

SENIOR THEIS FINAL REPORT

**The Virginia Commonwealth University
School of Business and Engineering**

Richmond, Virginia



LORI E. FARLEY

**Construction
Management**

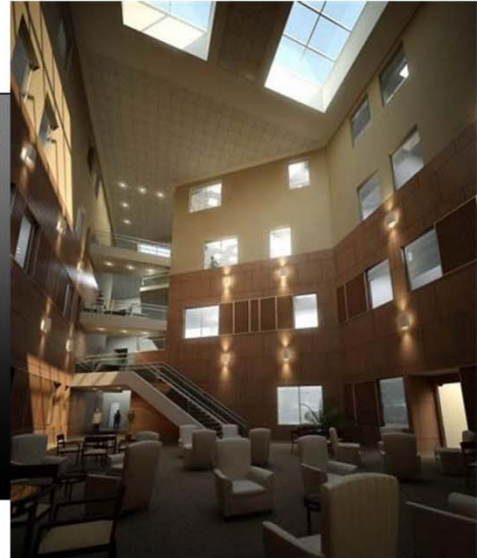
Faculty Consultant:
Dr. John Messner

SPRING 2008

General Building Information

Location Richmond, Virginia, Monroe Park Campus
Size 245,000 Square Feet
Levels Above Grade 4
Contract Size \$65 MM

Virginia Commonwealth University **Owner**
Moseley Architects **Architect**
Gilbane Building Co. **Construction Manager**
Construction Management **Delivery Method**



Systems

Electrical

- The incoming service feed is 3-Phase 480/277 V
- Distribution switch board is 4000A, 3-phase, 480/277 V; 120/208 V transformer to service each floor
- The system is backed up with a 1000kW, 3-phase, 480/277 V diesel-powered emergency generator.

Mechanical & Plumbing

- All-water variable volume air-handling system located on the rooftop with 10 RHUs
- Utilizes the following fire protection systems: Automatic wet-type, Class 1 standpipe systems, Wet-pipe sprinkler systems, Dry-Pipe sprinkler systems and Pre-action sprinkler systems

Structural

- The foundation is a 4-inch typical slab on grade; normal weight concrete
- Concrete Shear Wall ranging in thicknesses from 8-inches (full-height) to 12-inches (full height)
- Combination of steel and concrete structural framing; W-shaped beams and columns; 20-inch deep concrete joists



Architectural Features

- Two (2) full-height (4-story) atriums
- A roof screen at a 10:12 pitch to conceal the roof-top mechanical system
- A large crescent-shaped inlet (approximately a 50-foot radius along the side of the building) that will house a courtyard along with intricate brick/pavement walkways around the building

Lori E. Farley

ARCHITECTURAL ENGINEERING CONSTRUCTION MANAGEMENT

THE PENNSYLVANIA STATE UNIVERSITY

<http://www.engr.psu.edu/ae/thesis/portfolios/2008/lef143/>

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THESIS EXECUTIVE SUMMARY

THE VIRGINIA COMMONWEALTH UNIVERSITY SCHOOL OF BUSINESS AND ENGINEERING
RICHMOND, VIRGINIA

The following document is a senior thesis report that focuses on an in-depth study of the Virginia Commonwealth University School of Business and Engineering in Richmond, Virginia. This report includes construction depth work regarding the following areas of analysis.

The first area of analysis includes a structural redesign from concrete to steel, which provides a structural breadth. This was done to keep the entire building as a steel superstructure rather than have two separate structural systems. Through the redesign, it was seen that the cost savings would be **\$905,551** and **63** days on the overall schedule. It was also observed that the original erection sequence would easily absorb the redesign due to the fact that the other two sections of the building are erected in steel. A constructability review was also preformed which also favored the redesign of the concrete system to steel.

The second analysis preformed was a placement of a solar array on the south facing pitch of the roof screen and supports an electrical breadth. The elected system would be a 19-Kilowatt array at an estimated cost of **\$88,194**. By using a portion of the money that was saved by the redesign in analysis one, the system is not only affordable, but will also save **\$2272** per year on the electricity bill and over **143,000** pounds of CO₂ emissions. Not only will this array support the interest that academia has been taking regarding sustainable design, but will also be an aesthetic feature of the building.

The last area of analysis was researching the logistic of prefabrication and was broken into two parts. The first part of this research revolved around the incentives and disincentives of prefabrication and how companies should frame their decision making process of implementing pre-work. It was seen that the industry has doubled their use of prefabrication in the past ten years, but still has specific challenges to overcome when implementing prefabricated work.

The second portion of this research looked at enforcing prefabrication on the Virginia Commonwealth University's roof screen. This research centered on the "Framework for Decision Making" that was created by the Construction Industry Institute. This framework takes an in-depth look at all aspects of the project to help identify if prefabrication would be a beneficial choice for the project. Taking into account the questions they provide, I was able to formulate a plan that could be enforced on the project in regards to the mechanical roof screen.

PROJECT OVERVIEW

THE VIRGINIA COMMONWEALTH UNIVERSITY SCHOOL OF BUSINESS AND ENGINEERING
RICHMOND, VIRGINIA

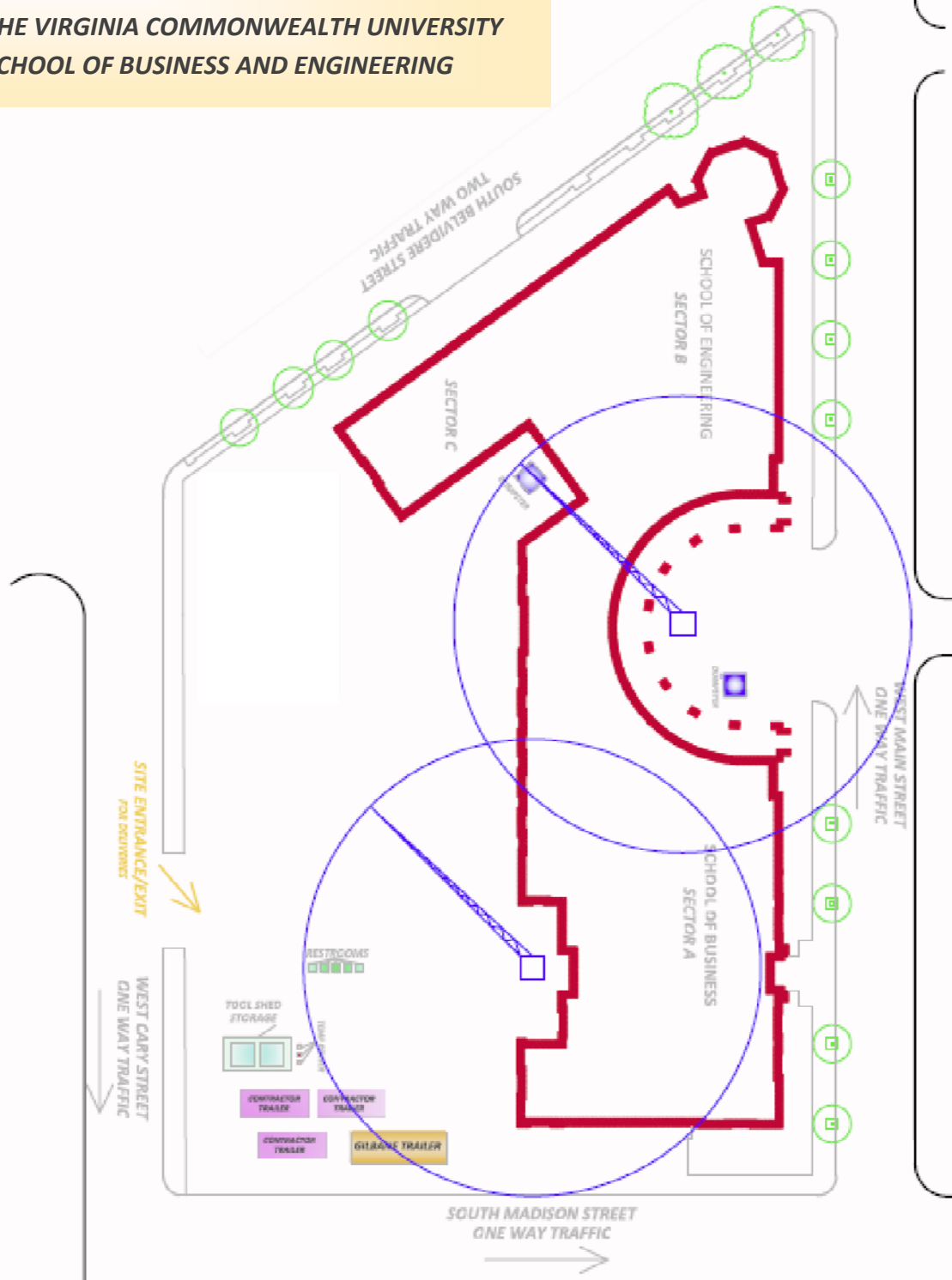
- **PROJECT OVERVIEW** - The Virginia Commonwealth University School of Business and Engineering is located in Richmond, Virginia, and is a new addition to the Monroe Park Campus. The location of the site sits on the south-east corner of the campus, where construction began in January of 2006. The building stands at four (4) levels above grade and is the new home to the Business and Engineering majors. The building functions as a mixed-use environment for the schools, containing cafés, cafeterias and common areas along with classrooms, labs and faculty offices on the upper levels. The building will dedicate features to each school: the business school will receive a trading room, career center and tiered case-study classrooms while the engineering school will receive state of the art lecture halls, research and teaching labs, and study spaces. The building will feature two (2) full height (4-story) atriums, one in the school of business and one in the school of engineering. There will be a large crescent entryway in the center of the western side of the building along with intricate brick/pavement patterned walkways around the building.



- The project site is bounded by South Belvidere Street on the west, West Main Street on the North, South Madison Street on the east, and West Cary street on the south. Of these roadways, South Belvidere Street is the only two-way traffic system. The rest of the mentioned roadways are one-way traffic. The following image is the site plan for the project.

SITE PLAN

THE VIRGINIA COMMONWEALTH UNIVERSITY SCHOOL OF BUSINESS AND ENGINEERING



- **PROJECT TEAM** – Below are the key players in the project.
 - **Owner** – The Virginia Commonwealth University
 - **Architect** – Moseley Architects
 - **Construction Manager** – Gilbane Building Company
 - **Civil Engineer** – Draper Aden Associates
 - **Structural Engineer** – Dunbar, M Enter away message text here.ilby, Williams, Pittman and Vaughn
 - **MEP Engineer** – R.G. Vanderweil

- **PROJECT DELIVERY METHOD** – The Construction Management Department oversees the construction, renovation, and restoration of University buildings and infrastructure. The Department ensures that contractors adhere to the project design while complying with the state code, construction, and contract requirements. The Department is also responsible for demolition of buildings that must be removed to make way for new facilities. The contract is held by the Virginia Commonwealth University and Gilbane Building Company was chosen as the Construction Manager for the project. A soft guaranteed maximum price (GMP) was established between Gilbane and VCU.

- **ARCHITECTURE** - The building will dedicate features to each school: the business school will receive a trading room, career center and tiered case-study classrooms while the engineering will receive state of the art lecture halls, research and teaching labs and study spaces. The building will feature two (2) full height (4-story) atriums, one in the school of business and one in the school of engineering. There will be a large crescent entryway in the center of the western side of the building along with intricate brick/pavement patterned walkways around the building.

- **APPLICABLE CODES** - Virginia Statewide Uniform Building Code, 2000 Edition, Effective on 10/1/2003.

- **ZONING** - VCU owned majority of the project site and the existing structures. There were no major zoning issues that conflicted with this project. The building is well under the allowable height of 180-feet (12 stories), with an actual height of 55-feet (4 stories).

- **BUILDING ENVELOPE** - The building envelope consists of a structural steel roof, which also houses the mechanical system, insulated glass roofing over the atrium areas, and a standing seam architectural metal roof system. This roof screen was installed to hide the rooftop mechanical system from neighboring buildings. Along the floor of the roof are walkway pads and water splash protection. The exterior envelope is made up of aluminum windows; metal panels, APC panels, arcs and decorative figures; with a main component of 4-inch face brick and 4-inch smooth CMU. Actual wall systems will require more investigation and information from project source.



- **BUILDING SYSTEMS SUMMARY**

- **DEMOLITION**

Several brick buildings, a maximum of 2-stories, had to be demolished before the construction of the Virginia Commonwealth University's School of Business and Engineering could take place. In addition to these buildings, a number of asphalt parking lots and existing sidewalks outlining the site also had to be removed. Portions of the property are owned by the university and therefore the campus construction services were responsible for the demolition of those structures.

- **STRUCTURAL STEEL FRAME**

The building is comprised of a structural steel frame in sectors A and B (School of Business). Sectors A and B entail wide flange beams, which are spaced equally within the dimensioned bays, as well as wide flange columns with all splicing occurring on the third floor (at 5-ft) when necessary. At the crescent however, curved HSS-Tube steel was used for the beams and, for connection purposes, was also used for the columns. The bracing in these two sectors include diagonal, k, and vee, all using HSS-Tube steel (46 ksi).

- **CAST IN PLACE CONCRETE**

For this project, the typical slab-on-grade consisted of 4-inch, normal weight concrete and a 5-1/2-inch thickness for steel framing floor deck construction. Concrete framing was also used in the northwest portion of sector C (School of Engineering). This sector consists of 20-inch deep concrete joists, with a typical pan width of 53-inches, as well as concrete columns and beams. In addition to these features, there are several full-height shear walls, ranging from 8-inches to 12-inches in thickness. Formwork, shores and reshores was enforced.

- **PRECAST CONCRETE**

The building will feature decorative pre-cast panels at the first floor, between the third and fourth floor and two figures on the roof overlooking the crescent and courtyard below. The panels will be connected by steel shapes and plates, carbon steel bolts and studs, welded headed studs and deformed steel wire-bar anchors. The panels will be distributed around the perimeter of the building at stages where they will then be picked.

- **MECHANICAL SYSTEM**

The mechanical system is housed on the rooftop of the building and is an all-water variable volume air-handling system. There is a total of 10 (ten) roof-top units meeting the following design criteria; 5 dedicated to the School of Engineering with a maximum SA of 20,800 CFM and a minimum OA of 8,000 CFM and 5 dedicated to the School of Business with a maximum SA of 26,000 CFM and a minimum OA of 10,000 CFM. There is also an AHU to service the chiller room. In addition to the mentioned RHU's, there is 1 (one) double cross-flow cooling tower, with two cells at 500 nominal tons/cell, and 2 (two) centrifugal water-cooled chillers with a maximum capacity of 500 tons. All rooftop equipment and associated ductwork and piping are mounted so they, nor their supports, are exposed above the top of the architectural roof screen.

- **ELECTRICAL SYSTEM**

The electrical system has a 480/277V, 3-phase service utility feed, which supplies the 4000A main switch board for the building (distributed radially). There is a total of four 208/120V

transformers; one to service each floor. The system is backed up with a 1000kW, 3-phase 480/277V diesel-powered generator.

- **MASONRY**

The masonry on this project consists of the following areas; Concrete Brick, the CMU foundation walls for the School of Business Face Brick, Building (common). The concrete brick will have a minimum compressive strength of 3500 psi and the concrete masonry units are to be fully grouted with a 28-day net compressive of 1500 psi. The building brick must match the face brick where exposed.

- **CURTAIN WALL**

The curtain wall framing system will consist of structural extruded tube sections, glazing pressure plate, and mullion caps for nominal 6-inch total section depth. In addition, there will be insulating glass on the interior and exterior. The total width will be 2.5-inches.

- **SUPPORT OF EXCAVATION**

The excavation support system included sheeting and shoring. There was no temporary de-watering system, only the permanent waterproofing that took place after the concrete was cast.

- **PROJECT SCHEDULE** - The construction schedule for the Virginia Commonwealth School of Business and Engineering was unique in the sense that two schedules were encompassed into one. The School of Business and the School of Engineering each had their own agenda, mainly to address the concrete structural system in the School of Engineering and the steel structural system in the School of Business. While the tasks for both buildings were concurrently taking place, the two separate schedules help to illustrate the progress of each building.

The full schedule of the as-built structure can be found in **Appendix A**. Below is a status summary of key phases within the design and building process of the Virginia Commonwealth University School of Business and Engineering.

2004	2005	2006	2007
PLANNING			
CM SELECTION & PRICING			
	CONSTRUCTION		

Below are key milestones within the construction phase of the project. They are the following:

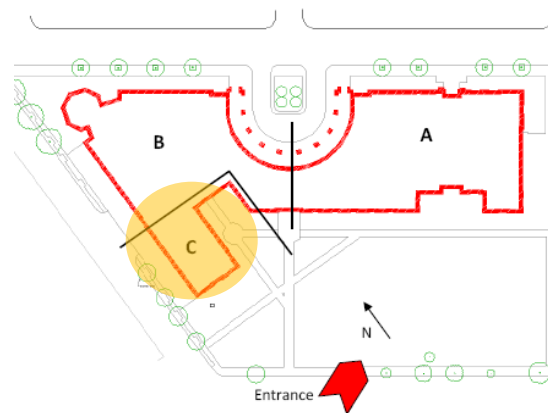
- **Notice to Proceed on 01.16.06**
- **School of Business dry on 11.28.06**
- **School of Engineering dry on 11.06.06**
- **Owner FFE on 09.28.07**
- **Substantial Completion on 11.28.07**
- **Spring Semester begins on 01.14.08**

ANALYSIS ONE

SKELETAL REDESIGN OF SECTOR C

A STRUCTURAL BREADTH

Background - Below is a basic layout as to how the building was broken down when developing the schedule. The focal point of this breadth will be on Sector C, which has been designated as the School of Engineering. This area alone had a concrete structural system, while the remainder of the building was done in steel.



- **Sector C** – When in the development phase of my thesis proposals last semester, I became curious as to why Sector C had not been done in steel, as the rest of the building had been. After reviewing the plans and site, alone and with faculty, I could not see the reason or logic behind having two different structural systems applied to one building. After consulting with Moseley Architects and the PM assigned to the project, it was established that the primary function of the concrete was to reduce deflection and vibration in the structure. That reason, however, was not the underlying purpose of the concrete skeleton, but it was quite simply, cost. At the time, there was a spike in the price of steel and this proved to be an easy solution. While there was no true “problem” with this specific area and the concrete framework it entails, I still maintain my proposal to pursue a redesign of Sector C to match the rest of the building.
- **Proposal** – The goal of this analysis is to address the impact of redesigning Sector C to a steel building, which supplies as breadth in the structural option. This is done with the intent to improve constructability, and, because steel erection tends to go more swimmingly, it is hopeful that this change will compress the schedule and save money. These potentialities will be compared to the actual sequence and actual cost of the completed project.

THE ANALYSIS

▪ DESIGN METHODOLOGY

RAM Steel was used when designing Sector C to a steel structure. I chose to use this software due to its integration of analysis and design of the members in a steel building. RAM Steel is very versatile in the fact it allows a quick design process, the exploration of different design options, and enables a swift cost prediction.

- I began my analysis by reviewing the structural and architectural drawings of the concrete structure. I made quick hand-sketches of each floor, noting the dimensions, bay sizes, and column locations to maintain a relationship between the as-built structure and my redesign. All floor heights square-footages also remained unchanged.
- The next step taken was inputting the grid of the building into RAM Structural System, Version 11, which included laying out the beams, girders, and columns as well as determining sufficient locations for the lateral frames (in this specific case, the façade along the east side that faces Belvidere Street would not allow for any bracing due to the abundance of windows). Proper fixities were also assigned at this stage.
- Once the layout was achieved, I then selected a decking from Vulcraft Catalog and kept the same slab depth of Sectors A and B, which was a 4-inch, 4,000 psi normal-weight concrete slab. I also chose to use composite beams to maintain consistency with Sectors A and B.
- Next, I ran the analysis of the beams for gravity loading and retrieved the sizes. Directly following this analysis, I ran the analysis of the columns, using only 12-inch wide flange columns because that is what the other building had used. The applicable design loadings were taken from the structural notes and were as follows:

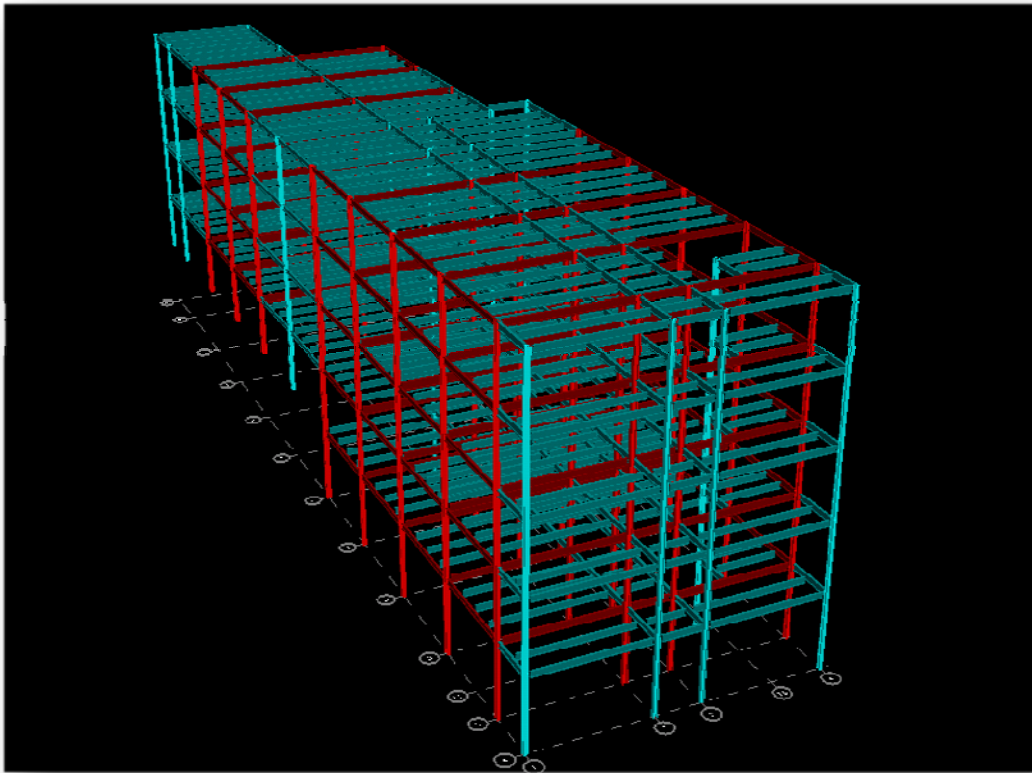
OCCUPANCY	DESIGN LOAD
Roof	20 PSF
Offices	50 PSF + 20 PSF Partitions
Corridors	100 PSF
Research Laboratories – First Floor	125 PSF
Research Laboratories – Above First Floor	100 PSF

- I then entered the frame mode and input design criteria for lateral loads and allowed the program to calculate and distribute lateral loads to the lateral force resisting systems. Once this process was completed, I went through each floor and adjusted the beam and column sizes based on the calculated stress levels to ensure that no members were over-stressed.
- After all members were acceptably designed, this marked the finale of the design process of Sector C to a steel building. Things to note: beams have a maximum of 100% composite action and a minimum of 25% composite action and load and resistance factor design (LRFD) was used in this process.

THE RESULTS

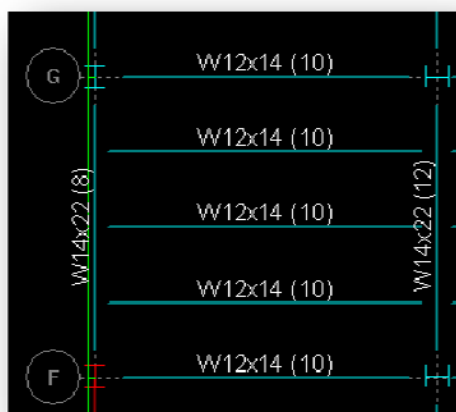
CONSTRUCTION RESULTS

The results based from the RAM model were first used to price the steel members and incorporated into the overall construction schedule. The floor layouts and subsequent steel takeoffs can be found in **Appendix B**. The results are summarized below in the cost comparison table.



STRUCTURAL STEEL DESIGN – SECTOR C

Some items to note about the above image of the designed steel structure are that the typical bay size is 21 feet by 24 feet and the red segments represent lateral framing which include moment connections.



TYPICAL BAY
21' X 24'

- **COST COMPARISON**

Beams, Girders, and Columns - Upon completing the design of Sector C to steel, I then was able to price the steel beams, girders, and columns according to finalized sizes of the respective members. R.S. Means Cost Data 2007 was used when pricing the steel pieces, but this cost is a much more conservative representation due to the fact that steel has increased in price since 2003, which is when this project was bid and is when the mill orders would have been placed. Any members that were not listed in R.S. Means Cost Data were taken to the next largest size to provide a more conservative estimate.

Fireproofing – The main function of Sector C is research laboratories. To determine the required fireproofing for such occupancies, the 2006 edition of the International Building Code was used. The laboratories fell into Section 304 of the IBC under the *Business Group (B)*, which also includes *Educational Occupancies for Students above Grade 12*. The requirements for this occupancy call for a 2-hour fire rating. A \$90,000 was allotted to the cost of fireproofing.

Moment Connections – The cost of moment connections also affects the final pricing of the steel structure. This breadth, however does not include a depth into the connections of the lateral framing system, so no dollar amount is predicted. It is recognized that these connections would increase the cost.

COST COMPARISON SUMMARY OF SECTOR C			
STEEL		CONCRETE	
Beams & Girders	\$341,151.67	Beams & Girders	\$778,461.91
Columns	\$252,897.98	Columns	\$404,606.99
Fire Protection	\$90,000.00	Joists	\$406,531.90
TOTAL	\$684,049.65	TOTAL	\$1,589,600.80

As seen from above, the total cost savings is estimated to be **\$905,551.15**. This is a significant amount of money that could be distributed to other demands of the project (NOTE: concrete costs were obtained from Technical Assignment 2).

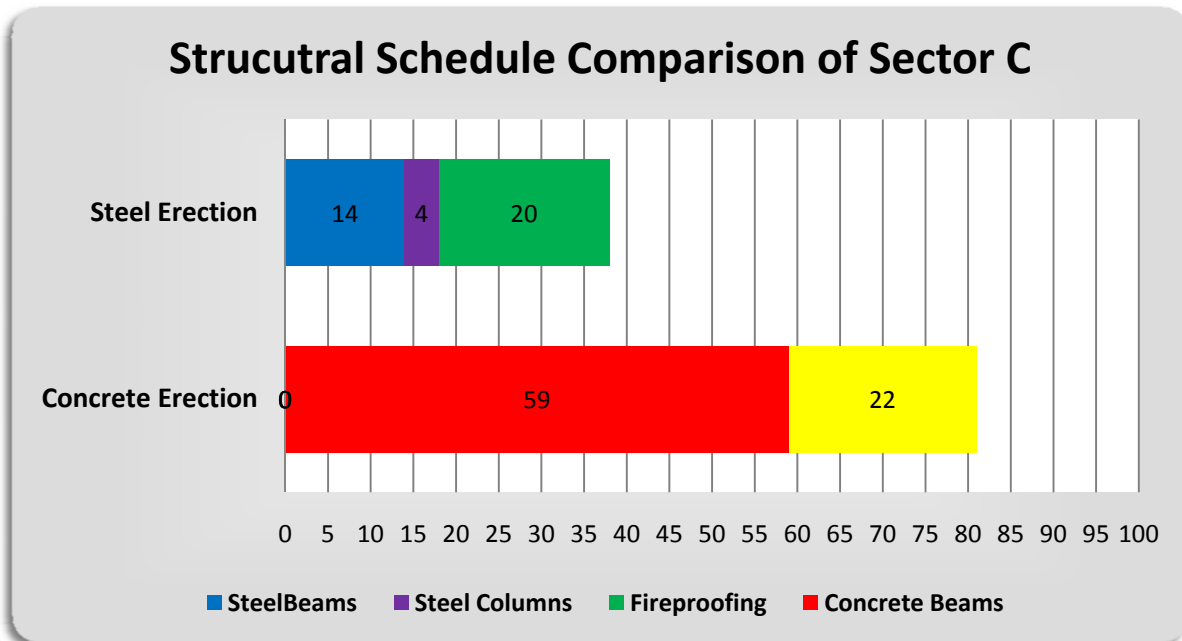
- SCHEDULE COMPARISON**

Once the pricing had been completed, the next step was to evaluate the impact this proposed redesign would have on the construction schedule. The goal, again, is to compress the overall duration of the project.

Original Schedule - The construction schedule for the Virginia Commonwealth School of Business and Engineering was unique in the sense that two schedules were encompassed into one. The School of Business and the School of Engineering each had their own agenda, mainly to address the concrete structural system in the School of Engineering and the steel structural system in the School of Business. The original schedule had the steel installation beginning on May 1, 2006 and concrete placement beginning on May 22, 2006.

Proposed Schedule - Below is a chart that compares the installation of the two structural systems, in days. The proposed schedule for the steel erection would take 14 days for beam installation and 4 days for the column installation, for a total duration of 18 days. The fireproofing of the steel will add an additional 5 days per floor, totaling 20 days. Below is a chart that compares the installation of the two structural systems, in days.

Type of Structure	Quantity	Daily Output/Crew	Crew No.	Total Duration
STEEL				
Beams	12424 L.F.	900 L.F.	E-2	14
Columns	3886 L.F.	1032 L.F.	E-2	4
CONCRETE				
Beams	1090.37 C.Y.	18.55 C.Y.	C-14A	59
Columns	374.63 C.Y.	17.71 C.Y.	C-14A	22



- **SITE IMPACT**

The project site would not be affected by the steel erection of Sector C due to the fact that the other two sectors are erected in steel. The erection sequence can be done by using the two cranes that were applied to Sectors A and B.

- **CONSTRUCTABILITY COMPARISON**

The two structural systems require different methods of construction. The original cast-in-place method requires formwork, a pump for placement purposes, and scaffolding for erection. The problem that arises from this is that the scaffolding used will be different than the scaffolding used by the masons which means it will have to be set up, torn down, and then different scaffolding will need to be put into place. This results in wasted labor and cost. The formwork is also an additional cost compared to the steel system.

To erect the structural steel elements, the first item to be addressed is the crane size. The weight of the proposed steel columns however will not increase the crane size because the redesign of this sector did not induce any larger members than what is used throughout the rest of the building. Furthermore, when the design was finished, it was realized that the concrete members were actually deeper than those of the steel members, so there was no loss in plenum space when switching to a steel frame. This is a beneficial factor since this will reduce coordination issues between the mechanical, electrical, and plumbing trades since they have more space to work with.

The intent of the concrete structural system was to address the issues of vibration and deflection, but these two issues can also be addressed through a structural steel system. Deflection concerns are easily dealt with by changing the deflection parameters when running the RAM analysis. This would not result in an increase of size in the members, but would only affect the number of bolts connecting the elements.

- **BREADTH CONCLUSIONS**

The structural steel framing would be an acceptable alternative to the as-built concrete framing structure. Not only is the steel the cheaper option when compared to the concrete framing, but it also compresses the overall construction schedule, allowing the building to be substantially completed at an earlier date. The increase in plenum space will also contribute to a smoother coordination between the MEP trades. This shorter duration will also reduce the number of days for crane rental costs. It is my recommendation that a steel superstructure replace the concrete superstructure.

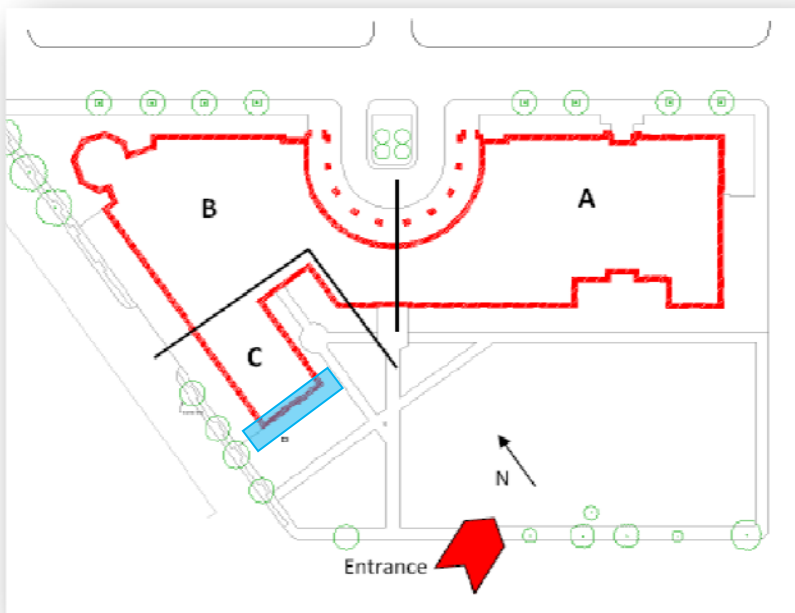
- **TOOLS USED**

RAM Structural System Version 11
R.S. Means Cost Data 2007
IBC 2006
Microsoft Excel
Microsoft Project
AISC Steel Manual 13th Edition
The VCU School of Business and Engineering Construction Drawings
The Gilbane Building Company

ANALYSIS TWO

ADDITION OF SOLAR ARRAYS TO THE MECHANICAL ROOF SCREEN AN ELECTRICAL BREADTH

- **BACKGROUND** – Green design and construction is becoming a growing trend within the respective industries and especially within campus construction across the nation at various universities. With the rapid urbanization of society today, all citizens are feeling the push to relieve our environmental footprint. Many college and universities are helping to set the development for green buildings and are extending their efforts to maintain healthy campuses. The Virginia Commonwealth University however, has no known green policy. The School of Business and Engineering is not LEED certified and does not feature any green characteristics.
- **PROPOSAL** – This analysis will incorporate placing solar photovoltaic panels on the south facing portion of the mechanical roof screen, which is located on Sector C of the building. This roof screen provides as a prime location for the placement of these panels since its only function is to shield the rooftop mechanical equipment. The roof screen is at a fixed angle of 39.5° which is a 2° difference from the latitude of Richmond, Virginia and the sunlight intensity is rated at “excellent”. The addition of these solar panels will not only be an aesthetic movement, but will also showcase the investment to the public, students, and employees both professionally and efficiently. This particular face of the roof screen faces due south, which is ideal, but also faces an open courtyard in which it will be observed. The goal of this analysis will be to analyze the amount of generated electricity, supply that amount to the building, and weigh the cost offset of implementing the panels.



The highlighted area in blue on the site plan is the proposed area of installation. As seen, it faces due south and has dimensions of 57-foot long and 27.5-foot wide at a 39.5° pitch.

THE ANALYSIS

DESIGN METHODOLOGY

- The analysis began by researching different photovoltaic panels. My selection ended by choosing to use a photovoltaic module made by BP Solar. The headquarters of BP Solar is located in Fredrick, Maryland, so this is useful due to the plant's proximity to the jobsite in Richmond, Virginia.
- After viewing the product range, I elected to use the BP **SX3190** module, which has a 190W rated power and is pictured to the right. This panel is typically used in residential and commercial construction, so it would be appropriate for this application. Full details of the module performance, configuration, electrical characteristics, and mechanical characteristics can be found in **Appendix C**.
- The next step was to determine how many panels could fit onto the south-facing portion of the roof screen, knowing the slope is 27.-feet in length'.
 - South Face (57-Feet Long) will fit **100 Panels**
 - **5 Rows of 20 Panels**
- Using the open-circuit voltage of 30.6V per panel and the U.S. NEC Rating of 600V, it was calculated that up to 19 panels could be connected in series while meeting code. My calculations are based on using 20 panels connecting in series. This is allowable due to the fact that by using the open-circuit voltage is very conservative.

$$\text{No. of Panels in Series} = 600\text{V}/30.6\text{V}/\text{panel} \\ = \mathbf{19.6 \text{ Panels}}$$

190 Watt Photovoltaic Module
SX 3190



MODULE CHARACTERISTICS

Maximum Power	190W
Voltage at Maximum Power	24.3V
Open-Circuit Voltage	30.6V
Current at Maximum Power	7.82A
Solar Cells	50
Maximum System Voltage	600V
Dimensions	
Length	66.0"
Width	33.0"
Depth	2.00"
Weight	33.95 lbs.



- To size the inverters, the maximum power was multiplied by the number of panels in series (20 panels in this case). This resulted in 3.8kW grid-tie inverters per 20 panels in series. The inverter model selected for this proposal is a Sunny Boy™ 3800U, 208V, which comes with a DC disconnect and 4-string fused combiner. The full specifications of the product can be found in **Appendix C** with the solar data.

- The proposed photovoltaic system uses 400 panels, and an inverter will be used per 20 panels, so this would result in a total of 5 inverters for the entire array. The calculation is below.

$$\text{No. of Inverters} = (100 \text{ panels} * 190\text{W}) / 3800\text{W/Inverter} = \mathbf{5 \text{ Inverters}}$$

- ELECTIRCAL IMPACT** – The next step was to consider the impact on the electrical system and tying the inverters into the current layout. There are several electrical rooms on the fourth floor with panel boards, which have spare room that would support the loadings of the inverters. In this case, there is room in close proximity to the panels, which is deal. Since there is only one sine wave of power (voltage) across the inverter, it is a single phase load. This means that each inverter will require 2 “spare” locations for the two phase wires. The impact on the panel board also requires calculations towards the wire size, loadings, and circuit breaker sizes per phase.

- Firstly it must be confirmed that the panel board can support the loadings of the inverters. The array needs inverters as previously mentioned and by inspecting the electrical panel board schedule, it was found that Panel P2N4A3 has the area to support all five (5) of the Sunny Boy inverters. This panel is rated at 225 Amps, which was used to determine the maximum loading that it could handle.

$$\text{Maximum Panel Loading} = (225\text{A})(208\text{V})(3)^{1/2} = \mathbf{81.1 \text{ kW}}$$

- Knowing that the panel can handle a maximum of 81.1 kW, this loading was weighed against the addition of loading five (5) inverters to ensure that the panel is not overloaded.

$$\text{Total Inverter Loading on Panel Board} = (5 \text{ inverters})(3.8\text{kW}) = \mathbf{19 \text{ kW}}$$

$$\mathbf{81.1 \text{ kW} > 19 \text{ kW}}$$

- To find the load (kW) each inverter has on the panel board, the kilowatts of the inverter was divided by 2 (single phase).

$$kW \text{ Load} = (3.8kW/2) = 1.9 \text{ kW}$$

- To size the circuit breaker, the kilowatts of the inverter were divided by 208V, which is what the panel is rated at.

$$\text{Circuit Breaker Size} = 3800W/208 = 18.27A \text{ use } 20A \text{ Circuit Breaker}$$

- Based off the circuit breaker size and the fact that the inverter comes with a ¾-inch conduit knockout for the wires, 2 - #12 AWG and 1 - #12 AWG was used (THHN/THWN, 600V).
- Below is a sample line of how the inverters would impact the panel board schedule. This form would essentially be the same for applying the remaining 19 inverters to the panel board(s). Please note that this is only half of the panel board contents. The full panel board can be found in **Appendix C**.

PANEL BOARD P2N4A3		RATING: 208/120V, 3φ, 4W			225 AMPS		
Load Description	Wire & Conduit	kW Load			CB/Phase	Circ. No.	φ
		φA	φB	φC			
Inverter 1	2#12 AWG + 1#12WAG G	1.9			20/2	1	A
			1.9			3	B
Inverter 2	2#12 AWG + 1#12WAG G			1.9	20/2	5	C
		1.9				7	A
Inverter 3	2#12 AWG + 1#12WAG G		1.9		20/2	9	B
				1.9		11	C
Inverter 4	2#12 AWG + 1#12WAG G	1.9			20/2	13	A
			1.9			15	B
Inverter 5	2#12 AWG + 1#12WAG G			1.9	20/2	17	C
		1.9				19	A

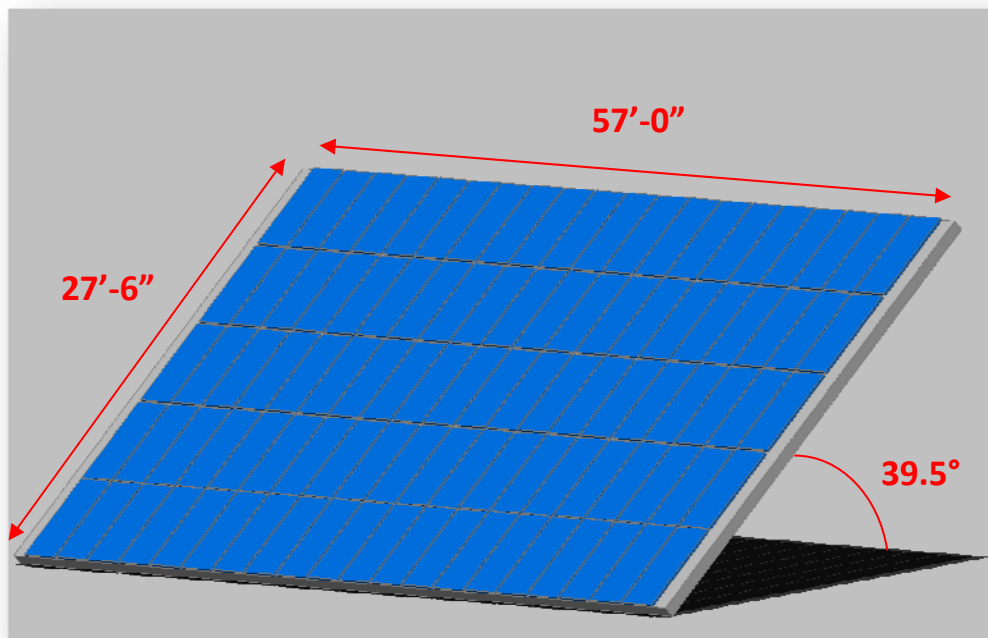
THE RESULTS

CONSTRUCTION RESULTS

- The solar data for Richmond, Virginia had to be adjusted to accommodate the tilt of the panels, which is 39.5° . This is due to the fact that the solar data is based off the latitude of a given location, which provides optimum performance of the solar panels (Richmond has latitude of 37.5°). The adjusted data can be found in **Appendix C**. From the values calculated in Appendix F, it was seen that the key direction is the Southern pitch of the roof screen and its data is summarized below.

ANGLED SURFACE DATA (kWh/m ² day) FOR RICHMOND, VA													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	AVG
S	3.29	3.9	4.57	5.05	5.21	5.40	4.85	5.10	4.74	4.30	3.54	3.02	4.47

- Below is a conceptual image of what the proposed array would look. It includes 100 panels, five rows of 20, and each row would be connected in series.



- **COST OFFSET** – When analyzing the amount of electricity generated by the solar array, the following figures were used in addition to the table above:
 - A power of 190 W (maximum power)
 - A voltage of 30.6 V (open-circuit voltage)
 - The corresponding days/month
 - An average price of \$0.09/kWh
 - 1.4 lbs of CO₂/kWh

SOUTHERN PITCH SAVINGS PER YEAR		
MO.	SAVINGS (\$)	SAVINGS (LBS OF CO₂)
JAN	\$190.31	2960.31
FEB	\$186.73	2904.72
MAR	\$242.26	3768.42
APR	\$259.07	4029.90
MAY	\$276.18	4296.17
JUN	\$277.02	4309.20
JUL	\$257.10	3999.31
AUG	\$270.35	4205.46
SEPT	\$243.16	3782.52
OCT	\$227.94	3545.78
NOV	\$181.60	2824.92
DEC	\$160.09	2490.29
AVG	\$230.98	3593.08
TOT	\$2771.81	43,117lbs

- **ADDITIONAL SAVINGS** – Additional savings would incur from the deduction of the materials that the panels would be replacing. The following table, taken from the assemblies estimate produced for Technical Assignment Ttwo, shows the cost savings of the materials. R.S. Means Construction Cost Data 2007 was used for pricing the materials, with the exception of the treated plywood, which was according to Home Depo. The plywood panels are at 8-feet by 4-feet and were priced at \$20 per panel. The savings were calculated based off a 50-panel deduction.

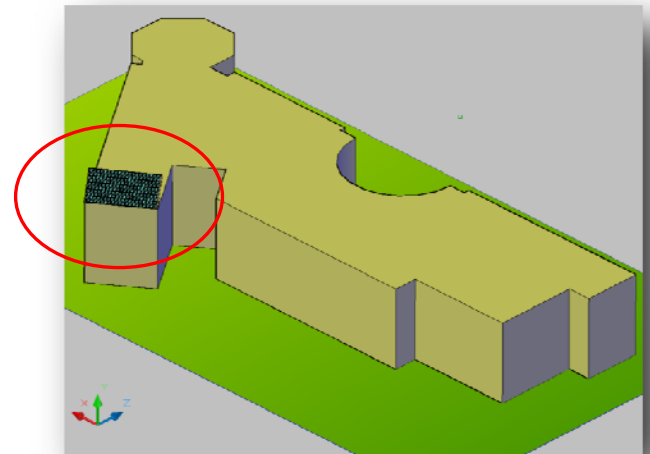
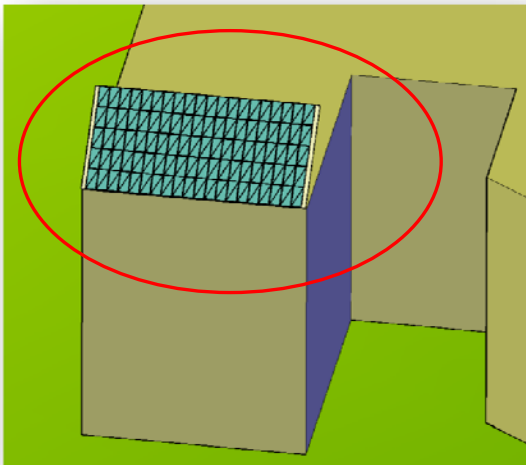
ESTIMATED MATERIALS SAVINGS	Total SF	Material Cost per SF	Total Material Cost	Installation Cost per SF	Total Installation Cost	TOTAL SAVINGS
Pre-Formed Metal Roofing	1567.5	\$2.86	\$4,483.05	\$1.88	\$2,946.9	\$7,429.95
Formed Metal Roofing	1567.5	\$14.35	\$22,493.62	\$4.71	\$7,382.93	\$29,876.55
Treated Wood Blocking						\$1000.00
TOTAL MATERIAL SAVINGS						\$38,306.5

- INVESTMENT**– When researching the cost of a photovoltaic system installation, it was seen that the cost of PV panels are roughly \$6.00 per Watt. The elected system uses a total of 100 panels at 190 watts, so the cost of the panels is estimated to be \$114,000. The cost per inverter is roughly \$2,500.00. Overall, the system costs roughly \$88,194 after deducting the savings calculated from above.

INVESTMENT			
ITEM	QTY.	COST/UNIT	TOTAL
Solar Panels	100 – 190W	\$6.00/W	\$114,000
Inverters	5 – 3800U	\$2,500.00 ea.	\$12,500
Savings			-38306.5
TOTAL			\$88,194

- VALUE ENGINEERING** – The addition of the solar panels to the building is obviously an implementation of value engineering. They should be viewed in terms of life-cycle cost and not just initial first-cost because the overall cost may be reduced by the avoided costs of the building materials they replace. It should also be reasonably assumed that the value of electricity produced by the PV’s will rise over time as the price of electricity increases. While it does minimize the energy and operating costs, it also relieves the footprint the building has on the environment.

- **CONSTRUCTABILITY REVIEW** – There are several areas of concern that might impact the constructability of the building when adding solar arrays.
 - **Panel Weight** – The panels are lightweight, 34 lbs, and the framing of the roof screen will provide adequate support for the PV system. BP systems are designed as lightweight as to not exceed roofing limitations.
 - **Mounting** – The proposed mounting for this system is “fixed.” Fixed-Mounted panels not only the least expensive alternative, but also easy to install.
 - **Wiring** – The panels are pre-wired for connection. Once they are aligned properly and then mounted, they simply connect together with the wire configuration for that model. No “assembly” is really required for wiring the panels together.
 - **Inverters** – The inverters tie directly into the grid of panels, which means there are no battery banks to deal with. The inverters would be located under the roof screen keeping their proximity to the panels very close as well as providing protection from the elements. The fact that they have dual disconnects is also very convenient. Inverters could be mounted on the supports for the roof screen, which would be at an adequate height for readings and connecting wires.
 - **Maintenance** – Once the system is installed, the maintenance is extremely minimal. If access is needed, the underside of the roof screen gives plenty of area to work with the inverters and panels.
 - **Utility Interconnection Requirements** – The local utility company needs to be notified of the array prior to the interconnection to their distribution system. Due to the fact that this system is only a 19-kilowatt system, there should not be any unique requirements.
 - **Local Inspector Requirements** – Consultation with local building and electrical inspectors will need to be done as well as to understand requirements that may be unique to the installation or service area.



- **SCHEDULE IMPACT** – The solar panel installation process would have a slight impact on the overall construction schedule. Key features that would have to be addressed through the building schedule would be the following along with the recommended plan of integration.
 - **Roof Penetrations** – The wiring of the PV system and integrating it into the electrical system would require several roof penetrations. This would need to be coordinated with the electrician to determine the proper areas to reach the specified panel board in the specified electrical room.
 - **Panel Installation** –The panel installation would have to be coordinated with the steel erector who is in charge of erecting the framework for the roof screen. The panels themselves only have to meet the deadline of August 3, 2007 which is when the commissioning for the electrical system takes place. More importantly would be the roughing-in of the electrical configuration that is associated with the PV array. The rough-in of the electrical system begins on October 4, 2006 and goes until October 25, 2006. The roughing in of the electrical necessities would not add any complications to the schedule as-is. There are already multiple roof penetrations as previously stated. The panels would be installed once the south portion of the roof screen is completed.

- **BREADTH CONCLSIONS** – It is recommended that the university erect the solar panels on the roof screen of the building. The investment is trivial when compared to the assemblies estimate for the roof screen itself (please see TECHNICAL ASSIGNMENT TWO). This investment could be made with the cost savings from analysis one. This installation could also start the movement for the university to put into effect a green policy on their campus.

- **TOOLS USED**
 - NEC 2006
 - BP SOLAR
 - SMA-AMERICA
 - CONSTRUCTION DRAWINGS
 - MICROSOFT EXCEL
 - WEATHER BRUEA ARMY NAVY DATA
 - R.S. MEANS CONSTRUCTION COST DATA
 - AUTOCAD 2008

CRITICAL RESEARCH

INCENTIVES AND DISINCENTIVES OF IMPLEMENTING PREFABRICATION

A CRITICAL INDUSTRY RESEARCH ISSUE

- **PACE SEMINAR SUMMARIZATION** - The PACE Seminar, which was held in October of 2007, began with a focus on prefabrication. While individuals within the industry recognized the benefits of prefabrication, convincing owners and builders of the benefits prove to be more difficult than easy. While prefabrication is currently gaining momentum, it is still not a conventional way of building. There are no standards to prefabrication; there is no single applicable technique and most techniques are project-specific. These facts raise difficulty in getting owners onboard early, which is a critical step in prefabrication. On the opposite side of the spectrum, are the subcontractors. As general contractors or construction managers, we must optimize prefabrication into a project through the individual trades making it necessary to recognize the opportunities and integrate them into the design of the structure. While there was a question addressing any union issues within the subcontractors, the panel and attendees expressed that there was little resistance from those union workers. The panel also discussed prefabrication from a green-build standpoint and the potential advantages that it can incur. Due to the fact that green-build continues to be a growing trend in the construction industry, it is logical to relate any sustainable opportunities to the act of prefabrication. Such “green” advantages that prefabrication can invite are a reduction in production costs, more efficient building systems, a better quality of building systems, a lessening of generated waste onsite, and a lower disturbance of the environment through minimizing lay down areas for materials.

- **GOAL** – The goal of my research is to identify the incentives and disincentives of implementing prefabrication within the construction industry. From the PACE Seminar, it is obvious that companies need to learn how to recognize the opportunities and potentialities for project improvement that is offered by pre-work. After this recognition occurs, it is critical to make the decisions regarding pre-work as early as possible. This report will address the following issues:
 - The motives of industry members to use pre-work (survey results).
 - How companies should frame their decision making process from the motives of pre-work.
 - Applying the same decision making process to the VCU School of Business and Engineering and the feasibility of prefabricating the mechanical roof screen.

- **INTRODUCTION** – Pre-work comes in various forms and has the potential to help project teams overcome difficult project conditions and can also reduce a project’s duration, improve productivity, and cut labor costs. To better understand the different methodologies of pre-work, the following term identifications were found useful when conducting my research.
 - **Prefabrication** – A manufacturing process that usually takes place in a controlled environment where different materials are joined together to form components for final installation. The components are usually in standard sizes that are easy to transport.

- **Preassembly** – A process where various materials, prefabricated elements, or and/or equipment are joined together by different trades at a remote location for ensuing installation.
- **Off-site Fabrication** – The practice of implementing prefabrication or preassembly of elements both on and off site at locations other than the point of final installation.

Companies who are considering the use of pre-work need a method to evaluate the benefits that are offered through the above mentioned pre-work.

- **PROBLEM STATEMENT** – Any type of pre-work mentioned above, when applied, impacts the management and execution of the construction process. There is no single applicable technique to prefabrication because in most instances, the type of method chosen will be project-specific, resulting in numerous ways in which pre-work can be applied. With that statement being said, there is however some generalities and needs that apply to most methods of pre-work.
 - Employing these methods require recognition of the benefits and risks associated with the method and a clearly defined scope of work. Without a distinct scope of work, crucial decisions will not be made in time to exercise any type of pre-work.
 - These methods demands proper planning and an early decision-making process considering all factors that are associated with the implementation of pre-work.
 - Pre-work may increase the requirements for design detail. If the location of the manufacturing shop or assembly locations are not close to the project site itself, inspections may be harder to complete.

The decision making process that companies use regarding pre-work is always adapting to the fact that technology is evolving on a daily basis and the construction environment is changing. Along with these changes, a lot of companies are not fully aware of the benefits that are associated with pre-work. Due to this lack of awareness the decision to utilize pre-work is made too late.

- **BACKGROUND** – The construction industry has seen a rise in the implementation of pre-work over the past decade and its use is very vast. While it initially had been more of a trial-error process, the industry has been improving the implementation of pre-work. In the sense that pre-work can address many scheduling and cost issues, the industry has become more aware of the impact that the construction process has on the environment. Pre-work is able to reduce the amount of waste that is generated onsite and this fact is valuable when considering the steps society has taken to enforce more “green” acts.

- **SCOPE AND METHODOLOGY OF RESEARCHING PREFABRICATION** - My research of prefabrication began by a short survey of industry members who have used or were currently using the methodology on past or current projects. The scope of the survey was limited to the construction industry in the United States and is specific to the commercial industry (residential and industrial construction was beyond this scope). The survey was to obtain a representation of the key factors that prefabrication has upon the mindset of the construction industry and was distributed to engineers, owners, and subcontractors. The survey, which consisted of advantages and disadvantages of implementing prefabrication, consisted of ranking the sub-topics on a scale from “Least Important” to “Extremely Important” (these sub-topics and their relationship to prefabrication are found below). The final question was open-ended and was to address any recommendations that the participator may have regarding prefabrication. I distributed thirty (30) separate surveys, but only received eleven (11) responses out of the thirty. While I realize that this number is not significant enough for an in-depth analysis, a small portion of my results does revolve around this number. The raw survey can be found in **Appendix D**.
- ***The Advantages: Driving and Benefiting Factors of Prefabrication***
 The driving and benefiting factors of prefabrication are two very closely related entities that both play critical roles in shaping the viability and extent of beneficial use of prefabrication on a project. Through performing a literature review, I found several common drivers and benefits of prefabrication:

 - **COST** – Prefabrication can reduce site overhead costs, as well as other time-related overhead costs, it can induce more efficient craft-labor onsite, lower off-site labor costs, and potentially lower equipment costs.
 - **RISK MANAGEMENT** –Off-site work contains fewer risks, such as those risks associated with weather delays, permitting delays, and interference with other trades. In addition, prefabrication also reduces the impact on the surrounding environment (i.e. reduces material waste, dust, and noise).
 - **SCHEDULE** – Another “pro” of prefabrication lies in the fact that fabrication may continue offsite while allowing delays at the project location and reduces onsite labor. Both of these factors can influence the timeframe of a project.
 - **QUALITY** – Prefabrication incurs higher quality control due to the controlled manufacturing settings.
 - **SAFETY** - Due to the fact that prefabrication is done on grade level, it makes sense to say that prefabrication exhibits safer working conditions for the various tradesmen. The safety scope ranges from workers not being exposed to inclement weather conditions, heights, interferences with concurrent activities, and, in some instances, hazardous processes.
 - **TOOLS** – The last driving factor is the advancement of the tools supplied to the construction industry. Building Information Modeling (BIM), for example, is making it easier for industry members to implement prefabrication onto their projects. Through BIM, the design becomes a certainty, making it easier to recognize the opportunities of prefabrication, from all aspects of the building.

- ***The Disadvantages: Risks and Barriers of Prefabrication***

While the motivating aspects are apparent and can be greatly beneficial, there are also several reoccurring barriers that face the industry, causing hesitation to implement prefabrication on a project. They are:

- ENGINEERING – Prefabrication invites an increase of engineering requirements. There is a limited knowledge base of designers, the industry is relatively inexperienced with the process, and inspections require a critical eye to ensure that locations and alignments will be met when the unit or assembly is set into its final position.
- TRANSPORTATION – The size and weight of the assembly may cause limitations regarding the transit to the project site. State departments have such limitations, which may require special permits for the transportation of the unit. In addition to this, the component will need some sort of protection when in transit.
- FLEXIBILITY – Prefabrication requires an early commitment. This commitment in turn decreases the amount of flexibility of the design, which may cause owners, architects, and engineers to recoil from employing prefabrication.
- COORDINATION AND COMMUNICATION – Coordination and communication are a critical and continual need during the process of prefabrication, from the design, to the transit, to the tracking, and finally to the installation. Owners, engineers, contractors, and suppliers all need to increase the communication with each other prior and during the process, which also increases their responsibility.
- SITE AVAILABILITY – The project site itself may deter any notion to employ prefabrication on a project. If the site is already congested, there may not be adequate space to accommodate the deliveries of the large assemblies.

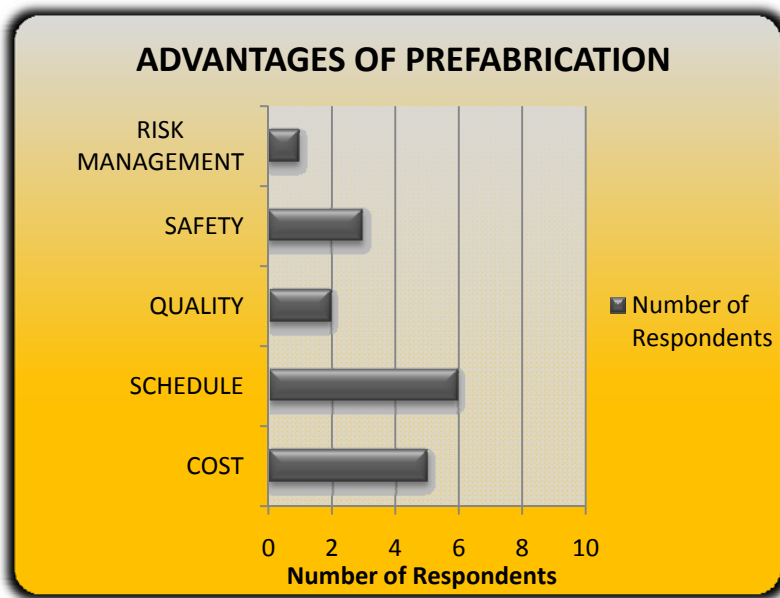


Figure 1 – Ranking of the Incentives of Prefabrication from Survey Participants

- RESULTS** - The results of my survey regarding the incentives of prefabrication are shown in Figure 1 to the left. It graphically represents that schedule is the primary incentive that pushes for prefabrication, followed by cost and quality. One item to note is that while these results are based on the eleven (11) respondents, there were instances where two advantages were rated as equally important. One comment was made regarding pre-work is that it makes the schedule much more predictable and, from that, the planning makes the management easier.

- RESULTS** – The results that were found regarding the disincentives of prefabrication were closely ranked between flexibility, transportation, and engineering when choosing to exercise pre-work. One comment from a survey participant that was made addressed that transportation is a major logistical concern as to what you can actually put on the road.

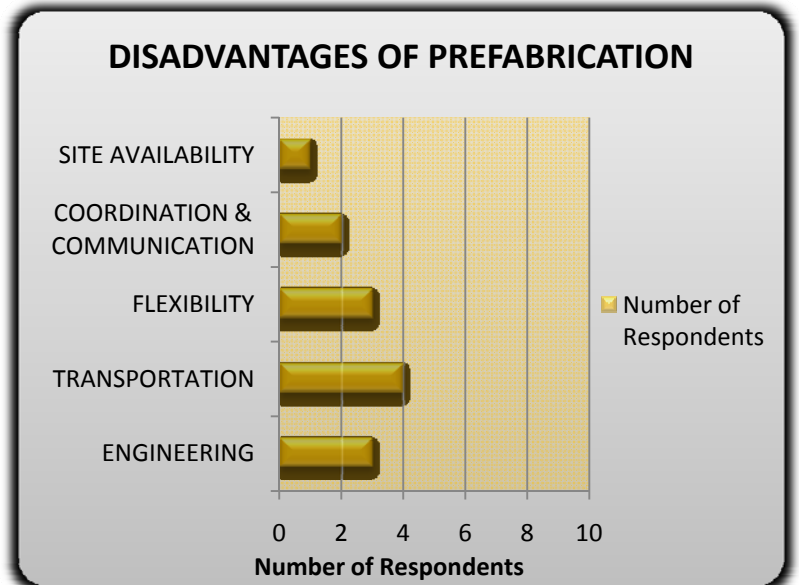


Figure 2 – Ranking of the Disincentives of Prefabrication from Survey Participants

- **INTERPRETATION OF SURVEY RESULTS** –I received several comments stating that the advantages and disadvantages are very specific to the job and can vary from project to project. This fact emphasizes the need to establish what the most important driving factor is, i.e. cost, schedule, quality, etc, as early as possible and then explore the different options of pre-work (assuming that a company has already decided to enforce pre-work on their project).
- **A FRAMEWORK FOR DECISION MAKING** – When the decision has been made to employ pre-work, the next step in the process is to establish which method is best suited for the project. This will not only take full advantage of the benefits of the method, but will also save wasted activity throughout the duration of the project. In a document written by the Construction Industry Institute in July of 2002, the group established a structured framework for decision making to successfully employ pre-work. Their generated framework revolved around the following criteria:
 - **Decision-Making Flow Chart**
 - **Conceptual Framework for Strategic Analysis** (Activities 1 -4) – Helps team members strategize the global drivers of the project.
 - **Conceptual Framework for Tactical Analysis of Pre-Work Alternatives** (Activities 5-7) – A methodology for team members to evaluate the cost impact of pre-work alternatives from the project drivers.

This framework provides general processes and guidelines for companies who are considering applying any type of pre-work. This framework promotes the discussion and thought-process of pre-work and an understanding of the benefits rather than a conclusive solution. The criteria that was set up for the decision making process is further explained below in the proposed order of operation that the Construction Industry Institute recommends.

- **Decision-Making Flow Chart**
The process begins in the early stages of the planning phase, where pre-planners are able to distinguish the opportunities of pre-work and directly relate them to the objectives of the project.
- **Activity One**
 - This step is designed to help pre-planners evaluate the potential use of pre-work. It involves asking a series of questions such as:
 - Is there specific restraints regarding the project schedule?
 - Is there a lack of local labor?
 - Is there an opportunity to reduce the lack of safety risks?
 - Are there site attributes that may hinder the project?
 - Do available routes and lifting paths allow or restrict using modules?

By answering yes or maybe to these questions, it is likely that pre-work is a logical choice and can be implemented. This step helps for early decision making.

- If any type of pre-work is not applicable, then the team will devise a plan based on conventional construction techniques.
- If pre-work is applicable, then the team will start to gather information that will help define the project.

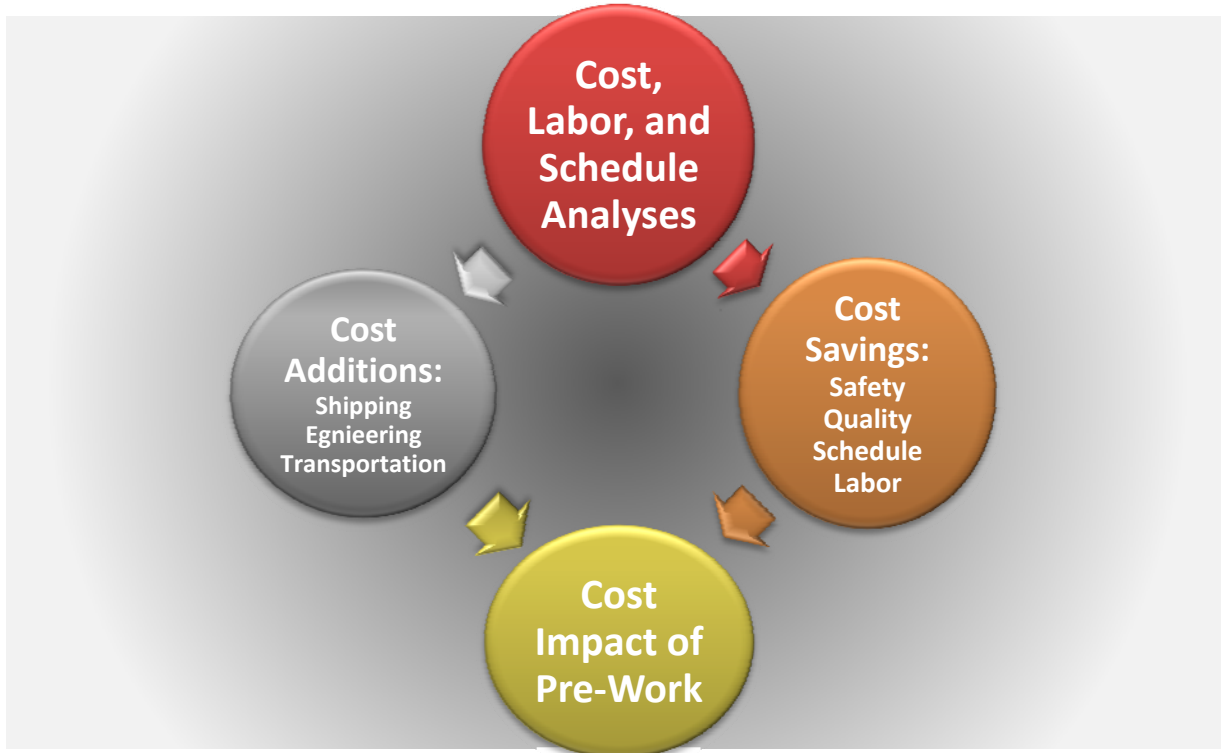
- **Activity Two**
 - This step involves collecting preliminary information regarding the questions of Activity One in more detail. These considerations can be found in the flow chart and are self-explanatory.

- **Activity Three**
 - Activity Three begins by further analyzing the categories in Activity One by posing questions that are beyond those found in Activity One. Some questions may be disregarded due to the fact that they may not apply to the specific project. This activity serves to stimulate discussion regarding ten areas of interest:
 - Cost
 - Schedule
 - Labor
 - Safety
 - Site Attributes
 - Mechanical System
 - Project and Contract Type
 - Transportation and Lifting Requirements
 - Supplier Capability

The project team can then evaluate the use of pre-work on each of these factors and whether or not pre-work supports each of these factors.

- **Activity Four**
 - Activity Four is aimed to recognize the specific incentives and disincentives from Activity Three and gauge their relative weights. This in turn enables the team to develop alternatives towards the types and levels of pre-work they are considering.

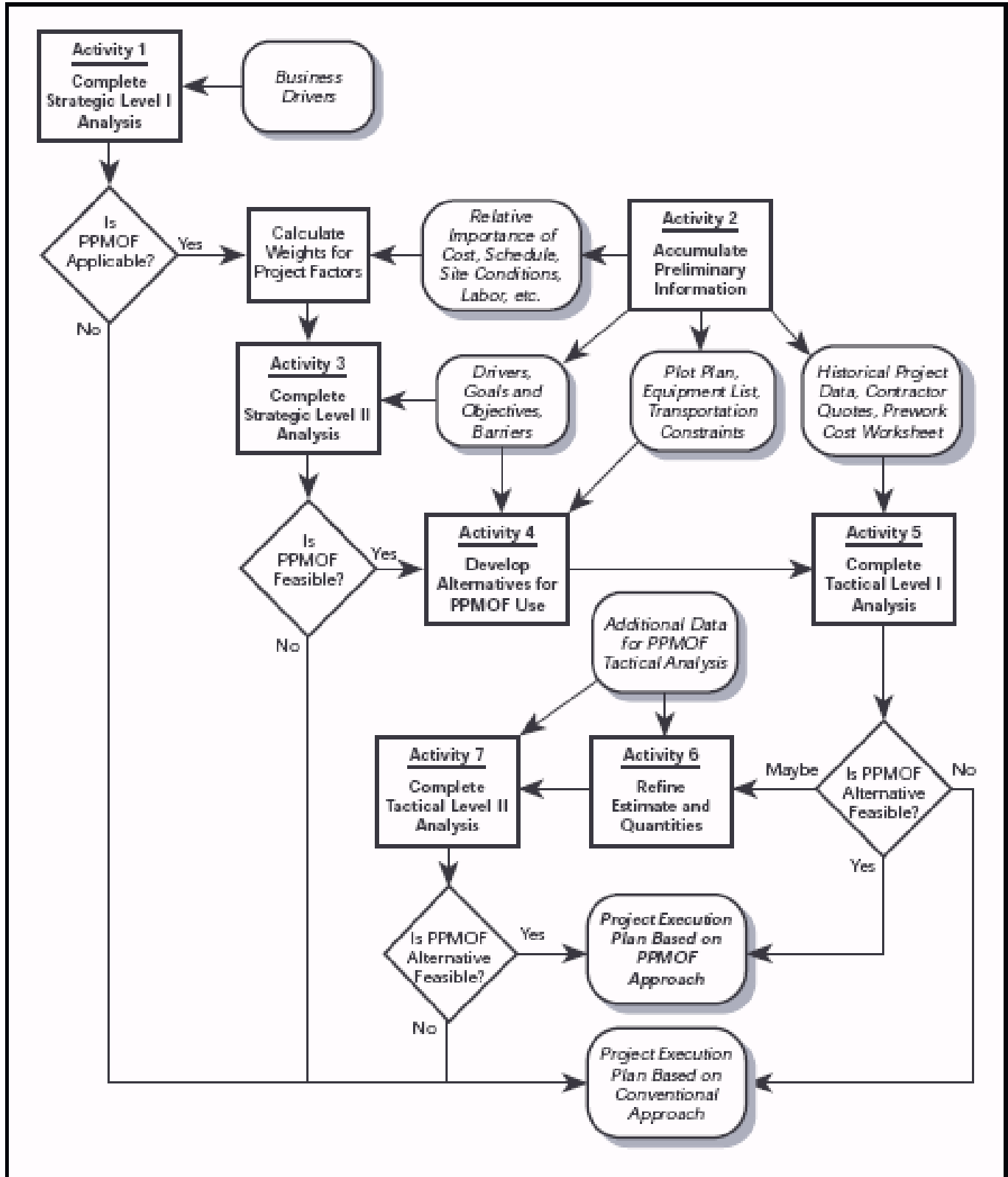
- **Activity Five**
 - This analysis begins the tactual investigation portion of the decision making process. It includes analyzing the different alternatives that were developed in Activity Four and a way to estimate the cost impact of pre-work strategies. This activity would take place during conceptual design phase/detailed design phase and requires the project team to gather project data (plot plan, equipment list, transportation constraints and flow sheets) and apply this data to formulate a cost-per-unit scenario for the project. This is due to the fact that modularization is typically quantified in a cost-per-unit fashion and this also is useful when comparing the modules to conventional construction methods.



A STRUCTURE FOR EVALUATING COST COMPARISONS OF PRE-WORK

- **Activities Six and Seven**
 - These two steps enable team members to pin-point the method(s) of pre-work they wish to pursue and refine their choice to optimize the cost comparison between their selection(s) versus traditional manners of building.

The chart that depicts the sequencing of activities is found on the next page and lays out all the discussed steps.



The Construction Industry Institute Decision Making Flow Chart

- **RESEARCH CONCLUSIONS** - Decisions to implement pre-work should be made at the strategic level of planning which includes weighing any specific demands of the project. The cost evaluation should be made at the tactical level of planning, where it's most often associated with the cost per unit.

Pre-work has several incentives, such as scheduling compression, cost reduction, addressing any safety concerns and a reduction in on-site labor.

However, there are certain challenges (communication, engineering, extra design requirements) that face the decision to implement pre-work. Technology is a key component to help overcome these challenges. Applications such as BIM are helping to identify the potentials of pre-work and also are helping to improve its efficiency.

- **RECOMMENDATIONS** – Companies who are deliberating the implementation of pre-work should use the framework for decision making to aid in the development of their ideas. This framework can help to distinguish the level of importance of specific factors and can also help to foresee potential burdens that are down the road. To maximize the potential of pre-work, it should be done in the stages before construction so that no time and/or money is lost if the decision is made too late. The following schedule is the recommended sequence of planning.

LIFE-CYCLE THROUGHOUT PROJECT	BUSINESS PLANNING	PRE- PROJECT PLANNING	CONCEPTUAL DESIGN	DETAILED DESIGN	CONSTRUCTION
ACTIVITY 1 Evaluate Pre-Work Potential	◆				
ACTIVITY 2 Gather Preliminary Information	■				
ACTIVITY 3 Evaluation of the Ten Areas		◆			
ACTIVITY 4 Produce Pre-Work Alternatives		■			
ACTIVITY 5 Analyze the Different Alternatives			◆		
ACTIVITY 6 Select Alternative			■		
ACTIVITY 7 Develop Estimates and Quantities				◆	

PREFABRICATION PLAN FOR VCU

IMPLEMENTING PREFABRICATION TO THE MECHANICAL ROOF SCREEN

- **PROBLEM STATEMENT** – The rooftop mechanical system of the Virginia Commonwealth University School of Business and Engineering was concealed by a customized roof-screen, which was very labor-intensive, timely, and costly. The screen is at a 10:12 pitch and involved laborers to be tied-off at 4-stories above ground, installing the wood-blocking and other roofing materials. Crane remobilization around the perimeter of the building induced extra fees. In addition to this, the roof had the majority of the mechanical system installed, so it was hard to find suitable lay down areas for the roofing materials and also incurred limitations to the maneuverability around the massive ductwork. I recognize this aspect of the project as a prospect of prefabrication. Researching the possibility of prefabricating the roof screen panels was done to determine any condensation of the schedule and lower any safety factors in having workers of different subcontractors on the steep incline of the roof. In addition to these issues, roughly \$90,000 worth of damage was done to the final roof of the building.



This aerial view of the building depicts the congestion of the rooftop mechanical system. The materials of the roof screen assembly consist of mansard screen steel supports, standing seam architectural metal roof, standing seam architectural metal roof “mansard screen” as well as the wood blocking for attachment purposes. This picture shows the installation of the wood blocking on the roof screen.

- **METHODOLOGY** – The process began by using the “Framework for Decision Making” that is posed by the Construction Industry Institute. The focus began by asking the proposed questions:
 - There are specific restraints for the project schedule – the building must be completed for the spring 2008 Semester.
 - There is a safety concern in having the workers of different sub-trades tied off in order to install the roofing materials.
 - The site does allow for the lifting of panels – the crane would be remobilizing around the building perimeter to erect the steel formwork.

By answering yes to these questions, the next stage was to gather the preliminary information regarding the site.

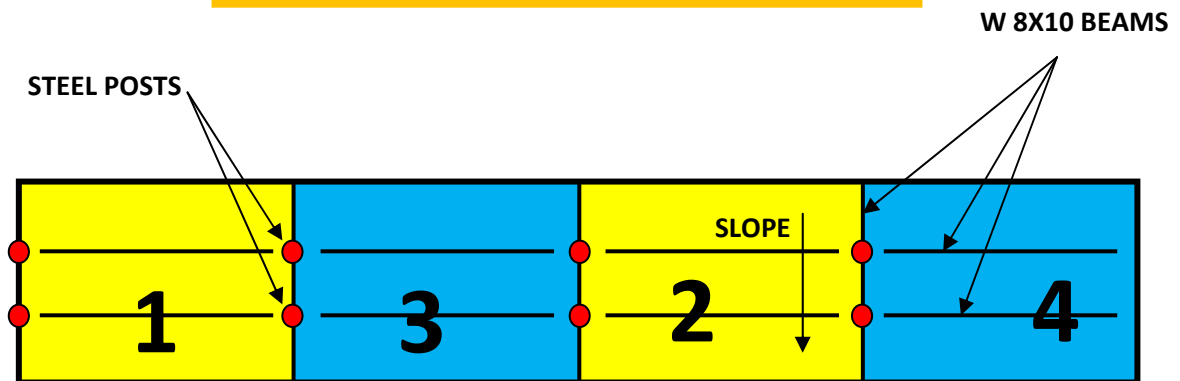
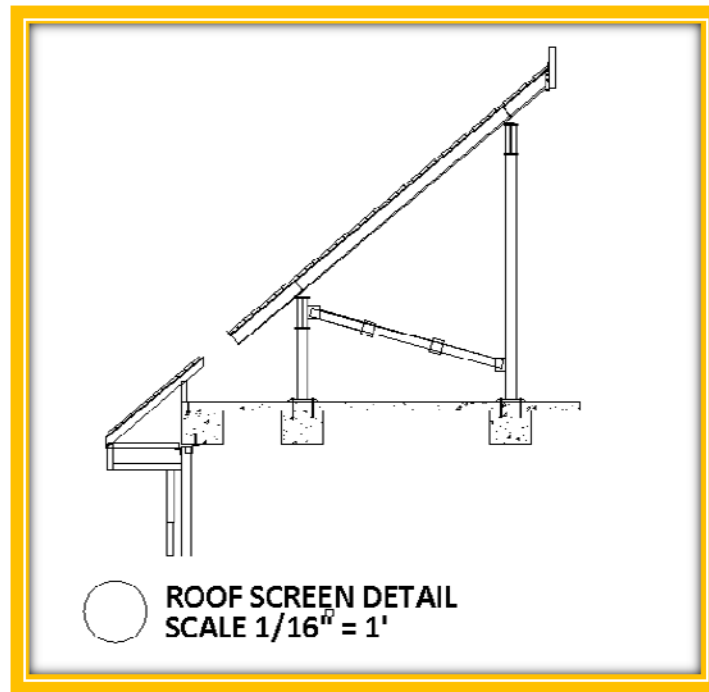
- The typical panel width is roughly 21-feet by 27.5-feet
- The maximum panel weight, including all materials assembled on it, is 3,500 lbs
- There is an estimated 65 panels in total
- The site does allow some room for the prefabrication area of the panels. The north-west area of the project site would provide for the assembly area. If this area became too congested, there is a parking lot on the other side of South Madison Street that would also suffice for an assembly area.

Next, it was necessary to address the ten areas of interest that are recommended on the decision making flowchart. Some of the ten items were eliminated due to the specificity of the project.

- **Cost** – The cost reduction will come through cutting the labor costs rather than saving on material. I chose to keep the amount of material the same and focus on relieving the labor on the roof.
- **Schedule** – The schedule is demanding in the sense that the building needs to be complete for the start of the spring semester.
- **Labor** – There is no labor shortage for this particular activity.
- **Safety** – The safety issues for the roof screen installation arise through the fact that several trades need to be tied off on the steep pitch of the roof. This is not only dangerous, but delays were incurred when the weather was the slightest bit rainy.
- **Site Attributes** – Due to the congestion of the site, panels should be assembled in the adjacent parking lot.
- **Transportation and Lifting Requirements** – The transportation would not be an issue, seeing that the materials would be delivered non-assembled. The crane that is currently on site at this particular time would be able to handle the weight of the panels.

The sequence then proceeds to evaluating the different alternatives of pre-work. I elected to use on-site assembly due to the fact that the materials are not to the level of complication where they need to be assembled in a controlled environment. This would also allow for the proper personnel to inspect the work more easily.

No cost estimate was done on a typical panel due to the fact that the savings was not directed towards the materials; hence the material cost did not change. Dimensions of the panel were also taken into consideration at this point. Below are a detail of the roof screen and a table of estimated quantities that would help with the erection planning.



The plan illustration above is to propose a possible erection sequence. This is a section of 4 typical panels, each 21-feet long, with the column supports indicated in red. The panels in yellow would be fabricated and erected with the steel posts intact. The panels in blue would then be simply placed and connected. Two yellow panels would need to be installed before the blue panels could be set into place, hence the numbering provided above. This pattern would continue around the perimeter of the building.

This finalizes the decision to implement pre-fabrication. There are however several issues that need to be discussed in regard to this concluding decision.

- The first is the obstacle of transferring the panels from the parking lot across the street to the project site. This is easily overcome when considering the weight of the panels, which is 3,000lbs. A smaller crane can be used to lift approximately 10 panels onto a trailer that is hitched to a standard pick up with the adequate towing capacity. This trailer can then be moved across the street where the crane can begin to place the panels on the roof.
- There would need to be some type of temporary supports for the panels.
- The panels would need to be erected somewhat “incomplete” to allow for the final connections of the units together, i.e. where the blue and yellow panels connect. This would induce some, but not much, work on the roof of the steel erecting trade.
- After speaking with the steel erector, it was estimated that somewhere between 6 to 9 panels could be erected each day. Keeping in mind there are 65 panels total, this equates to a range of 8 to 11 days for the roof screen installation.
- This decision would need to be made fairly early in the project due to the fact that their fabrication should begin during the superstructure erection. These two activities could be concurrently taking place to ensure the panels would be ready in time to erect.
- While the fabrication is recommended to take place in the adjacent parking lot, some security issues may be present as to how to protect the materials from vandalism and theft.

▪ **CONCLUSIONS AND RECOMMENDATIONS**

This idea seems to be a serious alternative that could have saved Gilbane money in terms of weather delays, the slower pace that was seen when having subcontractors working off the roof of the building, and lastly the damages associated to the finished roof. It should be recognized that all damages will not be eliminated due to the fact the installation of the mechanical equipment is also taking place at this time.

Lastly, labor costs would be expected to be less due to the fact that while on ground, the associated trades can work at a faster pace, possibly with a smaller crew. While there were no accidents when installing the roof, safety concerns are less severe when considering this method.

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Mr. Brian Ault – Mechanical Option

APPENDECIES

APPENDIX A

PROJECT OVERVIEW

PROJECT SUMMARY SCHEDULE

APPENDIX B

STRUCTURAL ANALYSIS DATA

Level 1 Design

Level 2 Design

Level 3 Design

Level 4 Design

Roof Design

Beam Summary

Steel Estimate

APPENDIX C

ELECTRICAL AND SOLAR DATA

BP Solar Photovoltaic Module Data Sheet

Sunny Boy 3800U Inverter Data Sheet

Panel Board P2N4A3 Schedule

Adjusted Solar Data for Richmond, Virginia

Array Savings Spreadsheet

Conceptual View of the Solar Array

APPENDIX D

RESEARCH DATA FOR PREFABRICATION

Industry Survey

Standing Seam Architectural Metal Roof "Mansard Screen" Detail