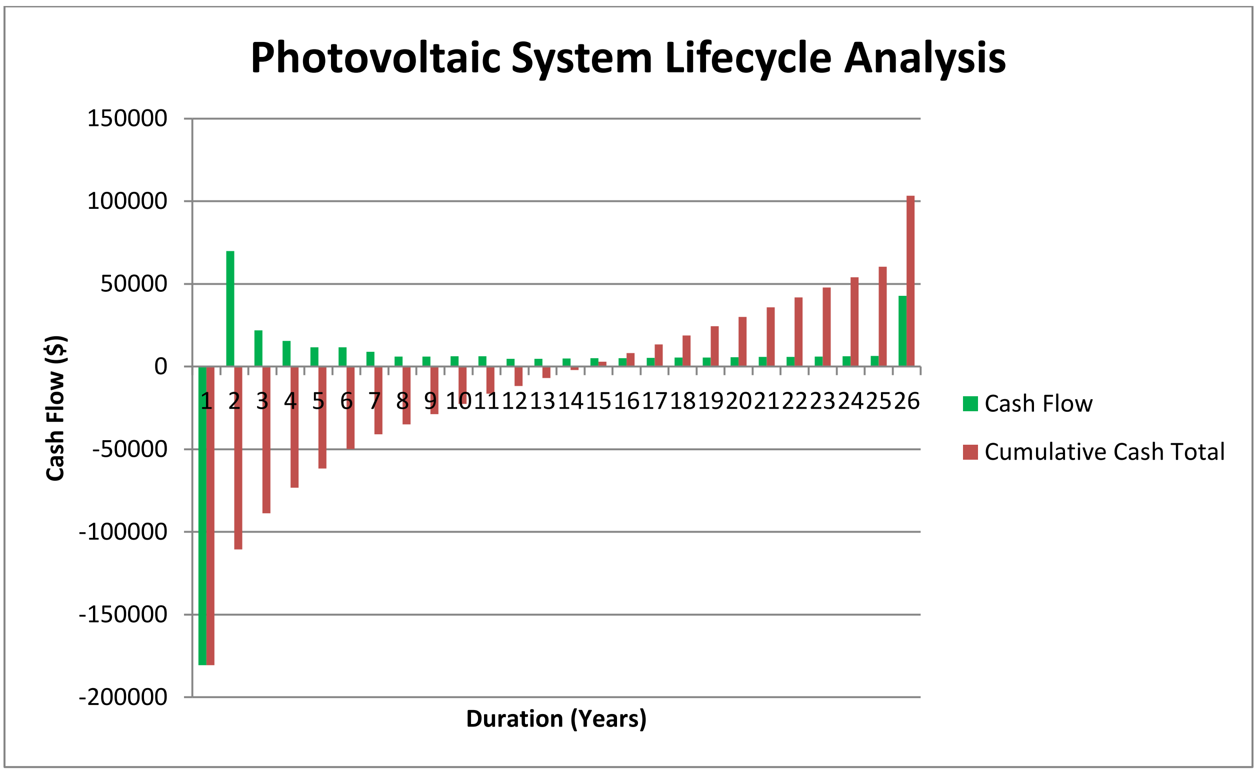


Figure 7.1: Photovoltaic System Lifecycle Analysis

Based on the analysis produced by SAM, the photovoltaic system has a payback period of 14 years. This means that it will take 14 years for the system to accrue enough money in energy savings and incentives to offset the initial investment costs.

7.2 Schedule Summary

The installation of a photovoltaic system at RFCS is estimated to take four weeks. The process will begin by hoisting the modules, racking system, inverter, and accessories to the rooftop through the use of a crane. From there, crews will begin laying out the array and marking penetrations. Once layout is complete, the roof mounting system will be installed along with the modules. Once the modules are in place and assembled, electricians will wire the strings of panels and connect those strings to the inverter. They will then connect the inverter to the circuit breakers in the basement then tying the system in to the utility grid. Once all the connections are made crews must check and balance the system to ensure it is working at full capacity. The following figure demonstrates the planned schedule for the installation. Please reference Appendix J- Takeoff for Solar Panel Scheduling to view the notes used to make this schedule.

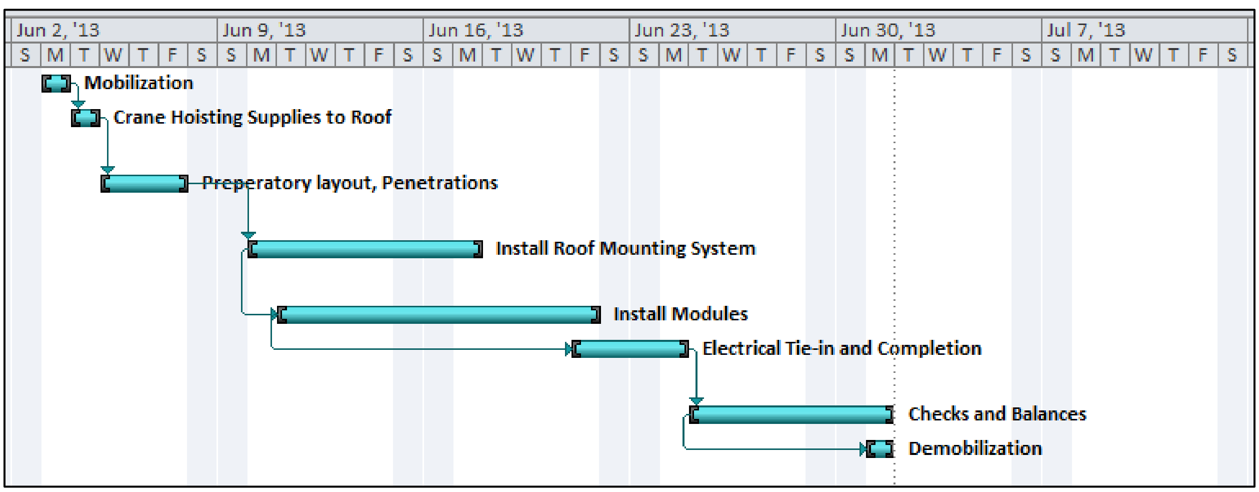


Figure 7.2: Photovoltaic System Installation Schedule

7.3 Constructability Concerns

Installing a photovoltaic system on the roof of RFCS poses a few challenges to the construction team. The team must initially be concerned with the racking system and how it will affect the waterproofing membrane. Ballast racking systems excel in the fact that they do not require as many penetrations into the roof as a direct mount but unfortunately can cause cuts in the membrane from the metal base rubbing back and forth from wind loads. It is important for the team to appropriately size the ballast weighting system to ensure that the system does not cut into the membrane as well as lay a protective boundary layer to absorb this friction. Damaging the waterproofing roof membrane could result in significant costs including damage to the roof system and the reinstallation of the panels that caused the problem.

Another item of concern will be the need for organization. The available space on the roof is reduced significantly by implementing this system. It will be important for the crews to remain organized during construction to ensure on-time completion and more importantly ensure a high level of safety. Clutter will cause a chaotic situation in such a small and refined space causing possible damage to the sensitive photovoltaic panels.

An item of concern that resides mainly on choosing a competent electrical subcontractor is the need for correct system balancing and connections. It will be important to the success of the energy output of the system to correctly connect and balance the system once installed. Minor mistakes can cause significant losses in solar energy harvesting systems. Because of this, the team must be diligent in their selection process.

7.4 Conclusion

The proposed photovoltaic rooftop system for RFCS is estimated to cost a direct amount of $180,534. Through government incentives and yearly energy production, the system is estimated to have a return on investment period of 14 years. Based simply on this number, it is this researcher's opinion that a photovoltaic system on the rooftop of RFCS should not be implemented. A factor that caused the need for this analysis, though, was the owners desire to achieve LEED Gold Certification. Depending on the outlook of the owner, the direct cost and payback period might be worth the investment in order to achieve the LEED Gold Certification.

All factors considered, this researcher recommends that the team at RFCS should look into other alternatives to achieving the LEED credits. The implementation of photovoltaic panels does not make sense based on the extended period of time that the owner must wait to see a full return. The problem with a rooftop solar panel system begins with the amount of obstructions on the already planned roof. The small roof area, large obstructions, and central placement of the mechanical equipment provides minimal space that is unaffected by shading.

This severely limits the size of the system which can be implemented thus limiting the size of energy production each year. Fourteen years is simply too long of a period to wait to see returns, especially with the volatile energy market that exists. If the owner wishes to achieve LEED Gold Certification through this system design, it will come at an expensive price.

Chapter 8: Mobile Technology Integration- Tablet Computers

8.1 Problem Identification

While the interest in using mobile technology in construction is increasing, many owners are not yet convinced by its benefits; leaving available and efficient technology in the background. These technologies, specifically tablet computer technologies, are being created and improved on a daily basis by software providers and the push for their integration and potential success is evident. Teams continue to pursue “archaic” approaches to performing day-to-day tasks and by doing so are thus missing potential General Condition’s savings.

Communicating field issues, documenting RFI’s, searching for the necessary drawing, and completing punch lists are a few of the main contributors that make up a project engineer’s day. Mobile technology processes currently exist to expedite and improve these processes. Engineers are spending valuable time entering data, walking to find things, and organizing. If time spent doing these remedial tasks was decreased by utilizing the available technologies, these engineers could spend their time increasing the value of the project by focusing on the actual systems of the building. This time savings could also decrease the size of the management team needed to oversee construction.

8.2 Research Goals

1. Investigate and present case study applications of mobile technology, specifically tablet computers.
2. Organize and present available technologies and the resulting schedule, cost, and quality impacts of their use.
3. Explain the process of integrating mobile technology on a job site.
4. Compare and contrast the current techniques used at RFCS with that of the available mobile technology applications.
5. Make recommendation for mobile technology integration at RFCS siting specific cost, schedule, and value savings.

8.3 Application Methodology

(1) Gather and Report information from case studies obtained from Innovation Team at DPR Construction on mobile technology.
(2) Study and document mobile tablet integration at DFW Airport in Dallas, TX.
(3) Research articles, essays, and journals referencing mobile technology to obtain facts and figures from sources such as ASCE Database and ENR.
(4) Find appropriate case studies that did not use tablets for comparison.
(5) Apply rates, values, benefits, and pitfalls to the situation at RFCS.
(6) Determine whether utilizing mobile tablets is appropriate for RFCS.

8.4 Preliminary Analysis

Mobile technology integration is a trending issue within the construction industry in recent years. Many companies and owners are racing towards a solution that will save their respective companies money and lower their bottom line. At the forefront of this search is a team at DPR Construction known as the Innovation Department. This researcher had the opportunity to work for the Innovation Department at DPR Construction over summer 2012 and was able to see mobile tablet integration first hand. This experience will be both informational and influential in creating this report.

The Innovation Department consulted with project teams at DPR and distributed numerous tablets in hopes of determining what technology, interfaces, and applications are suited to construction. The Innovation Department then tracked rates and project team comments regarding the benefits and concerns of such technologies which should prove to be essential to this analysis topic.

Another source for information regarding mobile tablet integration will be consultations and reports generated by companies associated with their experiences thus far. Once such source will be a webinar presented on June 6th, 2012 by ENR titled “Field Guide to Mobile Apps in Construction”. During this webinar industry professionals presented raw data regarding the use of mobile technology during the construction and renovation at DFW Airport in Dallas, TX. These values will help to create a better sampling for data as opposed to using simply one company’s reports.

ASCE and ENR have been covering mobile technology integration closely which has also generated numerous reports and journals. These publications will give additional support to presenting the successes and pitfalls of implementing mobile technology.

8.5 Background Information

RFCS is a $20 million, 130,000 square foot, research and office facility requiring the supervision of a team of 6 individuals. These six individuals include a regional manager, a project executive, a project manager, a superintendent, and two project engineers. The regional manager and project executive are dedicated to other projects in addition to RFCS. This implies that the majority of the day-to-day tasks rest in the hands of 4 individuals.

The day-to-day tasks of the on-site management team were mainly handled through laptop computers in the jobsite trailer. Engineers would return to the trailer to carry on tasks that needed to be electronically processed. While electronic drawings were utilized, paper drawings constituted a large portion of the documents used during discussion. The project team at RFCS utilized a cloud server to store the electronic drawings and distribute them to the other parties. The project has been successful thus far following these practices but this researcher sees an opportunity for additional gain through tablet integration at RFCS.

There is a delicate balance when calculating the size of the management team between keeping the General Conditions as low as possible and assembling a team large enough to properly manage the project. By investigating mobile technology integration and applying that to RFCS, the team could see a considerable impact in their daily routine.

8.6 Case Study 1: ASCE Journal- Making the Case for Mobile IT in Construction

The introduction to *Making the Case for Mobile IT in Construction*, taken from the ASCE Journal Database, describes the construction industry as “being slow to change and adopt new information technologies”. The purpose of the study was to document case studies that demonstrated mobile technology use by the “point of activity” workers in construction. Once the study was complete the observers were able to document which processes could be better improved through the use of mobile technology. This article will provide valuable insight into the available technologies that could have potential impact at RFCS.

The article begins by stating the reasons and barriers for the slow adoption of mobile technologies and technology in general within the construction industry. These barriers include the low profit margin most companies operate within, a hesitation towards the benefits, the lack of awareness of these technologies, and finally a lack of success stories documenting its use. The attempt of this article was to demonstrate success stories and discover the steps taken that were necessary for success. For the purposes of this thesis, those success stories will be summarized and the steps taken too ensure successful implementation will be described.

Based on the case studies analyzed in this ASCE Journal, the researchers found that mobile technology was successful when implemented for the following purposes:

- Preventative Maintenance
- Job Allocation and Timesheets
- Defect Management
- Fleet Management
- Management of Piling Works
- Managing Site Safety
- Timesheet and Payment
- Earthworks Examination
- Email and PIM
- Field Observations

Also found within these case studies were the benefits the teams saw through mobile IT integration. These benefits include:

- Reports produced quicker and easier
- Better Customer Service
- Identification of Trends
- More Efficient Task Allocation
- Reduced Task Turn Around Time
- Improvements in Quality
- Increased Accountability

Finally, the team found that to successfully implement mobile technology for these purposes and to see the benefits, the team is not required to change their behavior significantly. They found that in all cases the implementation of mobile IT was a “process improvement” rather than a “process reengineering”. This means that the process or work that the engineer is performing is not completely new but rather a modification that eliminates unnecessary steps. Based on these findings it appears clear that while introducing technology may be unfamiliar for some, it should not be regarded as something that completely changes the work structure of the individual’s day but rather a device that can be used to increase their efficiency. It can be compared quite nicely to a traditional hammer-nail and a nail-gun. The process of putting the nail in is the same but the nail-gun eliminates unnecessary steps in the process increasing efficiency and quality. Mobile technology should be considered in the same aspect. These findings provide a positive response to the overwhelming hesitation to adopt new technologies.

Furthering the discussion on the necessary steps to technology integration is the solutions that were found to the “people issues” during the transition. They found that in all cases under study, for a successful transition the team must “appoint a project IT champion, adopt IT-related applications with short learning curves, and allocate resources to IT training”("Making the Case for Mobile IT in Construction"). Accompanying these factors is the need for all parties to understand the purpose of these tools. Aside from the 6 hours of training per individual that this study recommends, an overall plan must be developed. All parties, at all levels, must negotiate a plan for the intended use of the technology. The findings from this research study, as well as the following two case studies will provide strong influence for the recommendations at RFCS.

8.7 Case Study 2: DFW Airport- Terminal Renovation and Improvement Project

The following information is provided through a webinar presented by *ENR* titled *Field Guide to Mobile Apps in Construction*; specifically a presentation by Jeff Pistor, a project manager for the DFW Airport Terminal Renovation.

Figure 8.1: DFW Airport Jobsite Aerial View

The DFW Airport- Terminal Renovation and Improvement Project is a grand scale construction project located in Dallas, TX. The construction entails renovating two 1,000,000 SF terminals in a total of 6 phases. The project is scheduled to take 7 years and the contract amount is $900 M. Balfour Beatty is the General Contractor on site and based on this project's enormous size has allocated numerous amounts of personnel to create a successful result.

Of the various challenges that exist for a project of this nature, a few were noted by the project manager of Balfour Beatty as been the highest of concern. According to the project manager, the main challenges consisted of working in an active airport, working with security sensitive information, and above all else communication issues. These communication issues stem from a drawing set of over 60,000 sheets, a massive team to supply the information to, multiple phases of project occurring at once, complicated systems that require extreme coordination, and the question of where they will put these drawings for project closeout. To add to these communication issues, the jobsite office was located one and a half miles from construction. The project manager expressed the severe concern the team had going into a project of this size. His solution to such communication and coordination road blocks- Mobile Technology Integration.

The project manager noted that it is important to have a plan when introducing a new technology of this nature stating that “Tools without process are worthless” (Pistor). He and his team set goals and requirements at the beginning of the project outlining what type of system they would require to be successful. Their four goals were: 1. Tools and processes must be able to quickly and efficiently manage drawings and documents. 2. Documentation must be available everywhere at all times. 3. Must be single source of drawings for entire team. 4. Must reduce reprographics costs, update drawings electronically, and make them available to all. Based on these goals the team at DFW decided to implement large digital plan tables as well as tablet computers.

The tablet computers operated off a single source cloud storage network where the drawings were updated from a single source in the jobsite office and pushed to the cloud for others to access from their tablet computers. According to the project manager, this was a tremendous success. Engineers were able to stay at the actual site of construction rather than returning to the office to view the drawings. They were able to coordinate the issues in the field in a fast manner, inform others of their findings speedily through emails containing the marked-up drawings, and remain assured that they were viewing the most current drawing set. In the case of DFW Airport, the main use for tablet computers resides in the ability to electronically view drawings and communicate the issues. The following figure summarizes the findings from the DFW Airport- Terminal Renovation and Improvement Project giving a clear view of the implementation of mobile technology for this specific project.

Main Implementation

- Updated Electronic Drawings
- Coordination in the Field
- Project Closeout and Archiving

Results

- Improved Efficiency
- Engineers Save 1 hr/day from Tablet Integration
- Reprographics Cost Decrease of 71% or $5.1M

Lessons Learned

- Technology Must Have an Implementation Plan
- Must Have Sole "Gatekeeper" of E-Documents
- Architect Must be On-board

Figure 8.2: Summary of DFW Airport Terminal Renovation and Improvement Project

8.8 Case Study 3: Pharmaceutical Processing Plant in Los Angeles, CA

Figure 8.3: Tablet Use on Jobsite

The Pharmaceutical Processing Plant (PPP) located in Los Angeles, CA is a 3 story, 90,000 SF processing plant with very detailed and hi-tech mechanical, electrical, and processing equipment. The coordination demands of this $150M, 2.5 year, fast paced and intricate project challenged the General Contractor on the job, DPR Construction, to develop a strategy for providing a successful final project on time and under budget. The team responsible for planning the strategy at PPP chose to pursue the innovative nature of mobile technology integration regardless of the weariness of some. This would be a first attempt for most individuals on the team but a project of this complexity demanded a new solution.

The team focused on a few main objectives. They wanted to: 1. Access electronic drawings in the field. 2. Mark-up drawings and pictures taken on site to email to other parties. 3. Coordinate with 3-D model in the field. 4. Perform Safety Evaluations. Based on these goals, the team decided to implement tablet computers and two BIM Kiosk Stations.

Similar to the DFW Airport Case Study, the tablet computers at PPP operated off a single source cloud storage network. Drawings were updated by an administrator in the jobsite office and individuals on site were able to access these drawings from their tablet computers in the field. The mobile technology proved to be successful. Members of the team used their tablets to discuss clash issues in the field rather than returning to the office and workers were able to mark up drawings in the field and send marked-up drawings via email to personnel in the office when necessary. Another attribute to these tablet computers was the camera function. Superintendents and engineers alike were able to take pictures of clashes and other systems, mark what the item in the picture was, and send them via email to the requested party. The camera function, as well as the ability to mark up drawings in the field, proved to be a very successful way of communicating RFI's.

Along with better communicating RFI's, Safety Evaluation quality has increased dramatically. Rather than engineers walking the site and returning to fill out the evaluation only to forgot what they saw, they can now fill out the evaluation as though go which gives ease to the process and increases the quality of the reports. One item that has not quite been fully developed is the ability to analyze the 3D model via tablet computers. The team at PPP is waiting for the technology to reach a level where the tablet computers can support 3D models in a smooth manner. The following figure summarizes the findings from the Pharmaceutical Processing Plant in Los Angeles, CA giving a clear view of the implementation of mobile technology for this specific project.

Main Implementation	• Updated Electronic Drawings • Coordination in the Field and RFI's • Safety Evaluations
Results	• Engineers Save 1.1 hr/day from Tablet Use • Superintendents Save 1.5 hr/day from Tablet Use • Reprographics Cost Decrease $4000/Addendum
Lessons Learned	• Tablet Becomes Integral. Must Keep With You • Must Have Sole "Gatekeeper" of E-Documents • Roadblocks with Technology (3D Model, Opening File Types)

Figure 8.4: Summary of Pharmaceutical Processing Plant in Los Angeles, CA

8.9 Proposed Mobile Technology Implementation Strategy at RFCS

Based on the case studies presented in this analysis, it can be argued that tablet computers provide a successful and efficient tool for various tasks that an engineer is required to perform each day. From large to small, and high to low complexity, the general use and results have shown success. *Making the Case for Mobile IT in Construction* shows that tablet computers are tools that must only be assigned to the necessary tasks. This means that while tablet computers are capable of various functions, the appropriate uses must be allocated based on the needs of the project. In the case of RFCS, the following tasks line up with the available uses for tablet computers:

Figure 8.5: Tablet Computer Implementation at RFCS

If the team is to implement such a plan, they will be significantly more "mobile" in their day-to-day tasks. They will be able to access the drawings in the field to resolve coordination issues and communicate those issues to the necessary parties. They will be able to document these issues, perform site safety evaluations, and perform daily checklist tasks such as time sheets and progress reports all while remaining on site. This will decrease the time the team spends walking to and from the trailer to access laptop computers or hard copy drawings as well as decrease the time spent each day with data entry.

Implementing such a strategy should allow the team at RFCS to see benefits similar to those documented in the case studies cited above. Customer service, efficiency, and quality are all factors that should show improvement. In order for tablet computers to be a success though, "human factors" must be considered. The team must be willing to dedicate an "IT Champion" to focus his attention on helping others with IT concerns, they must be willing to make a monetary investment in the technology, and they must dedicate time to training new users. In order to quantify the costs of implementing tablet computers and managing the human requirements for successful implementation, a cost estimate for RFCS including all factors must be considered. The following tables, Table 8.1 and Table 8.2, use values and rates from the case studies analyzed earlier in this section paired with time rates specific to RFCS to determine whether tablet computer make sense from a financial standpoint. For this study the tablet that will be considered is the 16GB iPad by Apple which provides a mid-range value tablet.

Table 8.1: Direct Costs of Tablet Integration

Direct Costs of Tablet Computer Implementation			
Description	**Quantity**	**Cost/Unit**	**Cost**
Tablet Computers	4	$500/iPad	-($2,000)
Contingency for Software & Add-ons	4	$300/iPad	-($1,200)
Training Project Manager	6 hours	-	-($624)
Training Superintendent	6 hours	-	-($624)
Training Project Engineer #1	6 hours	-	-($408)
Training Project Engineer #2	6 hours	-	-($408)
Total	-	-	**-($5,264)**

Table 8.2: Human Resource Costs of Tablet Integration

Human Resource Costs of Tablet Integration (Weekly)			
Description	**Quantity**	**Cost/Unit**	**Cost**
Costs			
IT Champion Time	2 hours	$68/hour	-($136)
Savings			
Project Manager Time	4	-	$416
Superintendent Time	7	-	$728
Project Engineer #1 Time	5	-	$340
Project Engineer #2 Time	5	-	$340
Total	-	-	**$1688/week**

After accounting for the "hard" costs of the initial investment including the purchase of the tablets, setup and training the total direct cost resulted at **(-$5,264)**. Based on the time savings reported from the case studies and extrapolated to RFCS including the time spent each week by the IT Champion, the total weekly savings cost resulted at **$1,688/week**. Based on these values, the investment into tablet computers has a payback period of just over three weeks. Considering the entire project duration of 18 months, the integration of tablet computers at RFCS has the opportunity to save **$116,272.** This overall savings represents the reduction in on-site management time necessary for RFCS and allows DPR to either offer a more competitive general conditions fee while providing the same quality as the original plan or allows DPR to provide even greater quality, efficiency and customer service to the Owner for no additional cost.

8.10 Conclusions and Recommendations

Based on the studies presented in this section, as well as the financial feasibility study presented above, this researcher recommends the integration of tablet computers at RFCS. Tablet computers offer the opportunity for DPR to differentiate itself from the competitors through benefits like decreased on-site management costs of $1,688/week; increased quality, efficiency, and customer service; and the adaptability to future practices in construction. On-site team members will save time through a more efficient process which eliminates the need for returning to the trailer to have coordination discussions, eliminates time spent entering data, and essentially increases the at-hand knowledge of individuals.

The results of this analysis show significant success with tablet computer integration. By utilizing tablet computers at RFCS, the team stands to save $116,272 in on-site management costs throughout the entire duration of the project. DPR also stands to differentiate itself from the competition by possibly sparking the interest of the owner to the extent of which tablets can be utilized.

Chapter 9: Overall Conclusions and Recommendations

9.1 Prefabricated Panels

It is this researcher's opinion that the project team at RFCS would benefit from implementing a partially prefabricated wall panel system as opposed to the original stick-built construction. The prefabricated panel plan is estimated to save $5,953 and more importantly, reduce the overall schedule duration by three weeks. This schedule reduction allows the project to be in use by the owner sooner which will in turn generate increased profits. This schedule reduction also can allow for a buffer period in the schedule as protection in case a different activity falls behind.

9.2 Detailed Scheduling of Prefabricated Panels

The detailed scheduling presented in Chapter 3 allows the team at RFCS to properly plan for both the construction and erection process that will be necessary to achieve a successful implementation of the partial prefabricated exterior panels. Through a detailed on-ground panel construction sequence, the preconstruction team is able to precisely schedule and estimate materials for the activity. They can ensure accurate values providing a smooth transition to the construction phase. The construction team can then use these plans to train the crew responsible for construction as well as properly oversee the activity.

Accompanying the benefits of the sequence created for the ground construction of the panels is the panel erection plan. This plan will help to safeguard against the injuries that could result during the erection process as well as the possibility of keeping the crane on-site for an unwarranted, extended period of time.

9.3 Solar Panel Installation at Roof Level

The proposed photovoltaic rooftop system for RFCS is estimated to cost a direct amount of $180,534. Through government incentives and yearly energy production, the system is estimated to have a return on investment period of 14 years. Based simply on this number, it is this researcher's opinion that a photovoltaic system on the rooftop of RFCS should not be implemented. A factor that caused the need for this analysis, though, was the owners desire to achieve LEED Gold Certification. Depending on the outlook of the owner, the direct cost and payback period might be worth the investment in order to achieve the LEED Gold Certification.

All factors considered, this researcher recommends that the team at RFCS should look into other alternatives to achieving the LEED credits. The implementation of photovoltaic panels does not make sense based on the extended period of time that the owner must wait to see a full return. The problem with a rooftop solar panel system begins with the amount of obstructions on the already planned roof. The small roof area, large obstructions, and central placement of the mechanical equipment provides minimal space that is unaffected by shading. This severely limits the size of the system which can be implemented thus limiting the size of energy production each year. Fourteen years is simply too long of a period to wait to see returns, especially with the volatile energy market that exists. If the owner wishes to achieve LEED Gold Certification through this system design, it will come at an expensive price.

9.4 Mobile Technology Integration- Tablet Computers

Based on the case studies and financial feasibility study presented in Chapter 8, this researcher recommends the integration of tablet computers at RFCS. Tablet computers offer the opportunity for DPR to differentiate itself from the competitors through benefits like decreased on-site management costs of $1,688/week; increased quality, efficiency, and customer service; and the adaptability to future practices in construction. On-site team members will save time through a more efficient process which eliminates the need for returning to the trailer to have coordination discussions, eliminates time spent entering data, and essentially increases the at-hand knowledge of individuals.

The results of this analysis show significant success with tablet computer integration. By utilizing tablet computers at RFCS, the team stands to save $116,272 in on-site management costs throughout the entire duration of the project. DPR also stands to differentiate itself from the competition by possibly sparking the interest of the owner to the extent of which tablets can be utilized.

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Appendix A: Preliminary Project Cost Evaluation

Assemblies Estimate					
Assembly Category/ Number	**Description**	**Quantity**	**Unit**	**Cost/Unit**	**Grand Total Incl. O & P**
Plumbing					
D 2010 110 1880	Water closet, vitreous china, elongated tank type, wall hung, two piece	32	Ea	$ 2,467.07	$ 78,946.24
D2010 210 2000	Urinal, Vitreous China, Wall Hung	8	Ea	$ 1,424.50	$ 11,396.00
D2010 310 1560	Lavatory w/ Trim, Wall hung, PE on Cl, 18" x 15"	18	Ea	$ 1,710.00	$ 30,780.00
D2010 710 1560	Shower, stall, baked enamel, molded stone receptor	2	Ea	$ 2,108.54	$ 4,217.08
D2020 240 1820	Electric water heater, commercial, 100 deg F rise, 50 gal tank, 9KW, 37 GPH	2	Ea	$ 6,188.65	$ 12,377.30
D2040 210 1880	Roof Drain, DWV PVC Pipe, 2" Diam., 10' High	10	Ea	$ 920.76	$ 9,207.60
Subtotal					**$ 146,924.22**
HVAC					
D3020 104 1400	Large heating systems, electric boiler, 666 K.W., 2,273 MBH, 4 floors, piping & accessories incl.	127373	SF	$ 9.27	$ 1,180,747.71
D3050 165 3200	Medical Centers 33.33 ton weight AHU w/ 15% reduction bc chilled water is sent from central plant	127373	SF	$ 10.33	$ 1,315,763.09
Subtotal					**$ 2,496,510.80**
Fire Sprinkler					
D4010 310 0740	Dry pipe sprinkler, steel, black, Sch 40 pipe, light hazard,multiple floors, >10,00 SF/floor	127373	SF	$ 3.26	$ 415,235.98
Subtotal					**$ 415,235.98**
Electrical					
D5010 240 0410	Switchgear installation, incl. swbd., panels and circ bkr, 2000 A, 277/480 V	3	Ea	$ 67,680.00	$ 203,040.00
D5020 208 1800	Fluorescent fixtures mount 9'11" above floor, 100 FC, type b, 11 fixtures per 400 SF	34	Ea	$ 13.65	$ 464.10
Subtotal					**$ 203,504.10**
Grandtotal					**$ 3,262,175.10**

Square Foot Estimate	
Appraisal Information	
Gross Floor Area (excl. basement)	127,373 SF
Basement Area	31,917 SF
Perimeter	734 ft
Story Height 1st, 2nd, 3rd	16 ft
Story Height 4th	20 ft
Story Height Avg.	17 ft
Exterior Wall Construction	
South, East, West Wall	Metal stud with punch windows and stone veneer
Closest Comparable	Face brick veneer on steel studs w/ Steel Frame
North Wall	Glass and Metal Curtain Wall
Closest Comparable	Glass and Metal Curtain Wall w/ Steel Frame
Frame	Steel
Estimate Breakdown	
Adjustments for Exterior Wall Variation	
North Wall Percentage of Perimeter	33%
South, East, and West Wall Percentage of Perimeter	67%
Interpolated Wall Price	170.12 $/SF
Height Adjustment	5(1.05) = 5.25 $/SF extra
Perimeter Adjustment	1.5(2.40) = 3.6 $/SF extra
Adjusted Base Cost per square foot	178.97 $/SF
Building Cost	178.97*127,373 = $22,795,950
Basement Cost	35.20*31917= $1,123,478.4
Total Building Cost	$24,099,429
Location Modifier	x1.03
Less Depreciation	0
Total Cost before estimated to Core and Shell	24822410
Remove 20% for Mechanical and Electrical	(.2*24,822,410)
Final Total Cost	**$19,857,928**

*Adjustments for the square foot estimate can be seen in the table above.

*Based on RS Means % breakdown information on mechanical and electrical as well as the need to incorporate some of these systems, 20% reduction was chosen as an average.

Assemblies Takeoff			
Plumbing System	**Quantity**	**Electrical System**	**Quantity**
50 Gallon Electric Hot Water Heater	2	3000 KVA Transformer	1
2 GPM 85 W Hot Water Pump	2	1500 KVA Transformer	2
1st Floor		1st Floor	
Wall Mounted Toilet	8	Flourescent Lights	10
Wall Mounted Urinal	2	2nd Floor	
Wall Mounted Sink	6	Flourescent Lights	8
Shower	2	Sconce Lighting	4
2nd Floor		3rd Floor	
Wall Mounted Toilet	8	Flourescent Lights	8
Wall Mounted Urinal	2	4th Floor	
Wall Mounted Sink	4	Flourescent Lights	8
Shower	0	**Mechanical System**	**Quantity**
3rd Floor		Roof	
Wall Mounted Toilet	8	Air Handler: 50,000 CFM SA, 46,000 CFM RA	2
Wall Mounted Urinal	2	HW Boiler: 80% eff, 140 GPM, Output 2080 MBH	2
Wall Mounted Sink	4	HW Pump: Inline, 140 GPM 61% eff	2
Shower	0	HW Pump: End Suction, 280 GPM, 75 % eff	2
4th Floor		**Fire Sprinkler**	**Quantity**
Wall Mounted Toilet	8	Dry Pipe System	1
Wall Mounted Urinal	2		
Wall Mounted Sink	4		
Shower	0		

Assumptions

*The 3000 KVA and two 1500 KVA transformers equaled the KVA produced by three 2000 KVA transformers and since RS Means has listed only the 2000 KVA system, it was estimated that the cost can be compared on this basis.

COMMERCIAL/INDUSTRIAL/ INSTITUTIONAL | M.460 | Office, 2-4 Story

Costs per square foot of floor area

Exterior Wall	S.F. Area	5000	8000	12000	16000	20000	35000	50000	65000	80000
	L.F. Perimeter	220	260	310	330	360	440	490	548	580
Face Brick with Concrete Block Back-up	Wood Joists	250.75	218.75	200.50	187.80	181.10	167.80	161.40	158.20	155.50
	Steel Joists	254.20	222.20	203.95	191.25	184.55	171.25	164.90	161.65	158.95
Glass and Metal Curtain Wall	Steel Frame	298.50	256.35	232.20	214.90	205.90	187.80	179.00	174.60	170.85
	R/Conc. Frame	294.70	253.10	229.25	212.10	203.20	185.30	176.55	172.15	168.40
Wood Siding	Wood Frame	200.15	177.50	164.65	156.10	151.60	142.75	138.55	136.50	134.75
Brick Veneer	Wood Frame	222.25	193.85	177.60	166.55	160.65	149.05	143.50	140.70	138.40
Perimeter Adj., Add or Deduct	Per 100 L.F.	38.20	23.95	15.95	11.85	9.55	5.50	3.80	2.90	2.40
Story Hgt. Adj., Add or Deduct	Per 1 Ft.	6.25	4.65	3.65	2.90	2.55	1.80	1.35	1.20	1.05

For Basement, *add $35.20 per square foot of basement area*

The above costs were calculated using the basic specifications shown on the facing page. These costs should be adjusted where necessary for design alternatives and owner's requirements. Reported completed project costs, for this type of structure, range from $70.40 to $272.80 per S.F.

Common additives

Description	Unit	$ Cost
Closed circuit surveillance, one station		
Camera and monitor	Each	1925
For additional camera stations, add	Each	1025
Directory boards, plastic, glass covered		
30" x 20"	Each	645
36" x 48"	Each	1475
Aluminum, 24" x 18"	Each	615
36" x 24"	Each	725
48" x 32"	Each	1025
48" x 60"	Each	2150
Electronic, wall mounted	S.F.	895
Free standing	S.F.	1175
Escalators, 10' rise, 32" wide, glass balustrade	Each	137,300
Metal balustrade	Each	143,300
48" wide, glass balustrade	Each	143,300
Metal balustrade	Each	150,800
Pedestal access floor system w/plastic laminate cover		
Computer room, less than 6000 SF	S.F.	11.90
Greater than 6000 SF	S.F.	11.15
Office, greater than 6000 S.F.	S.F.	7.95

Description	Unit	$ Cost
Security access systems		
Metal detectors, wand type	Each	98
Walk-through portal type, single-zone	Each	3750
Multi-zone	Each	4700
X-ray equipment		
Desk top, for mail, small packages	Each	3850
Conveyer type, including monitor, minimum	Each	17,500
Maximum	Each	31,100
Explosive detection equipment		
Hand held, battery operated	Each	28,100
Walk-through portal type	Each	47,900
Uninterruptible power supply, 15 kVA/12.75 kW	kW	1720

176

Important: See the Reference Section for Location Fact

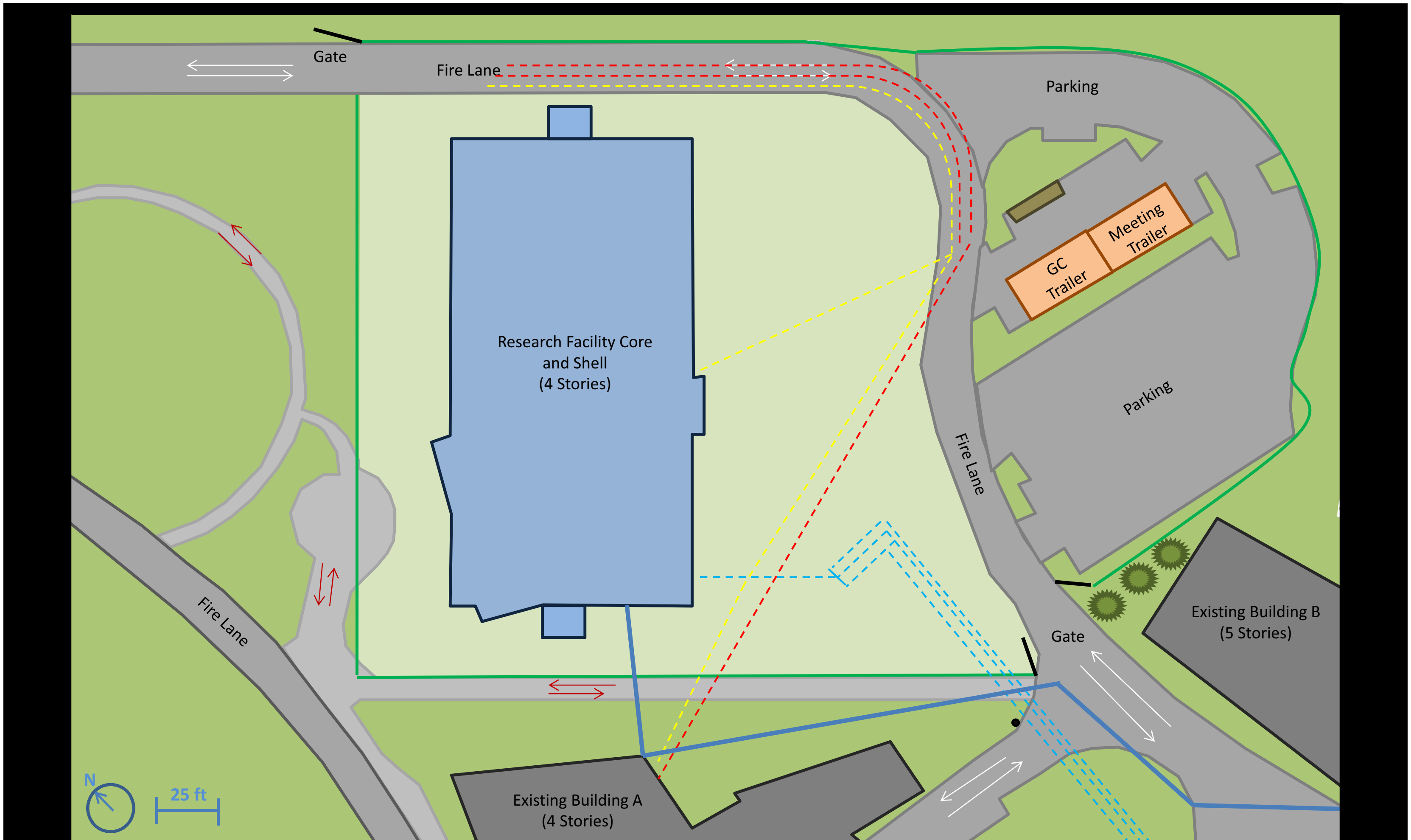
Model costs calculated for a 3 story building with 12′ story height and 20,000 square feet of floor area

Office, 2-4 Story

				Unit	Unit Cost	Cost Per S.F.	% Of Sub-Total
A. SUBSTRUCTURE							
1010	Standard Foundations	Poured concrete; strip and spread footings		S.F. Ground	7.41	2.47	
1020	Special Foundations	N/A		—	—	—	
1030	Slab on Grade	4" reinforced concrete with vapor barrier and granular base		S.F. Slab	5.11	1.70	4.3%
2010	Basement Excavation	Site preparation for slab and trench for foundation wall and footing		S.F. Ground	.18	.06	
2020	Basement Walls	4′ foundation wall		L.F. Wall	76	1.69	
B. SHELL							
	B10 Superstructure						
1010	Floor Construction	Open web steel joists, slab form, concrete, columns		S.F. Floor	18.20	12.13	10.4%
1020	Roof Construction	Metal deck, open web steel joists, columns		S.F. Roof	6.84	2.28	
	B20 Exterior Enclosure						
2010	Exterior Walls	Face brick with concrete block backup	*80% of wall*	S.F. Wall	31.91	16.54	
2020	Exterior Windows	Aluminum outward projecting	*20% of wall*	Each	727	4.09	15.7%
2030	Exterior Doors	Aluminum and glass, hollow metal		Each	3418	1.04	
	B30 Roofing						
3010	Roof Coverings	Built-up tar and gravel with flashing; perlite/EPS composite		S.F. Roof	6.69	2.23	1.6%
3020	Roof Openings	N/A		—	—	—	
C. INTERIORS							
1010	Partitions	Gypsum board on metal studs	*20 S.F. Floor/L.F. Partition*	S.F. Partition	9.45	3.78	
1020	Interior Doors	Single leaf hollow metal	*200 S.F. Floor/Door*	Each	1194	5.97	
1030	Fittings	Toilet partitions		S.F. Floor	1.04	1.04	
2010	Stair Construction	Concrete filled metal pan		Flight	13,700	4.80	23.2%
3010	Wall Finishes	60% vinyl wall covering, 40% paint		S.F. Surface	1.49	1.19	
3020	Floor Finishes	60% carpet, 30% vinyl composition tile, 10% ceramic tile		S.F. Floor	8.33	8.33	
3030	Ceiling Finishes	Mineral fiber tile on concealed zee bars		S.F. Ceiling	6.86	6.86	
D. SERVICES							
	D10 Conveying						
1010	Elevators & Lifts	Two hydraulic passenger elevators		Each	125,600	12.56	9.1%
1020	Escalators & Moving Walks	N/A		—	—	—	
	D20 Plumbing						
2010	Plumbing Fixtures	Toilet and service fixtures, supply and drainage	*1 Fixture/1320 S.F. Floor*	Each	4884	3.70	
2020	Domestic Water Distribution	Gas fired water heater		S.F. Floor	.44	.44	3.4%
2040	Rain Water Drainage	Roof drains		S.F. Roof	1.86	.62	
	D30 HVAC						
3010	Energy Supply	N/A		—	—	—	
3020	Heat Generating Systems	Included in D3050		—	—	—	
3030	Cooling Generating Systems	N/A		—	—	—	12.1 %
3050	Terminal & Package Units	Multizone unit gas heating, electric cooling		S.F. Floor	16.75	16.75	
3090	Other HVAC Sys. & Equipment	N/A		—	—	—	
	D40 Fire Protection						
4010	Sprinklers	Wet pipe sprinkler system		S.F. Floor	3.82	3.82	3.4%
4020	Standpipes	Standpipes and hose systems		S.F. Floor	.91	.91	
	D50 Electrical						
5010	Electrical Service/Distribution	1000 ampere service, panel board and feeders		S.F. Floor	4.71	4.71	
5020	Lighting & Branch Wiring	High efficiency fluorescent fixtures, receptacles, switches, A.C. and misc. power		S.F. Floor	12.06	12.06	16.7%
5030	Communications & Security	Addressable alarm systems, internet and phone wiring, and emergency lighting		S.F. Floor	5.97	5.97	
5090	Other Electrical Systems	Emergency generator, 7.5 kW, uninterruptible power supply		S.F. Floor	.24	.24	
E. EQUIPMENT & FURNISHINGS							
1010	Commercial Equipment	N/A		—	—	—	
1020	Institutional Equipment	N/A		—	—	—	0.0 %
1030	Vehicular Equipment	N/A		—	—	—	
1090	Other Equipment	N/A		—	—	—	
F. SPECIAL CONSTRUCTION							
1020	Integrated Construction	N/A		—	—	—	0.0 %
1040	Special Facilities	N/A		—	—	—	
G. BUILDING SITEWORK	**N/A**						
					Sub-Total	137.98	**100%**
	CONTRACTOR FEES (General Requirements: 10%, Overhead: 5%, Profit: 10%)				25%	34.50	
	ARCHITECT FEES				7%	12.07	
					Total Building Cost	**184.55**	

177

Appendix B: Existing Conditions Plan and Phasing Plans



Existing Conditions Plan

Research Facility Core and Shell

September 21, 2012

Timothy Maffett

LEGEND

New Building	Boundaries of Site	High Voltage Line	Vehicle Traffic
Temporary Facility	Site Fence	Low Voltage Line	Pedestrian Traffic
Existing Building	Fire Hydrant	Gas Line	
Portable Toilet		Water Line	

Building Excavation Plan

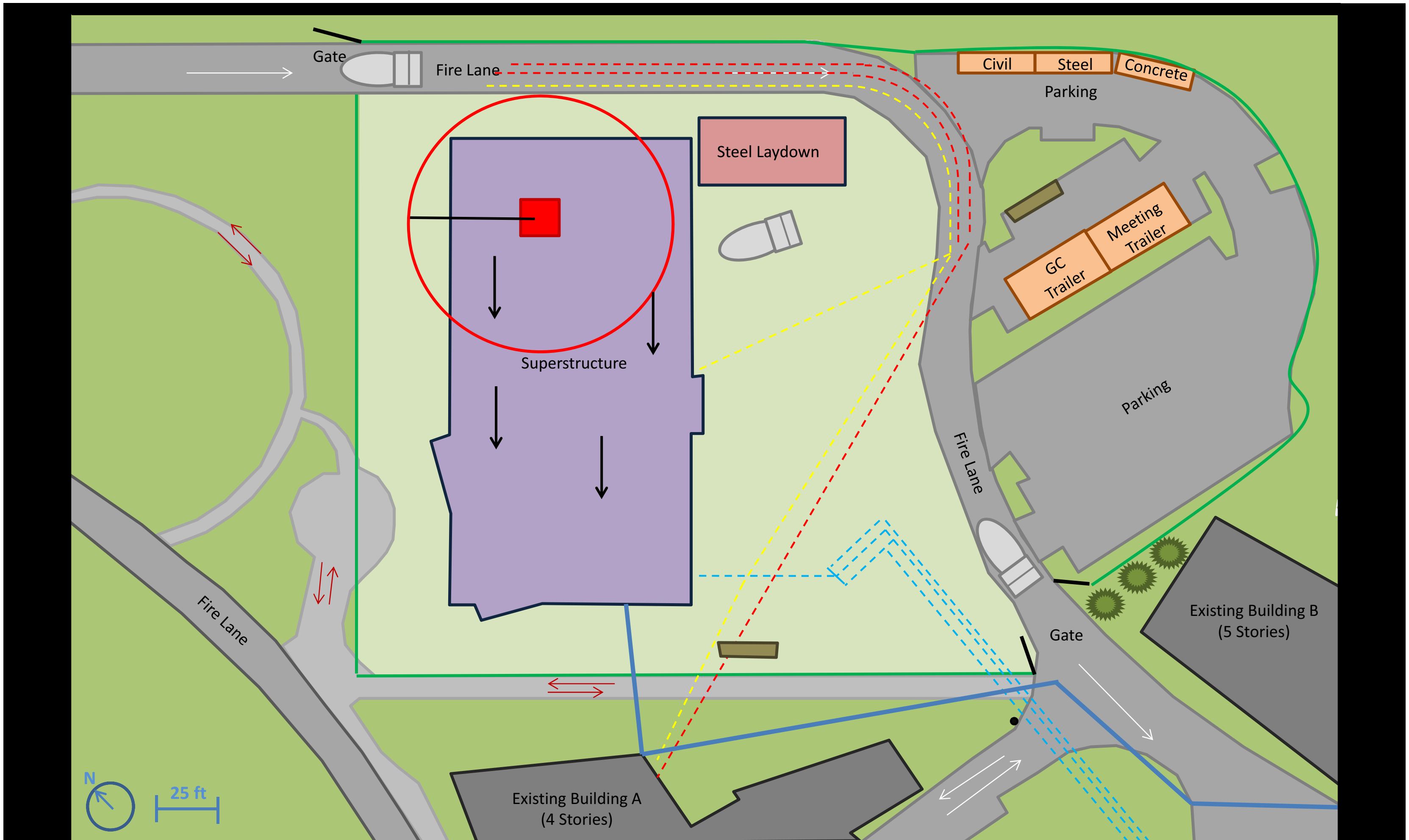
Research Facility Core and Shell

September 21, 2012

Timothy Maffett

LEGEND

- Soil
- Temporary Facility
- Existing Building
- Portable Toilet
- Boundaries of Site
- Site Fence
- Fire Hydrant
- High Voltage Line
- Low Voltage Line
- Gas Line
- Water Line
- Vehicle Traffic
- Pedestrian Traffic
- Dump Truck
- Excavator



Superstructure Logistics Plan

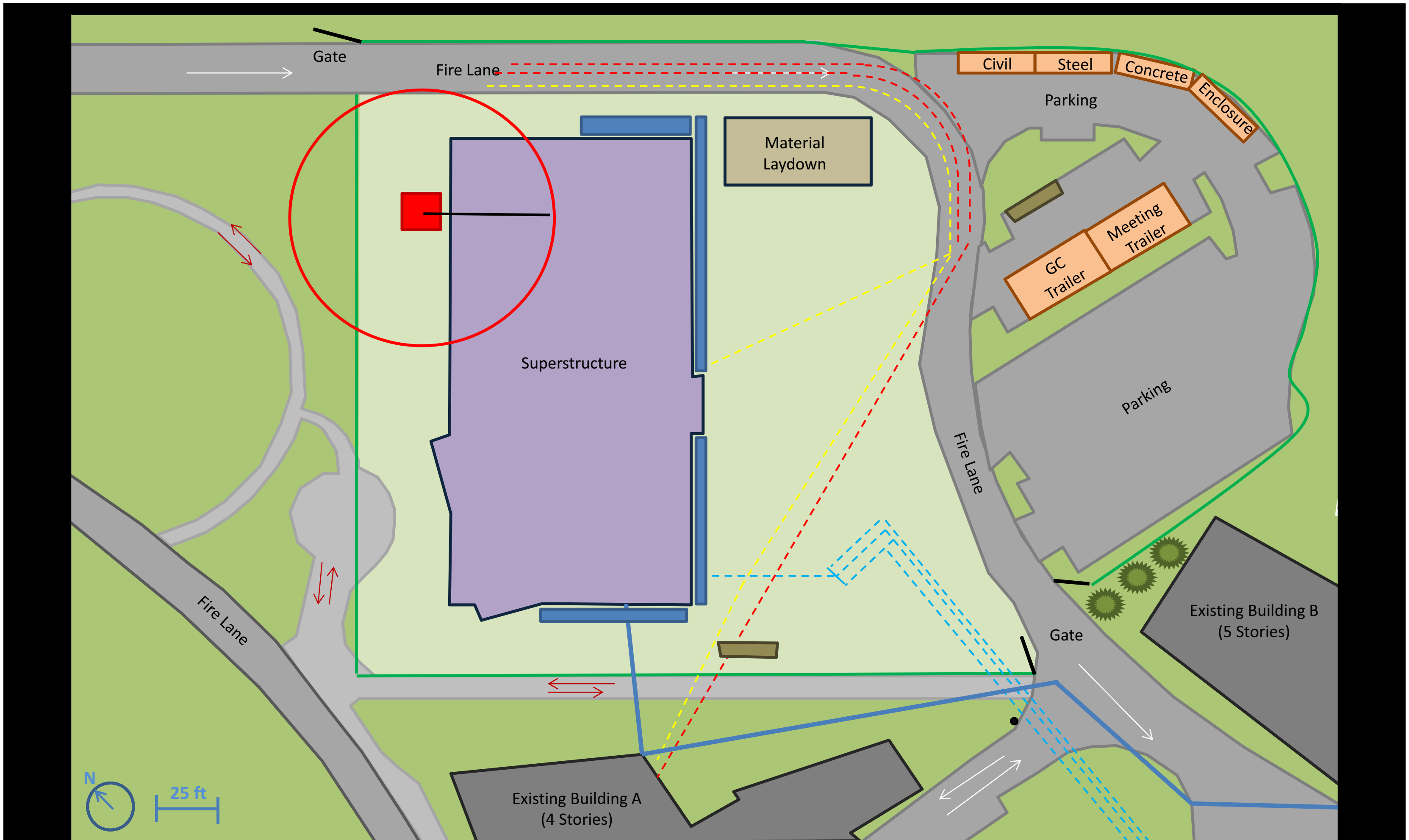
Research Facility Core and Shell

September 21, 2012

Timothy Maffett

LEGEND

- Superstructure
- Temporary Facility
- Existing Building
- Portable Toilet
- Boundaries of Site
- Site Fence
- Fire Hydrant
- Steel Laydown
- High Voltage Line
- Low Voltage Line
- Gas Line
- Water Line
- Vehicle Traffic
- Pedestrian Traffic
- Crane
- Concrete Truck



Building Enclosure Plan

Research Facility Core and Shell

September 21, 2012

Timothy Maffett

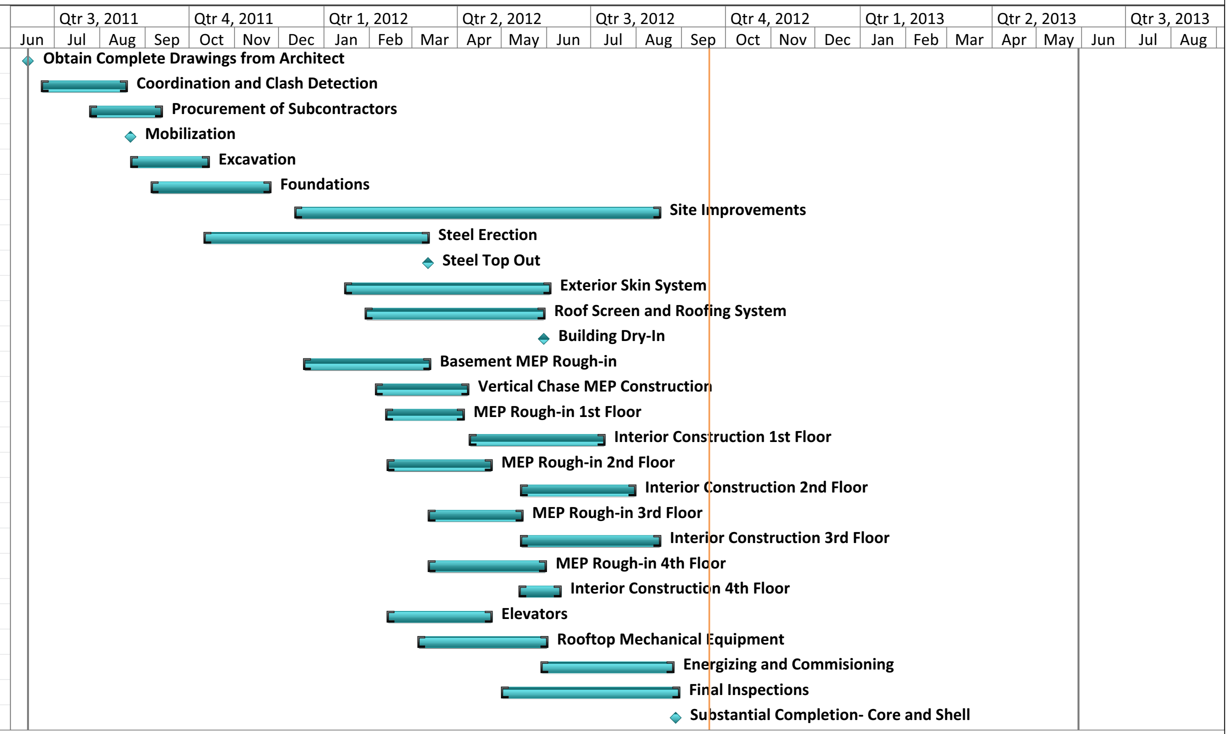
LEGEND

Superstructure
Temporary Facility
Existing Building
Portable Toilet
Boundaries of Site
Site Fence
Fire Hydrant
Material Laydown
High Voltage Line
Low Voltage Line
Gas Line
Water Line
Vehicle Traffic
Pedestrian Traffic
Crane
Scaffolding

Appendix C: Overall Project Schedule

Research Facility Core and Shell Schedule | Timothy Maffett | September 21st, 2012

ID	Task Name	Duration	Start	Finish
1	Obtain Complete Drawings from Architect	0 days	Mon 6/13/11	Mon 6/13/11
2	Coordination and Clash Detection	43 days	Wed 6/22/11	Fri 8/19/11
3	Procurement of Subcontractors	36 days	Mon 7/25/11	Mon 9/12/11
4	Mobilization	0 days	Mon 8/22/11	Mon 8/22/11
5	Excavation	40 days	Mon 8/22/11	Fri 10/14/11
6	Foundations	60 days	Mon 9/5/11	Fri 11/25/11
7	Site Improvements	180 days	Mon 12/12/11	Fri 8/17/12
8	Steel Erection	110 days	Tue 10/11/11	Mon 3/12/12
9	Steel Top Out	0 days	Mon 3/12/12	Mon 3/12/12
10	Exterior Skin System	102 days	Sun 1/15/12	Sun 6/3/12
11	Roof Screen and Roofing System	89 days	Sun 1/29/12	Wed 5/30/12
12	Building Dry-In	0 days	Wed 5/30/12	Wed 5/30/12
13	Basement MEP Rough-in	63 days	Sun 12/18/11	Tue 3/13/12
14	Vertical Chase MEP Construction	47 days	Sun 2/5/12	Sun 4/8/12
15	MEP Rough-in 1st Floor	40 days	Sun 2/12/12	Thu 4/5/12
16	Interior Construction 1st Floor	67 days	Mon 4/9/12	Tue 7/10/12
17	MEP Rough-in 2nd Floor	52 days	Mon 2/13/12	Tue 4/24/12
18	Interior Construction 2nd Floor	57 days	Mon 5/14/12	Tue 7/31/12
19	MEP Rough-in 3rd Floor	47 days	Mon 3/12/12	Tue 5/15/12
20	Interior Construction 3rd Floor	70 days	Mon 5/14/12	Fri 8/17/12
21	MEP Rough-in 4th Floor	59 days	Mon 3/12/12	Thu 5/31/12
22	Interior Construction 4th Floor	22 days	Sun 5/13/12	Sun 6/10/12
23	Elevators	52 days	Mon 2/13/12	Tue 4/24/12
24	Rooftop Mechanical Equipment	65 days	Mon 3/5/12	Fri 6/1/12
25	Energizing and Commisioning	66 days	Mon 5/28/12	Sun 8/26/12
26	Final Inspections	88 days	Tue 5/1/12	Thu 8/30/12
27	Substantial Completion- Core and Shell	0 days	Tue 8/28/12	Tue 8/28/12



Project: Project Schedule Summa
Date: Thu 9/20/12

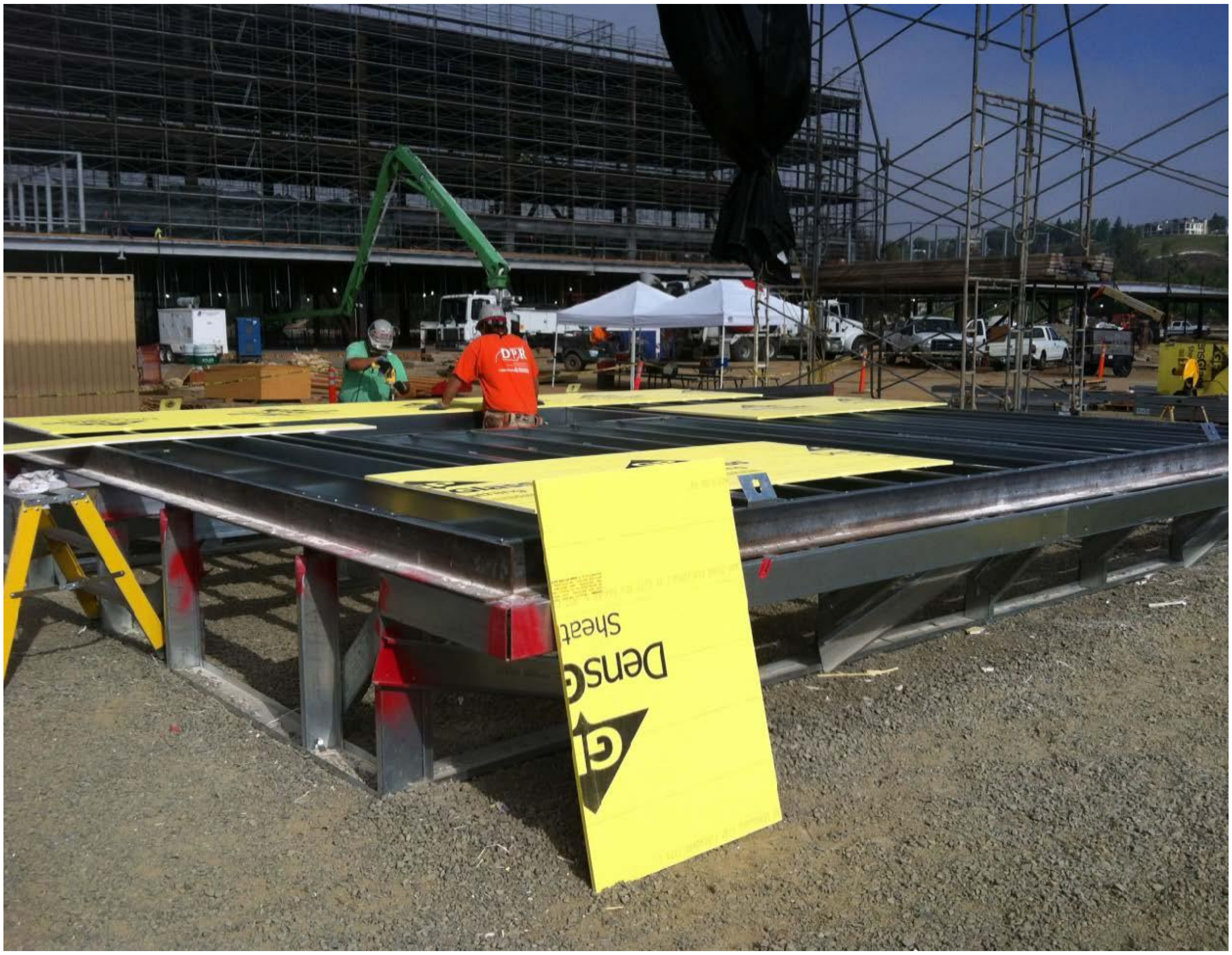
Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

Appendix D: Case Study- Hospital in Temecula Valley, Ca.

To give a better understanding of the "On-Site Partial Panel Prefabrication", the following images demonstrate some of the main steps of the construction process that occurred at the Temecula Valley hospital project. The text accompanying each picture describes what is taking place.

"This is the tent that the panels were built at. Behind the tent construction is the staging area where the panels were stored."

"This is closer view of the tent where the panels were built. Workers would build the modules here and then move them to the staging area located in the background of the picture."



"These workers are building the panels at ground level. The metal "bench" allows the panels to be built at waist height creating a safe and productive work environment."

"Depicted here is the staging area where the panels were stored. They were covered with tarp that was held down by sand bags to protect the panels from the weather. Fortunately, the California climate is tame in comparison to other areas of the United States allowing for a basic protection system."

Appendix E: Partial Prefabricated Panel Estimate

Costs (PANELS) Taken From GMP and Previous Panel Projects

Description	Quantity	Unit	Unit Cost	Total Cost
Scaffolding				
Scaffolding Subcontractor	1	ls	$ 41,300.00	$ 41,300
Scaffolding Bridge	1	ls	$ 2,500.00	$ 2,500
Toe Boards at all levels	1	ls	$ 4,000.00	$ 4,000
Relocate Scaffolding at Lift	1	ls	$ 5,000.00	$ 5,000
Add'l Three Months Rent	1	ls	$ 7,000.00	$ 7,000
Subtotal				**$ 59,800**
Stone				
Exterior Stone Subcontractor	1	ls	$ 237,580.00	$ 237,580
Site Stone Allowance	1	ls	$ 16,000.00	$ 16,000
Patch Stone at Scaffolding	1	ls	$ 5,000.00	$ 5,000
Layout Embeds	1	ls	$ 3,000.00	$ 3,000
Balcony Floor Stone Allowance	1	ls	$ 9,000.00	$ 9,000
Dumpsters and Trash Haul	1	ls	$ 2,500.00	$ 2,500
Exterior Stone Mock-up	1	ls	$ 5,000.00	$ 5,000
Subtotal				**$ 278,080**
Framing and Sheathing				
Engineering	1	LS	$ 19,000.00	$ 19,000.00
Exterior Framing Mock-up	1	LS	$ 15,000.00	$ 15,000.00
Crane Rental	1	LS	$ 35,000.00	$ 35,000.00
Onsite Panel Shop	1	LS	$ 5,000.00	$ 5,000.00
Build Panels	26943	SF	$ 6.95	$ 187,253.85
Install Panels	26943	SF	$ 1.35	$ 36,373.05
Complete screwoff of panels	26943	SF	$ 2.15	$ 57,927.45
Patch in Densglass sheathing form pick points	26943	SF	$ 0.40	$ 10,777.20
Sheath backside of parapets	1300	SF	$ 2.15	$ 2,795.00
Deduct of scaffold time usage (-3 weeks rent)	1	LS	$ (7,000.00)	$ (7,000.00)
Schedule savings general conditions cost (-3 weeks)	3	weeks	$ (10,700.00)	$ (32,100.00)
Subtotal				**$ 330,027**
Thermal Insulation				
Themal Insulation Subcontractor	1	ls	$ 58,743.00	$ 58,743
Subtotal				**$ 58,743**
Fire Safing				
Fire Safing Subcontractor	1	ls	$ 20,000.00	$ 20,000
Top of Wall Fire Safing	1	ls	$ 9,000.00	$ 9,000
Fire Stop Penetrations	1	ls	$ 5,000.00	$ 5,000
Perimeter Angle Stop	1	ls	$ 7,500.00	$ 7,500
Subtotal				**$ 41,500**
Preformed Metal Paneling				
Metal Panels Subcontractor	1	ls	$ 154,537.00	$ 154,537
Mock-up Design and Construction	1	ls	$ 16,609.00	$ 16,609
Design Development Due to Mock-up	1	ls	$ 10,000.00	$ 10,000
Subtotal				**$ 181,146**

Metal Flashing						
Roof Screen Subcontractor	1	ls	$	130,031.00	$	130,031
Subtotal					**$**	**130,031**
Sealants						
Exterior Sealants	69000	SF	$	0.45	$	31,050
Subtotal					**$**	**31,050**
Hollow Metal Doors/Frames/Hardware						
Card Access Accommodations	8	ea	$	133.63	$	1,069
6'0" x 8'0" Pair	2	pr	$	500.00	$	1,000
8'0" x 8'0" Pair	2	pr	$	500.00	$	1,000
8'0" x 9'0" Pair	1	pr	$	500.00	$	500
8'0" x 7'10" Pair	1	pr	$	500.00	$	500
3'0" x 7'0" to 8'0" Single	2	ea	$	450.00	$	900
Subtotal					**$**	**4,969**
Wall Louvers						
Wall Louvers	200	SF	$	14.86	$	2,972
Subtotal					**$**	**2,972**
Overhead Coiling Doors						
Overhead Coiling Door, 10'x10'	2	ea		$ 21,000.00		$ 42,000
Subtotal						**$ 42,000**
Lath and Plaster						
Lath and Plaster Sub	1	ls	$	273,485.00	$	273,485
Framing Engr Modifications	1	ls	$	5,000.00	$	5,000
Freveal Design Development	1	ls	$	7,000.00	$	7,000
Plaster Patch at Scaffolding	1	ls	$	4,500.00	$	4,500
Mold Insurance	1	ls	$	820.00	$	820
Plaster Adds	1	ls	$	31,770.00	$	31,770
Plaster Mock-up	1	ls	$	5,196.00	$	5,196
Subtotal						**$ 327,771**
Painting						
Paint Doors and Frames	18	leaf	$	78.78	$	1,418
Exterior Painting Allowance	1	ls	$	7,500.00	$	7,500
Misc. Exterior Garage Painting	1	ls	$	5,000.00	$	5,000
Subtotal					**$**	**13,918**
				Avg. Cost/SF		**Total Cost**
Grand Total			**$**	**55.75**	**$**	**1,502,007**

Appendix F: Detailed Partial Panel Prefabrication Schedule and Estimate

Detailed Panel Prefabrication Schedule and Material Estimate

Prefabricating 33' x 10' Panels on Ground

Task	Quantity (Feet of Metal Stud)	Quantity (Feet of Track)	Quantity (SF of Sheating)	Duration (Minutes)
Build Outer Framing	32	66	-	30
Install Full Length Studs	128	-	-	30
Frame Window Opening 1	35	-	-	20
Frame Window Opening 2	35	-	-	20
Frame Window Opening 3	35	-	-	20
Install Small Studs Supporting Window Framing	80	-	-	40
Sheath Panel	-	-	303	50
Move to Staging Area	-	-	-	20
Subtotal	345	66	303	230
(28) Panels- Total:	**9660**	**1848**	**8484**	**6440**

Prefabricating 22' x 10' Panels on Ground

Task	Quantity (Feet of Metal Stud)	Quantity (Feet of Track)	Quantity (SF of Sheating)	Duration (Minutes)
Build Outer Framing	32	44	-	30
Install Full Length Studs	80	-	-	30
Frame Window Opening 1	35	-	-	20
Frame Window Opening 2	35	-	-	20
Install Small Studs Supporting Window Framing	54	-	-	35
Sheath Panel	-	-	202	40
Move to Staging Area	-	-	-	20
Subtotal	236	44	202	195
(21) Panels- Total:	**4956**	**924**	**4242**	**4095**

Prefabricating 11' x 10' Panels on Ground

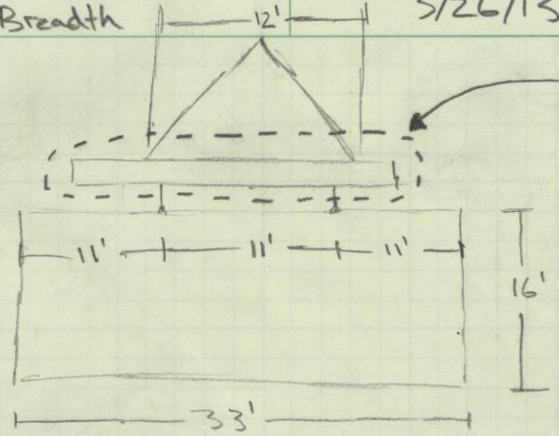
Task	Quantity (Feet of Metal Stud)	Quantity (Feet of Track)	Quantity (SF of Sheating)	Duration (Minutes)
Build Outer Framing	32	22	-	30
Install Full Length Studs	32	-	-	20
Frame Window Opening 1	35	-	-	20
Install Small Studs Supporting Window Framing	27	-	-	30
Sheath Panel	-	-	101	30
Move to Staging Area	-	-	-	20
Subtotal	126	22	101	150
(3) Panels- Total:	**378**	**66**	**303**	**450**

Grand Total	Quantity (Feet of Metal Stud)	Quantity (Feet of Track)	Quantity (SF of Sheating)	Duration (Minutes)
	14,994	**2,838**	**13,029**	**10,985**

Appendix G: Structural Breadth Calculations

TFM | Structural Breadth | 3/26/13 | pg 1 of 3

Sizing the Beam Necessary to Erect Panels.



Panel Self Weight

Metal stud Framing: 411 ft of 16 Gage Metal studs / Panel

16 gage metal studs: 2 lb/lf

411' x 2 lb/lf = 822 lb

Dens Glass Sheathing: 303 SF of Sheathing / Panel

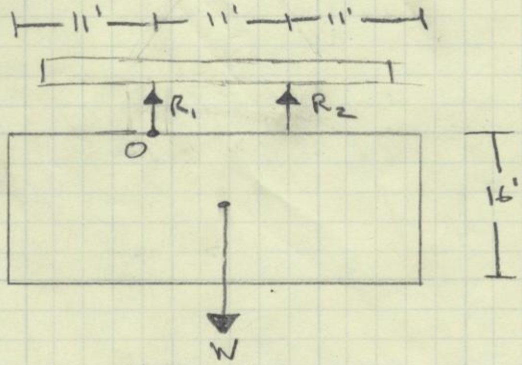
Dens Glass weigh/sf = 2.5 lb/SF

303 SF x 2.5 lb/SF = 758 lb

Total Weight Panel = 822 lb + 758 lb = **1580 lb**

TFM Structural Breadth | 3/26/13 | pg 2 of 3

Free Body Diagram of System



$\Sigma F_y = R_1 + R_2 - W = 0$; $W = 1580$ lb (Panel Self Weight)

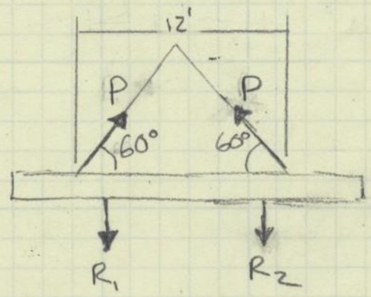
$\Sigma M_o = -[5.5'(W)] + [11(R_2)] = 0$

$11R_2 = 8690$ lb

$R_2 = 790$ lb ; $R_1 = 1580 - 790$

$R_1 = 790$ lb

Free Body Diagram of Erection Beam



$R_1 = R_2 = 790$ lb

$\Sigma F_y = 2[P\sin 60°] - 2(790) = 0$; $P = 913$ lb

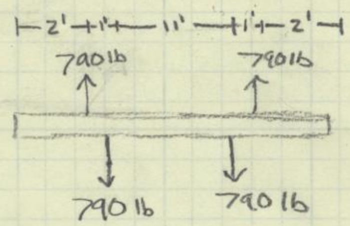
$P_y = 790$ lb

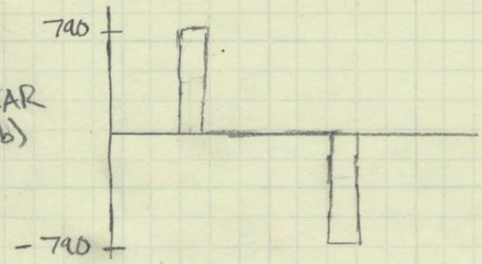
$P_x = 457$ lb

FM | Structural Breadth | 3/26/13 | pg 3 of 3

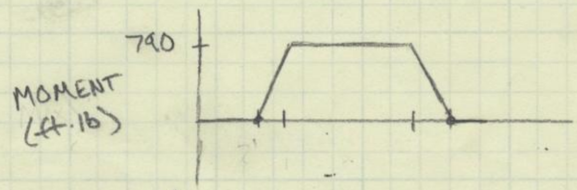
Shear Diagram

Y-axis:





Moment Diagram



Erection Beam Sizing

Max Shear: 790 lb or .790 kip

Max Moment: 790 ft·lb or .790 kip·ft

Reference AISC Steel Construction Manual Fourteenth Edition

Smallest Beam in Manual:

ASD: W 8X10 → Max Allowable Shear 26.8 kips
Max Allowable Moment 21.9 kip·ft

26.8 >> .790 kip
21.9 >> .790 kip·ft

Design erection beam for Max Shear of .790 kip & Max Moment of .790 kip·ft

★ Smallest beam in Steel Manual (W8X10) is more than sufficient to handle the loads.

F_y = 50 ksi

Table 3-2 (continued)
W-Shapes
Selection by Z_x

Z_x

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.³	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.⁴	ASD	LRFD
W12×16	**20.1**	**50.1**	**75.4**	**29.9**	**44.9**	**3.80**	**5.73**	**2.73**	**8.05**	**103**	**52.8**	**79.2**
W10×17	18.7	46.7	70.1	28.3	42.5	2.98	4.47	2.98	9.16	81.9	48.5	72.7
W12×14[v]	**17.4**	**43.4**	**65.3**	**26.0**	**39.1**	**3.43**	**5.17**	**2.66**	**7.73**	**88.6**	**42.8**	**64.3**
W8×18	17.0	42.4	63.8	26.5	39.9	1.74	2.61	4.34	13.5	61.9	37.4	56.2
W10×15	16.0	39.9	60.0	24.1	36.2	2.75	4.14	2.86	8.61	68.9	46.0	68.9
W8×15	13.6	33.9	51.0	20.6	31.0	1.90	2.85	3.09	10.1	48.0	39.7	59.6
W10×12[f]	**12.6**	**31.2**	**46.9**	**19.0**	**28.6**	**2.36**	**3.53**	**2.87**	**8.05**	**53.8**	**37.5**	**56.3**
W8×13	11.4	28.4	42.8	17.3	26.0	1.76	2.67	2.98	9.27	39.6	36.8	55.1
W8×10[f]	**8.87**	**21.9**	**32.9**	**13.6**	**20.5**	**1.54**	**2.30**	**3.14**	**8.52**	**30.8**	**26.8**	**40.2**

ASD	LRFD
$\Omega_b = 1.67$	$\phi_b = 0.90$
$\Omega_v = 1.50$	$\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.
[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with $F_y = 50$ ksi; therefore, $\phi_v = 0.90$ and $\Omega_v = 1.67$.

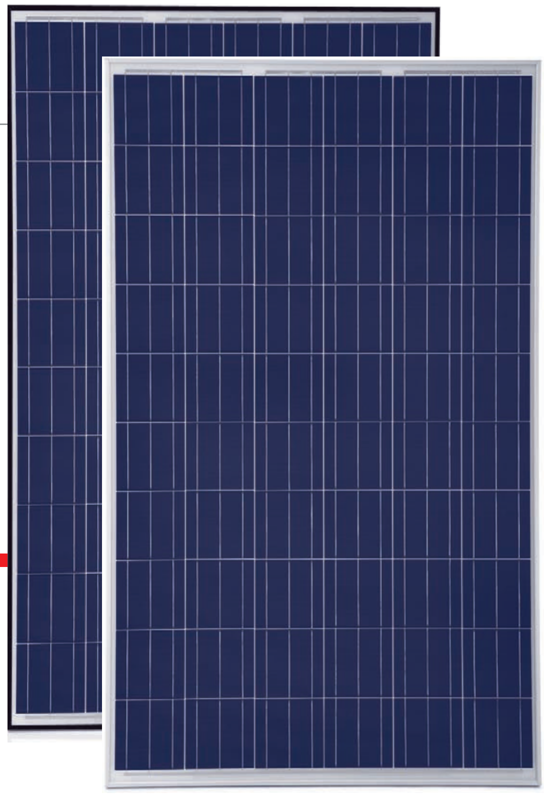
AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Appendix H: Solar Module, Inverter, and Ballast Racking Specifications

Mono Multi Solutions

TSM-PC05
TSM-PA05

THE UNIVERSAL SOLUTION



15.3%
MAX EFFICIENCY

250W
MAX POWER OUTPUT

10 YEAR
PRODUCT WARRANTY

25 YEAR
LINEAR POWER WARRANTY

Module can bear snow loads up to **5400Pa** and wind loads up to **2400Pa**

Guaranteed power output
0~+3%

High performance under low light conditions
Cloudy days, mornings and evenings

Manufactured according to International Quality and Environment Management System Standards
ISO9001, ISO14001

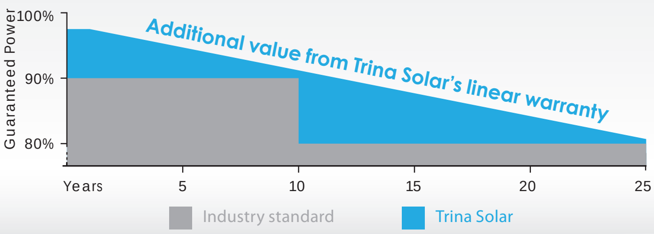
MC4 photovoltaic connectors increase system reliability

Founded in 1997, Trina Solar (NYSE: TSL) has established itself as a leader in the solar community with its vertically integrated business model. Our modules and system solutions provide clean solar power in on-grid and off-grid residential, commercial, industrial and utility-scale systems.

With more than 22 offices worldwide, Trina Solar has partnerships with leading installers, distributors, utilities and developers in all major PV markets. Trina Solar is committed to driving smarter energy choices.

LINEAR PERFORMANCE WARRANTY

10 Year Product Warranty • 25 Year Linear Power Warranty



Trina Solar Limited
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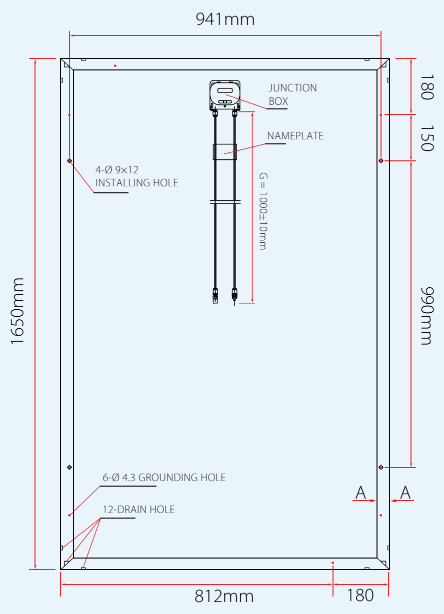
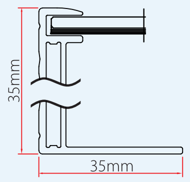
Trinasolar
Smart Energy Together

TSM-PC05 / TSM-PA05 THE UNIVERSAL SOLUTION

DIMENSIONS OF PV MODULE TSM-PC/PA05

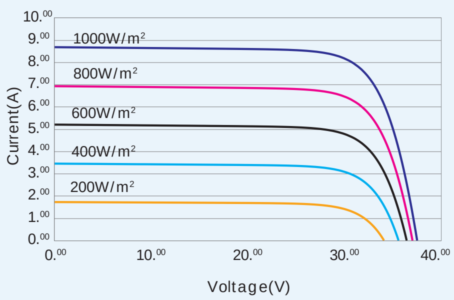


Back View



A-A

I-V CURVES OF PV MODULE TSM-245 PC/PA05



Average efficiency reduction of 4.5% at 200W/m² according to EN 60904-1.

CERTIFICATION

ELECTRICAL DATA @ STC	TSM-235 PC/PA05	TSM-240 PC/PA05	TSM-245 PC/PA05	TSM-250 PC/PA05
Peak Power Watts-P_{MAX} (Wp)	235	240	245	250
Power Output Tolerance-P_{MAX} (%)	0/+3	0/+3	0/+3	0/+3
Maximum Power Voltage-V_{MP} (V)	29.3	29.7	30.2	30.3
Maximum Power Current-I_{MPP} (A)	8.03	8.10	8.13	8.27
Open Circuit Voltage-V_{OC} (V)	37.2	37.3	37.5	37.6
Short Circuit Current-I_{SC} (A)	8.55	8.62	8.68	8.85
Module Efficiency η_m (%)	14.4	14.7	15.0	15.3

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C).
Power measurement tolerance: ±3%

ELECTRICAL DATA @ NOCT	TSM-235 PC/PA05	TSM-240 PC/PA05	TSM-245 PC/PA05	TSM-250 PC/PA05
Maximum Power-P_{MAX} (Wp)	171	174	178	181
Maximum Power Voltage-V_{MP} (V)	26.4	26.6	26.8	27.0
Maximum Power Current-I_{MPP} (A)	6.48	6.55	6.64	6.70
Open Circuit Voltage (V)-V_{OC} (V)	34.0	34.1	34.2	34.3
Short Circuit Current (A)-I_{SC} (A)	6.97	7.04	7.10	7.25

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.
Power measurement tolerance: ±3%

MECHANICAL DATA	
Solar cells	Multicrystalline 156 × 156mm (6 inches)
Cell orientation	60 cells (6 × 10)
Module dimensions	1650 × 992 × 35mm (64.95 × 39.05 × 1.37 inches)
Weight	18.6kg (41.0 lb)
Glass	High transparency solar glass 3.2mm (0.13 inches)
Frame	Anodized aluminium alloy
J-Box	IP 65 rated
Cables	Photovoltaic Technology cable 4.0mm² (0.006 inches²), 1000mm (39.4 inches)
Connector	Original MC4 Multi-Contact MC STÄUBLI GROUP

TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	45°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.43%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.047%/°C

MAXIMUM RATINGS	
Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC(IEC)/ 600V DC(UL)
Max Series Fuse Rating	15A

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 29 pieces

Modules per 40' container: 812 pieces

TSM_US_Nov_2012

Trinasolar
Smart Energy Together

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Sunny Tower

The Flexible Solution for Commercial PV Systems

The Sunny Tower

The Latest Innovation from SMA

SMA brings you the best in commercial inverter solutions: The Sunny Tower. Designed with the installer in mind; we've combined ease of installation, the lowest specific cost ($/Watt), and highest efficiency to maximize rebates and power production while minimizing your pay-back period. The Sunny Tower combines all the advantages of string inverters with the installation advantages of central in-verters. The Sunny Tower offers you the flexibility and the reliability you've come to expect from SMA.

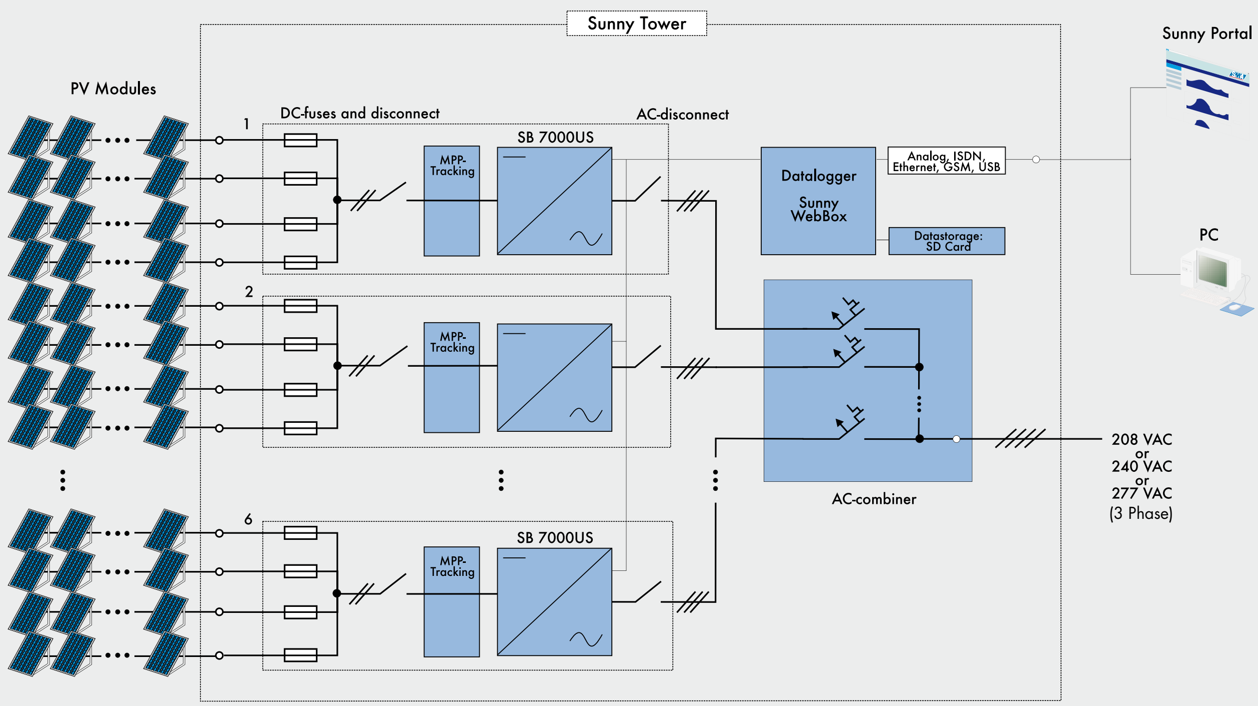
» **The Sunny Tower is available in several configurations designed to match your project requirements.**

96% Efficiency

Maximum Rebate – Maximum Energy Production

The Sunny Boy 7000US is the most efficient inverter in its class. The 96% CEC weighted efficiency maximizes your rebate value. The high efficiency also means maximized energy production. Get the most from your PV incentive program whether it is based on installed capacity or energy production (PBI), the 96% weighted efficiency maximizes the benefit while minimizing your investment payback time.

The Sunny Tower: The concept that offers maximum value. 96% efficiency means higher energy production and the shortest payback period.



Quick and Easy Installation

Time is money. The easiest way to reduce installation cost is to minimize your installation time. The modular design of the Sunny Tower offers a powerful installation advantage, indoors or out. Each component of the Sunny Tower can be transported without the use of heavy equipment. Mount the Sunny Tower rack on a firm foundation, hang each Sunny Boy 7000 or Sunny Boy 6000 inverter on the rack and connect your AC and DC wiring. All internal wiring is done at the factory to minimize your on-site installation time. It's that simple!

All the Benefits of String Inverters

Sunny Boy string inverters combine individual PV maximum-power-point tracking and inverter redundancy to harvest the maximum energy from the PV array. Mixed module configuration, orientation and technology are no problem for the Sunny Tower. Combine your PV panels in any manner necessary to best utilize available roof-space. Each Sunny Boy individually controls each sub-array to maximize energy collection from the entire array. If one portion of the PV system is disabled, the majority of the system continues to operate unaffected. The Sunny Boy string inverter concept ensures the best possible performance and flexibility of your PV system.

Maximize Your PV System Availability

The multiple string inverter design provides system redundancy should a problem develop with a portion of the PV system. The majority of the system continues to operate unaffected. The system is designed to be serviceable easily and on-site when convenient without worrying about a major loss of PV energy production. Each inverter of the Sunny Tower is replaceable, keeping service and maintenence costs to a minimum.

Everything You Need – Just Add PV

The Sunny Tower integrates the newest Sunny Boy string inverter technology into a single commercial package. Install 6 of the Sunny Boy 7000 Watt or 6000 Watt inverters on the Sunny Tower rack for a combined 42 kW or 36 kW. Use multiple Sunny Towers for larger projects. Simply run your AC and DC wiring to the Sunny Tower and you're finished! All PV DC wiring is landed in a convenient, fuse protected wiring compartment. The Sunny Tower includes an integrated lockable AC/DC disconnect switch for each Sunny Boy pre-wired at the factory. Individual AC breakers protect each Sunny Boy. AC wiring from each Sunny Boy is pre-wired into one AC interconnection terminal block in the wiring compartment. What could be easier?

Sunny WebBox

System Monitoring Made Simple

Information is key. The integrated Sunny WebBox is the most advanced communication gateway in the PV industry and it is included with the Sunny Tower. Simply connect the Sunny WebBox to a network or the internet and you can monitor your PV system from any web browser, anywhere in the world. Data is automatically compiled by the Sunny Portal (www.SunnyPortal.com) which automatically notifies you of system performance and faults. Intelligent monitoring; what more could you ask for from your PV system?

The Sunny Tower
Specifically Designed for Today's Market

PV system owners not only want environmentally responsible technology, but also a lucrative investment. The Sunny Tower offers maximized rebates, tax incentives and energy generation. High efficiency combined with the lowest installation cost result in maximum power production and the shortest payback period. Expect only the best of all possibilities from SMA.

Advantages Overview

Improved Energy Production

- Lowest specific price ($/W)
- High efficiency: 96% (CEC weighted efficiency)
- Increased production from multiple MPP trackers
- Multiple PV array power tracking
- Optimum operation under partial load
- Highly flexible, modular design
- OptiCool patented temperature management
- Appealing system design

Cost-Effective Installation

- Standard production inverters
- Fast delivery
- Delivered as a turnkey assembly
- Pre-wired from the factory
- Integrated cabling
- Integrated balance-of-system components
- Integrated data acquisition with Sunny WebBox
- Internet ready
- Service-friendly design
- Minimized service and maintenance costs

Technical Summary

	SB 6000US	SB 7000US	ST 36	ST 42
Output				
AC Maximum Output Power	6000 W	7000 W	36 kW	42 kW
AC Output Voltage (3-Phase)	208 V nominal (183 – 229 V) 240 V nominal (211 – 264 V) 277 V nominal (244 – 305 V)	208 V nominal (183 – 229 V) 240 V nominal (211 – 264 V) 277 V nominal (244 – 305 V)	208 V nominal (183 – 229 V) 240 V nominal (211 – 264 V) 277 V nominal (244 – 305 V)	208 V nominal (183 – 229 V) 240 V nominal (211 – 264 V) 277 V nominal (244 – 305 V)
AC Output Frequency	60 Hz nominal (59.3 – 60.5 Hz)	60 Hz nominal (59.3 – 60.5 Hz)	60 Hz nominal (59.3 – 60.5 Hz)	60 Hz nominal (59.3 – 60.5 Hz)
AC Maximum Output Current	29 A @ 208 V 25 A @ 240 V 22 A @ 277 V	34 A @ 208 V 29 A @ 240 V 25 A @ 277 V	100 A per phase @ 208 V 87 A per phase @ 240 V 44 A per phase @ 277 V	117 A per phase @ 208 V 101 A per phase @ 240 V 51 A per phase @ 277 V
Input				
DC Input Voltage Range	250 – 600 V	250 – 600 V	250 – 600 V	250 – 600 V
Peak Power Tracking Voltage	250 – 480 V	250 – 480 V	250 – 480 V	250 – 480 V
DC Maximum Current	25 A	30 A	6 x 25 A	6 x 30 A
Efficiency				
Peak Inverter Efficiency	97.0%	97.1%	97.0%	97.1%
CEC Weighted Efficiency	95.5% @ 208 V_{AC} 95.5% @ 240 V_{AC} 96.0% @ 277 V_{AC}	95.5% @ 208 V_{AC} 96.0% @ 240 V_{AC} 96.0% @ 277 V_{AC}	95.5% @ 208 V_{AC} 95.5% @ 240 V_{AC} 96.0% @ 277 V_{AC}	95.5% @ 208 V_{AC} 96.0% @ 240 V_{AC} 96.0% @ 277 V_{AC}
Mechanical Data				
Weight	143 lbs.	143 lbs.	approx. 1129 lbs.	approx. 1129 lbs.
Enclosure Type	NEMA 3R	NEMA 3R	NEMA 3R	NEMA 3R
Ambient Temperature	–13 °F to +113 °F	–13 °F to +113 °F	–13 °F to +113 °F	–13 °F to +113 °F

www.SMA-America.com
Phone 916 625 0870
Toll Free 888 4 SMA USA

SMA America, Inc.

Trinamount III

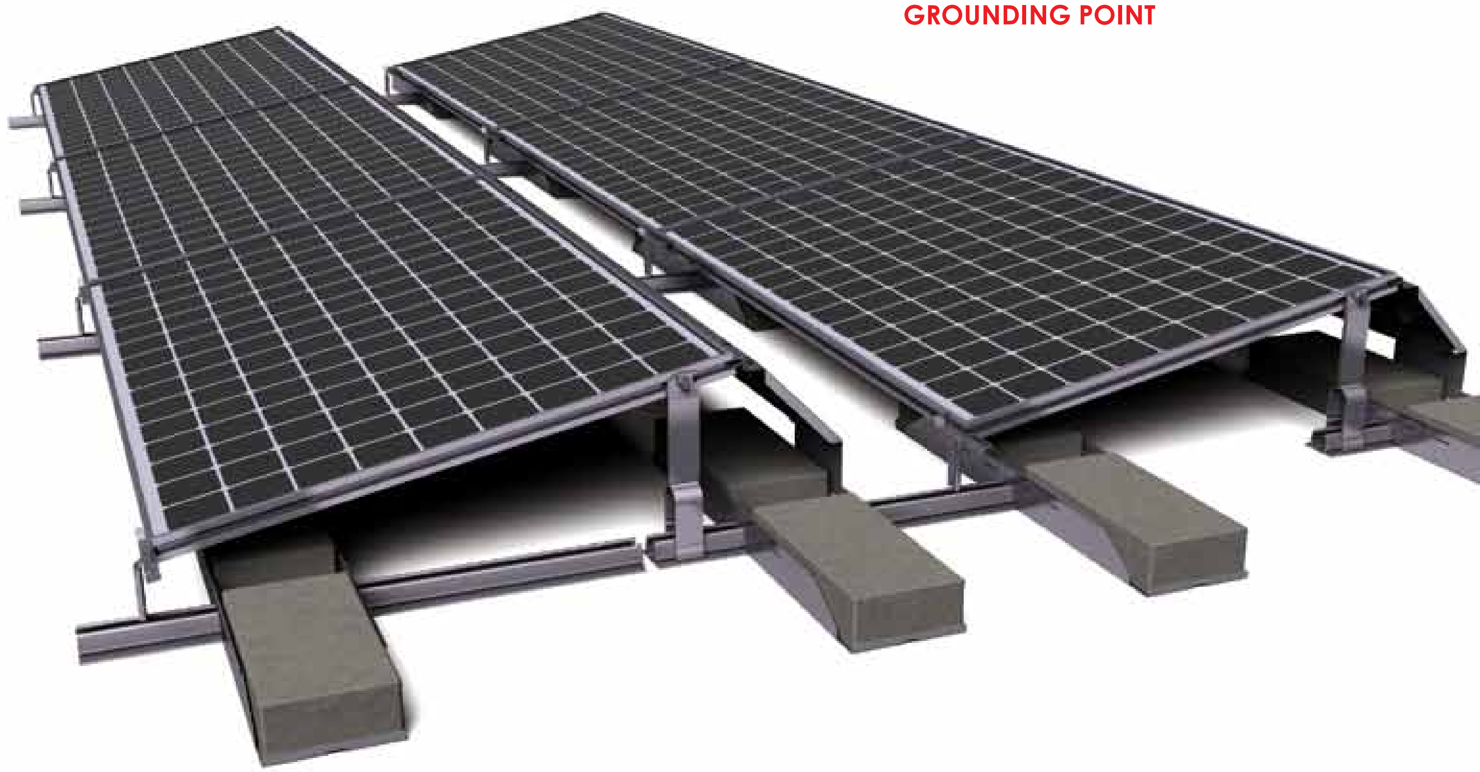
by Trinasolar

FOR FLAT ROOF

10 YEAR
PRODUCT WARRANTY FOR MODULE AND MOUNTING SYSTEM

11 DEGREES
FIXED TILT ANGLE

SIMPLIFIED GROUNDING
UP TO 72 MODULES WITH ONE GROUNDING POINT



TRINAMOUNT III OF TRINA SOLAR OFFERS THE FASTEST AND LEAST EXPENSIVE WAY TO MOUNT PV ARRAYS ON FLAT ROOFS.

With a series of drop-in and quarter turn connections, Trinamount III greatly accelerates the process of commercial rooftop installation. Trinamount III eliminates the need for mounting rails, requires very few parts, and simultaneously accomplishes structural and grounding connections. With far less complexity than conventional systems, Trinamount III delivers both labor and logistics savings for commercial PV projects.

Trinasolar
The power behind the panel

ZEP COMPATIBLE

Trinamount III FOR FLAT ROOF TSM-PC05.18

Tool-free installation through drop in mounting solution

Low parts and SKU count in comparison to conventional mounting solutions

Long rail elimination **reduces** inventory and freight **cost**

Theft resistant with **auto grounding** hardware

Compact packaging with module and mounting hardware delivered together

ORDERING INFORMATION

Part Number	Description	Type
720074	11° Row Connector	H
720076	Ballast Pan	H
720077	11° Front Leg	H
720078	11° Rear Leg	H
720079	11° Wind Diffuser	H
720080	11° Diffuser Support	H
720070	Ground Lug	H
720071	Wire Clip	H
720081	Trinamount Tool	A
720190	TM III removal kit	A

H = Basic hardware A = Accessories (sold separately)

Trinamount I
For tile roof

Trinamount II
For pitched roof

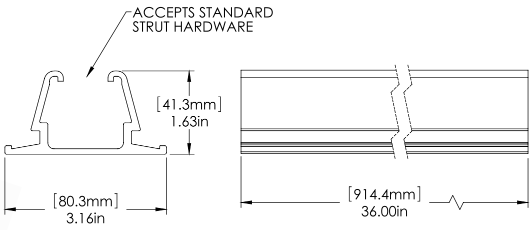
Trinamount III
For flat roof

TRINA MODULE + MOUNTING SYSTEM HARDWARE

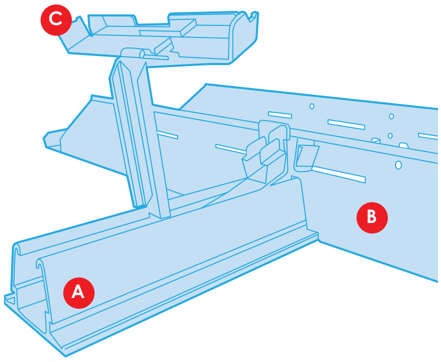
TRINAMOUNT SYSTEM

BASIC HARDWARE

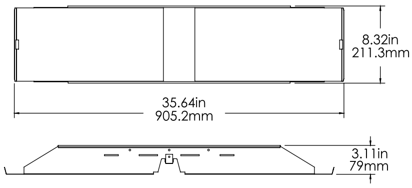
A Row Connector



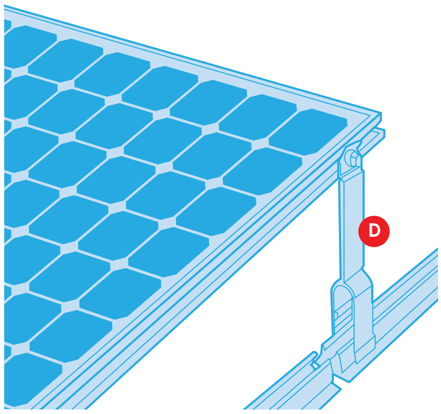
The row connector provides a point of attachment for the Front and Rear Legs and creates a rigid connection beween rows. The profile of the Row Connector accepts standard strut nuts for attaching standard strut or brackets for applications that require bracing for seismic and high wind applications.



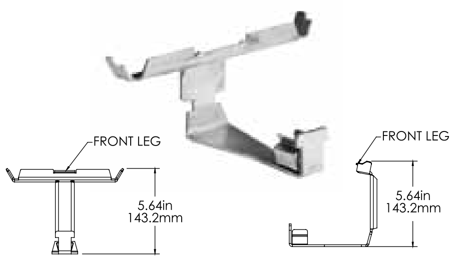
B Ballast Pan



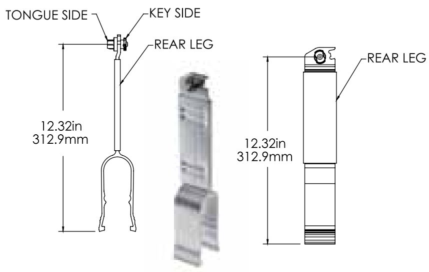
The Ballast Pan installs, by hand, over the Row Connector and receives ballast blocks to add ballast weight to the system.



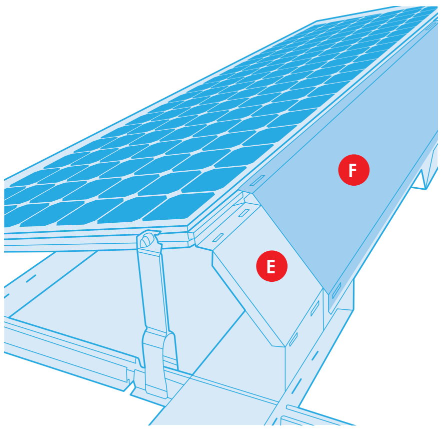
C D Front & Rear Legs



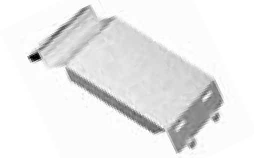
The Front Leg snaps, by hand, into the Row Connectors and receives the Zep Groove of Zep Compatible PV modules. The structural connections are auto-grounding.



The Rear Leg rotates, by hand, into the Zep Groove of Zep Compatible PV modules and snaps into the Row Connectors. The Rear Leg automatically establishes east-west module grounding.



E Diffuser Support



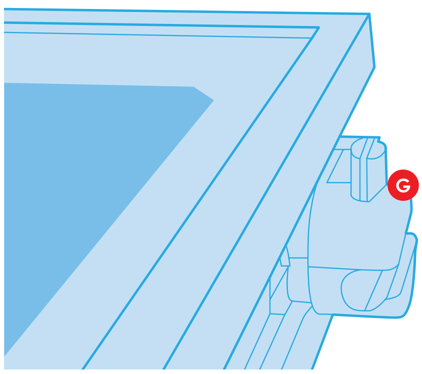
The diffuser support provides additional rigidity along the upper edge of the module row and supports the ends of the wind diffusers.

F Wind Diffuser

The wind diffuser is installed on the back side of each row and reduces uplift forces due to wind by redirecting air over and around the array, balancing air pressures across the upper and lower sides of the array.

G Ground Lug

Attaches to the module groove. One lug grounds up to 24 modules per row.



ACCESSORIES

Trinamount Tool

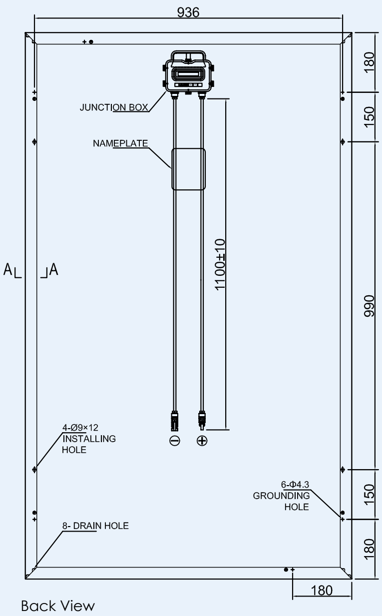
4 functions, 1 tool

TM III removal kit

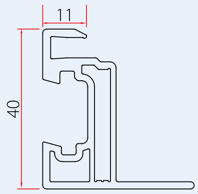
Real leg remove tool

Trinamount III FOR FLAT ROOF TSM-PC05.18

DIMENSIONS OF PV MODULE TSM-PC05.18

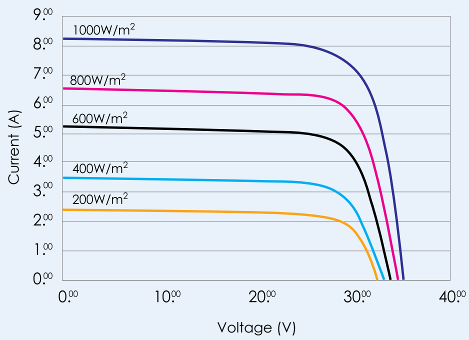


Back View



A-A

I-V CURVES OF PV MODULE TSM-230PC05.18



CERTIFICATION

ELECTRICAL DATA @ STC	225	230	235	240	245
Peak Power Watts-PMAX (Wp)	225	230	235	240	245
Power Output Tolerance-PMAX (%)	0/+3	0/+3	0/+3	0/+3	0/+3
Maximum Power Voltage-VMP (V)	29.4	29.8	30.1	30.4	30.7
Maximum Power Current-IMPP (A)	7.66	7.72	7.81	7.89	7.98
Open Circuit Voltage-VOC (V)	36.9	37.0	37.1	37.2	37.3
Short Circuit Current-Isc (A)	8.20	8.26	8.31	8.37	8.47
Module Efficiency η_m (%)	13.7	14.1	14.4	14.7	15.0

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C).

ELECTRICAL DATA @ NOCT	225	230	235	240	245
Maximum Power (W)	164	168	172	175	178
Maximum Power Voltage (V)	26.9	27.1	27.4	27.7	27.8
Maximum Power Current (A)	6.12	6.20	6.27	6.32	6.41
Open Circuit Voltage (V)	33.8	33.9	34.0	34.1	34.2
Short Circuit Current (A)	6.62	6.68	6.70	6.75	6.83

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1M/s.

MECHANICAL DATA	
Solar cells	Multicrystalline 156 × 156mm (6 inches)
Cell orientation	60 cells (6 × 10)
Module dimension	1650 × 992 × 40mm (64.95 × 39.05 × 1.57 inches)
Weight	20.3kg (44.8 lb)
Glass	High transparency solar glass 3.2mm (0.13 inches)
Frame	Black anodized aluminium alloy
J-Box	IP 65 rated
Cables / Connector	Photovoltaic Technology cable 4.0mm² (0.006 inches²), 1100mm (43.3 inches), MC4 / H4

TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	46°C (±2°C)
Temperature Coefficient of PMAX	- 0.43%/K
Temperature Coefficient of VOC	- 0.32%/K
Temperature Coefficient of ISC	0.047%/K

MAXIMUM RATINGS	
Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC(IEC)
Max Series Fuse Rating	15A

WARRANTY
10 year workmanship warranty
25 year linear performance warranty

(Please refer to product warranty for details)

TSM_EU_Apr2012_Trinamount_III

Trinasolar
The power behind the panel

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Appendix I: References Used for Conductor Sizing

PV Source and Output Circuits										
STC Array Isc	PV 690.8(B)(1)(a) Current and Required OCPD Size	Adjusted Current - ≤3 conductors	Minimum Conductor Size ≤3 90ºC terminals	Minimum Conductor Size ≤3 75ºC terminals	Adjusted Current 4-6 conductors	Minimum Conductor Size 4-6 90ºC terminals	Minimum Conductor Size 4-6 75ºC terminals	Adjusted Current 7-9 conductors	Minimum Conductor Size 7-9 90ºC terminals	Minimum Conductor Size 7-9 75ºC terminals
Assumptions: 48ºC maximum ambient temperature; conduit 0.5 - 3.5" above roof surface										
51.2	80	110.34	3	2	137.93	1	1/0	157.64	1/0	2/0
44.8	70	96.55	3	3	120.69	2	1	137.93	1	1/0
38.4	60	82.76	4	4	103.45	3	2	118.23	2	1
32	50	68.97	6	4	86.21	4	3	98.52	3	3
28.8	45	62.07	6	6	77.59	4	4	88.67	4	3
25.6	40	55.17	6	6	68.97	6	4	78.82	4	4
22.4	35	48.28	8	8	60.34	6	6	68.97	6	4
19.2	30	41.38	8	8	51.72	8	6	59.11	6	6
16	25	34.48	10	10	43.10	8	8	49.26	8	8
12.8	20	27.59	12	10	34.48	10	10	39.41	10	8
9.6	15	20.69	14	12	25.86	12	10	29.56	12	10
7.68	12	16.55	14	14	20.69	14	12	23.65	14	12
6.4	10	13.79	14	14	17.24	14	14	19.70	14	14
Assumptions: 50ºC maximum ambient temperature; conduit not on roof										
51.2	80	78.05	4	4	97.56	3	3	111.50	3	2
44.8	70	68.29	6	4	85.37	4	4	97.56	3	3
38.4	60	58.54	6	6	73.17	6	4	83.62	4	4
32	50	48.78	8	8	60.98	6	6	69.69	6	4
28.8	45	43.90	8	8	54.88	8	6	62.72	6	6
25.6	40	39.02	8	8	48.78	8	8	55.75	6	6
22.4	35	34.15	8	8	42.68	8	8	48.78	8	8
19.2	30	29.27	10	10	36.59	10	8	41.81	8	8
16	25	24.39	10	10	30.49	10	10	34.84	10	8
12.8	20	19.51	12	12	24.39	12	10	27.87	12	10
9.6	15	14.63	14	14	18.29	14	14	20.91	14	12
7.68	12	11.71	14	14	14.63	14	14	16.72	14	14
6.4	10	9.76	14	14	12.20	14	14	13.94	14	14

Table 15.1: PV Source and Output Circuit Conductor Size

Inverter Output Circuits										
Maximum Inverter Continuous Output Current Rating	Inverter 690.8(B)(1)(a) Current and Required OCPD Size	Adjusted Current - ≤3 conductors	Minimum Conductor Size ≤3 90°C terminals	Minimum Conductor Size ≤3 75°C terminals	Adjusted Current 4-6 conductors	Minimum Conductor Size 4-6 90°C terminals	Minimum Conductor Size 4-6 75°C terminals	Adjusted Current 7-9 conductors	Minimum Conductor Size 7-9 90°C terminals	Minimum Conductor Size 7-9 75°C terminals
Assumptions: 50°C maximum ambient temperature; conduit not on roof										
64	80	78.05	4	4	97.56	3	3	111.50	3	2
56	70	68.29	6	4	85.37	4	4	97.56	3	3
48	60	58.54	6	6	73.17	6	4	83.62	4	4
40	50	48.78	8	8	60.98	6	6	69.69	6	4
36	45	43.90	8	8	54.88	8	6	62.72	6	6
32	40	39.02	8	8	48.78	8	8	55.75	6	6
28	35	34.15	8	8	42.68	8	8	48.78	8	8
24	30	29.27	10	10	36.59	10	8	41.81	8	8
20	25	24.39	10	10	30.49	10	10	34.84	10	8
16	20	19.51	12	12	24.39	12	10	27.87	12	10
12	15	14.63	14	14	18.29	14	14	20.91	14	12

Table 15.2: Inverter Output Circuit Conductor Size

CALCULATING VOLTAGE DROP

1% Voltage Drop, 1 V, Distance in Feet - 75°C maximum conductor temperature
Multiply by circuit voltage and desired voltage drop % (ex. 240 V, 1.5% drop - multiply by 360)

Current	AWG	14	12	10	8	6	4	3	2	1	1/0	2/0	3/0	4/0	250	300	350	400	500
1		1.5924	2.5253	4.0323	6.4267	10.1833	16.2338	20.4082	25.7732	32.4675	40.9836	51.7063	65.2742	82.2368	97.0874	116.5501	136.2398	155.7632	193.7984
2		0.7962	1.2626	2.0161	3.2134	5.0916	8.1169	10.2041	12.8866	16.2338	20.4918	25.8532	32.6371	41.1184	48.5437	58.2751	68.1199	77.8816	96.8992
3		0.5308	0.8418	1.3441	2.1422	3.3944	5.4113	6.8027	8.5911	10.8225	13.6612	17.2354	21.7581	27.4123	32.3625	38.8500	45.4133	51.9211	64.5995
4		0.3981	0.6313	1.0081	1.6067	2.5458	4.0584	5.1020	6.4433	8.1169	10.2459	12.9266	16.3185	20.5592	24.2718	29.1375	34.0599	38.9408	48.4496
5		0.3185	0.5051	0.8065	1.2853	2.0367	3.2468	4.0816	5.1546	6.4935	8.1967	10.3413	13.0548	16.4474	19.4175	23.3100	27.2480	31.1526	38.7597
6		0.2654	0.4209	0.6720	1.0711	1.6972	2.7056	3.4014	4.2955	5.4113	6.8306	8.6177	10.8790	13.7061	16.1812	19.4250	22.7066	25.9605	32.2997
7		0.2275	0.3608	0.5760	0.9181	1.4548	2.3191	2.9155	3.6819	4.6382	5.8548	7.3866	9.3249	11.7481	13.8696	16.6500	19.4628	22.2519	27.6855
8		0.1990	0.3157	0.5040	0.8033	1.2729	2.0292	2.5510	3.2216	4.0584	5.1230	6.4633	8.1593	10.2796	12.1359	14.5688	17.0300	19.4704	24.2248
9		0.1769	0.2806	0.4480	0.7141	1.1315	1.8038	2.2676	2.8637	3.6075	4.5537	5.7451	7.2527	9.1374	10.7875	12.9500	15.1378	17.3070	21.5332
10		0.1592	0.2525	0.4032	0.6427	1.0183	1.6234	2.0408	2.5773	3.2468	4.0984	5.1706	6.5274	8.2237	9.7087	11.6550	13.6240	15.5763	19.3798
15		0.1062	0.1684	0.2688	0.4284	0.6789	1.0823	1.3605	1.7182	2.1645	2.7322	3.4471	4.3516	5.4825	6.4725	7.7700	9.0827	10.3842	12.9199
20		0.0796	0.1263	0.2016	0.3213	0.5092	0.8117	1.0204	1.2887	1.6234	2.0492	2.5853	3.2637	4.1118	4.8544	5.8275	6.8120	7.7882	9.6899
25		0.0637	0.1010	0.1613	0.2571	0.4073	0.6494	0.8163	1.0309	1.2987	1.6393	2.0683	2.6110	3.2895	3.8835	4.6620	5.4496	6.2305	7.7519
30		0.0531	0.0842	0.1344	0.2142	0.3394	0.5411	0.6803	0.8591	1.0823	1.3661	1.7235	2.1758	2.7412	3.2362	3.8850	4.5413	5.1921	6.4599
35		0.0455	0.0722	0.1152	0.1836	0.2910	0.4638	0.5831	0.7364	0.9276	1.1710	1.4773	1.8650	2.3496	2.7739	3.3300	3.8926	4.4504	5.5371
40		0.0398	0.0631	0.1008	0.1607	0.2546	0.4058	0.5102	0.6443	0.8117	1.0246	1.2927	1.6319	2.0559	2.4272	2.9138	3.4060	3.8941	4.8450
45		0.0354	0.0561	0.0896	0.1428	0.2263	0.3608	0.4535	0.5727	0.7215	0.9107	1.1490	1.4505	1.8275	2.1575	2.5900	3.0276	3.4614	4.3066
50		0.0318	0.0505	0.0806	0.1285	0.2037	0.3247	0.4082	0.5155	0.6494	0.8197	1.0341	1.3055	1.6447	1.9417	2.3310	2.7248	3.1153	3.8760
55		0.0290	0.0459	0.0733	0.1168	0.1852	0.2952	0.3711	0.4686	0.5903	0.7452	0.9401	1.1868	1.4952	1.7652	2.1191	2.4771	2.8321	3.5236
60		0.0265	0.0421	0.0672	0.1071	0.1697	0.2706	0.3401	0.4296	0.5411	0.6831	0.8618	1.0879	1.3706	1.6181	1.9425	2.2707	2.5961	3.2300
65		0.0245	0.0389	0.0620	0.0989	0.1567	0.2498	0.3140	0.3965	0.4995	0.6305	0.7955	1.0042	1.2652	1.4937	1.7931	2.0960	2.3964	2.9815
70		0.0227	0.0361	0.0576	0.0918	0.1455	0.2319	0.2915	0.3682	0.4638	0.5855	0.7387	0.9325	1.1748	1.3870	1.6650	1.9463	2.2252	2.7685
75		0.0212	0.0337	0.0538	0.0857	0.1358	0.2165	0.2721	0.3436	0.4329	0.5464	0.6894	0.8703	1.0965	1.2945	1.5540	1.8165	2.0768	2.5840
80		0.0199	0.0316	0.0504	0.0803	0.1273	0.2029	0.2551	0.3222	0.4058	0.5123	0.6463	0.8159	1.0280	1.2136	1.4569	1.7030	1.9470	2.4225
85		0.0187	0.0297	0.0474	0.0756	0.1198	0.1910	0.2401	0.3032	0.3820	0.4822	0.6083	0.7679	0.9675	1.1422	1.3712	1.6028	1.8325	2.2800
90		0.0177	0.0281	0.0448	0.0714	0.1131	0.1804	0.2268	0.2864	0.3608	0.4554	0.5745	0.7253	0.9137	1.0787	1.2950	1.5138	1.7307	2.1533
95		0.0168	0.0266	0.0424	0.0676	0.1072	0.1709	0.2148	0.2713	0.3418	0.4314	0.5443	0.6871	0.8657	1.0220	1.2268	1.4341	1.6396	2.0400
100		0.0159	0.0253	0.0403	0.0643	0.1018	0.1623	0.2041	0.2577	0.3247	0.4098	0.5171	0.6527	0.8224	0.9709	1.1655	1.3624	1.5576	1.9380
110		0.0145	0.0230	0.0367	0.0584	0.0926	0.1476	0.1855	0.2343	0.2952	0.3726	0.4701	0.5934	0.7476	0.8826	1.0595	1.2385	1.4160	1.7618
120		0.0133	0.0210	0.0336	0.0536	0.0849	0.1353	0.1701	0.2148	0.2706	0.3415	0.4309	0.5440	0.6853	0.8091	0.9713	1.1353	1.2980	1.6150
130		0.0122	0.0194	0.0310	0.0494	0.0783	0.1249	0.1570	0.1983	0.2498	0.3153	0.3977	0.5021	0.6326	0.7468	0.8965	1.0480	1.1982	1.4908
140		0.0114	0.0180	0.0288	0.0459	0.0727	0.1160	0.1458	0.1841	0.2319	0.2927	0.3693	0.4662	0.5874	0.6935	0.8325	0.9731	1.1126	1.3843
150		0.0106	0.0168	0.0269	0.0428	0.0679	0.1082	0.1361	0.1718	0.2165	0.2732	0.3447	0.4352	0.5482	0.6472	0.7770	0.9083	1.0384	1.2920
160		0.0100	0.0158	0.0252	0.0402	0.0636	0.1015	0.1276	0.1611	0.2029	0.2561	0.3232	0.4080	0.5140	0.6068	0.7284	0.8515	0.9735	1.2112
170		0.0094	0.0149	0.0237	0.0378	0.0599	0.0955	0.1200	0.1516	0.1910	0.2411	0.3042	0.3840	0.4837	0.5711	0.6856	0.8014	0.9163	1.1400
180		0.0088	0.0140	0.0224	0.0357	0.0566	0.0902	0.1134	0.1432	0.1804	0.2277	0.2873	0.3626	0.4569	0.5394	0.6475	0.7569	0.8654	1.0767
190		0.0084	0.0133	0.0212	0.0338	0.0536	0.0854	0.1074	0.1356	0.1709	0.2157	0.2721	0.3435	0.4328	0.5110	0.6134	0.7171	0.8198	1.0200
200		0.0080	0.0126	0.0202	0.0321	0.0509	0.0812	0.1020	0.1289	0.1623	0.2049	0.2585	0.3264	0.4112	0.4854	0.5828	0.6812	0.7788	0.9690
Ω/kFT		3.1400	1.9800	1.2400	0.7780	0.4910	0.3080	0.2450	0.1940	0.1540	0.1220	0.0967	0.0766	0.0608	0.0515	0.0429	0.0367	0.0321	0.0258

Values in shaded area are current levels that may or do exceed the allowable ampaicty of the conductor

The values in this table can be used as multipliers to determine the acceptable length (in feet) of conductor carrying a given current (in amps), as well as voltage drop as a percentage. Multiply the value in the chart by the system voltage and the desired voltage drop to get a length in feet (see example on next page).

Appendix J: Takeoff for Solar Panel Scheduling

Schedule for Solar Panel Installation (Takeoff)

Reference	Description	Daily Output	Quantity	Total Duration
-	Mobilization	-	-	1
Estimate	Hoisting Supplies to Roof- Crane	-	-	1
Estimate	Preperatory Layout, Penetrations	-	-	3
RS Means 263113.50.0490	Roof Mounting Frame, for 6 Modules	4	24	6
RS Means 263113.5.0002	Alt. Energy Source, Photovoltaic Module	16	143	9
Estimate	Electrical Tie-in and Completion	-	-	2
Estimate	Checks and Balances	-	-	5
-	DeMobilization	-	-	1

Academic Vita

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Permanent Address: 15 Dapp Lane, Mechanicsburg PA 17050● (717) 697-3330

Objective

To begin work at DPR Construction (Mid-Atlantic) in July 2013.

Education

The Pennsylvania State University *Spring 2013*

Schreyer Honors College

Bachelor of Architectural Engineering
Degree Accreditation: ABET

Work Experience

DPR Construction, Newport Beach, CA *Summer 2012*

Innovation Team Intern

- Teamed with group of five to facilitate new ideas within the company globally
- Gathered information from craft workers on smarter ways to build
- Authored training guide for mobile technology and iPads at DPR
- Taught engineers how to effectively use technology in the field

DPR Construction, Falls Church, VA *Summer 2011*

Project Engineer Intern

- Assisted in $40,000,000 renovation of existing M.O.B. and addition
- Wrote RFI's, processed submittals, and co-sequenced schedule
- Renovated an emergency exit including installing new exit door and framing
- Performed daily safety walks

Euphoria at Le Salon, State College, PA *Summer 2010- Spring 2011*

Receptionist

- Organized schedule for stylists and assistants
- Satisfied various client and business requirements including P.O.S. system and telephones

DM Landscaping, Carlisle, PA *Summer 2010*

Laborer

- Collaborated in group of three to install fencing, swing sets, and play houses
- Built custom walkways and entrances with paver stones
- Gained a passion for quality work

Activities and Awards

Sigma Pi, International Fraternity *Initiated December 2008*

Philanthropy Chair *Spring 2010-Spring 2011*

- Increased yearly donation totals by 400%
- Created and Organized "SpagHaiti" dinner (raised over $1500 for Haiti relief)
- Coordinated multiple philanthropic events
- Developed workshops to educate brotherhood about safe habits with regards to drinking

Lacrosse *Fall 2004 - Spring 2008*

- US Lacrosse 2008 High School All-American
- Awarded Eagle Lacrosse Foundation Scholarship
- Captain of Cumberland Valley High School lacrosse team
- Received 2005, 2006 Leadership and Sportsmanship Award

References Available Upon Request