2011

REVISED SENIOR THESIS PROPOSAL
Submitted 1/10/2012

Construction Management
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Executive Summary

The purpose of this proposal is to outline four analyses conducted on the Biological Research Laboratory. The in depth analyses are designed to improve the construction processes of the project while delivering a better overall facility to the researching staff. Topics covered in the analyses include the design of modularization for interior spaces, Building Information Modeling incorporating virtual mockups, renewable energy systems and labor productivity. These technical analyses will be developed over the course of the spring 2012 semester. At the end of the course the proposed analyses are presented to the Architectural Engineering faculty and jury members.

Analysis 1: Modularization of the Laboratory Spaces

Modular units in recent years have been a viable solution for quality construction. Fabricating in an offsite location is less expensive compared to field assembly as well as the schedule benefiting by reducing the overall duration of the activity. Quality is also assumed to be higher than if constructed in the field. Inexperienced subcontractors can perform unacceptable work which can delay the schedule in order to fix. The goal of the analysis is to increase the quality of finishes in the laboratory space while decreasing the schedule. Along with fabrication of the modular units other areas of the building will be evaluated such as the structure and the MEP systems in this analysis.

Analysis 2: BIM Implementation with Virtual Mockups

Virtual mockups allow users to also get to express their opinion on sample lab areas for space requirements and layouts without construction. Comparing virtual mockups to field mockups along with the users' opinion on which space can be more effective is a large piece of this analysis. A benefit of not using as many field mockups is the reduction of waste associated with the project which can affect the LEED rating. Virtual mockups can also be made well before the purchasing of any lab equipment and used as a selection process for specialty equipment. Techniques learned in 597A will be applied regarding modeling and the presentation of the virtual mockup.

Analysis 3: Sustainability

Sustainable and energy efficient design is becoming mandatory by many owners and facility managers. The BRL labs are high in consuming energy because of the redundant systems, only achieving LEED silver. Using techniques learned in AE 897G as well as other architectural engineering classes the idea of solar panels will be implemented as well as utilizing geothermal loops. Adding these two energy systems accomplishes multiple goals; it significantly lowers electric usage as well as the amount of heated water. A cost analysis of the total system will be examined as well as the possible redesign of the K joists located in the roof.

Analysis 4: Labor Resources Schedule Acceleration

The critical path of the project lies with the construction process, if one or more of these activities are not completed on time the project completion date would not be achieved. This analysis will examine the schedule of the project and break down different activities, imposing several changes to accelerate the project schedule. The goal of the technical analysis is to return the project to the planned completion date with minimal cost implications.

Contents

Project Description

The Biological Research Lab is an Animal Biological Safe Laboratory (ABSL-3) located on the Pennsylvania State University Campus. The laboratory's design of a modern barn captures the nature of the surrounding facilities. Making up the façade, the rusticated concrete masonry units, metal roof and unique windows fit with the agricultural part of campus while providing a high efficiency building envelope. The facility as seen in figure 1 is approximately 20, 330 square feet and has a scheduled cost of $23 million which is funded by the National Institutes of Health (NIH) along with Penn State.

Figure 1 - Courtesy of Payette Associates

The Animal Biological Safe Laboratory went through a lot of different designs due to the source of funding as well as taking into account the complex and one of a kind facility. Many BSL-3 facilities (Biological Safety Laboratory) across the country are modular built making it easier to construct the redundant mechanical systems required to carry out testing. The central design of the lab allows for a single corridor down the center of the building with a conference room utilizing the large window for natural daylight in figure 1. One benefit of design was to incorporate future expansion on the north side of the building.

The facility is comprised of three floors plus a basement; research will take place on the ground floor while Air Handling Units are located above, and the chilled water system and hydronic (boiler) system below in the basement. Other systems that are included in the mechanical penthouse are the effluent decontamination system, electrical and plumbing. Due to NIH standards the research laboratory was designed to meet construction and redundancy standards for ABSL-3 facilities. The U.S. Green Building Council, an organization that promotes sustainability in how buildings are designed and constructed, created a certification for green building entitled LEED. The new Bio-Research Lab is currently seeking the level of LEED Silver just above LEED Certified which is mandatory for all new construction on The Pennsylvania State University campus. The new facility will achieve this rating through concepts such as utilizing recycled materials and local materials to construct the new building.

Analysis 1: Modularization of the Laboratory Spaces

Problem

The Biological Research Facility is currently in early stages of construction and through research pertaining to Vivariums, interior finishes tends to be an area where subcontractors struggle. Contractors usually cut corners in order to stay on schedule which results in fixing the problem as a punch list item. For seeing this problem from reading case studies it seems traditional construction of the interior lab spaces is inadequate. Especially with the lack of experience of local contractors in vivarium construction an alternative method could be implemented to keep both the quality of work and project on schedule.

Research Goal

The goal of the analysis is to increase productivity of labor crews on certain activities to bring the project back on schedule. Length and widths of the module are typically designed as multiples of each other, providing easier flexibility for layout. Also, examining the units could suggest that each room be assembled separately because of size constraints with transportation. Modularizing the lab spaces would result in approximately 15 units, sized at 11' by 20'. Manufacturing the labs off site with a contractor who has experience with ABSL facilities ensures the primary goal of acceptable finishes which can significantly impact the schedule.

Methodology

- Research the design of the Laboratory spaces pertaining to Animal Bio Safety Laboratories
  - Seamlessly integrating modules
  - Adapt sustainability and special requirements
- Interview Local Manufacturers about fabrication, transportation, and lead times affecting the schedule
  - Ensure Commissioning Agent as well as the manufacturer have the same standard of quality of finishes
- Analyze the structural system of the existing building because of the added weight of each modularized unit
- Evaluate design impacts of MEP systems within the building and the connections between the laboratory spaces
- Re-sequence the schedule for the Laboratory to allow the installation of modular rooms
- Compare the Cost of traditional versus modular as well as the implications to the new schedule reduction

Resources and Tools

- Industry Professionals from PACE, internships and guest lecturers
- Torcon – Construction Manager
- AE Faculty – Construction Management, Structural
- Office of Physical Plant
    - Design and Construction Team
    - Engineering Services/ Design Services
- Modular Contractors with ABSL experience
- Supportive coursework
    - AE 308, AE 404, AE 397A, AE 570, AE 473
- Architectural Engineering students with a focus in Structures
- Applicable Case Studies, Books, Online Publications

Expected Outcome

Modularization can be beneficial though proper planning and is extremely lucrative when shortening the schedule of a project. The quality of fabrication is also high because of the repetitive process in a closed work environment. Schedule and quality of work are important to the owner and the user but significant design and planning should be taken into account before implementing modular design. The National Institutes of Health (NIH), the primary funder of the project, has specific design requirements in order to receive the $15 million in grant money. Specifically, when designing the modular spaces the mechanical and plumbing systems must be left as designed.

Interactions and connecting utilities between the adjoining lab spaces will be the most challenging to implement. Due to NIH, specific wall penetration details need to be implemented which could pose possible constructability issues. Structurally the system will need to be evaluated, through previous research and case studies additional weight of the prefabricated "POD" could require a structure redesign. The metal decking with 2" of light weight concrete is the biggest concern followed by column and beams connections, and finally the size of the footings.

After researching the required areas, the implementation of modular lab units will be viable in the construction of the Biological Research Laboratory. One benefit of the imposed change is expected to be decreasing the schedule which is already behind. Another big benefit would be quality of finishes; contractors would no longer have to return to fix punch list items after the inspection by the commissioning agent. This not only saves time on the schedule but also money for change order due to lack of information on drawings.

Analysis 2: BIM Implementation - Benefits of Virtual Mockups over Traditional Field Mockups

Problem

The Researchers and Users of the Biological Research facility have complete control over the design of the laboratory spaces. Field mockups pose issues of high construction cost and they do not always provide the users with adequate flexibility in the design of the space. Many times construction contracts specify how many different field mock ups will be constructed throughout the duration of the project but sometimes more are needed to prefect the design of the facility. Field mockups also negatively impact the LEED score card because of wasted material after the mockup is dissembled. While field mock ups deliver the hands on approach, an alternative method could be implemented to perfect the quality of details as well as the spatial layout of the laboratory spaces.

Research Goal

The goal of the analysis is to implement virtual mockups and reduce field mockups while obtaining a better quality and design of the space. A series of the different laboratory spaces will be modeled in Revit Architecture including the holding areas, procedure rooms and prep spaces to be evaluated by the users. Virtual mockups would eliminate the need for much iteration of field constructed model spaces, reducing waste and cutting cost to the owner and the construction team. Another goal is to reduce change order in the final months of construction, which usually increase the cost and the duration of the schedule. Due to the simplicity of virtual models imposing changes based upon the researcher's preferences is easy creating a better designed laboratory space.

Methodology

- Research the design and presentation of virtual mockups for researchers of the facility
- Develop the virtual models of the different spaces within the Animal Biological Safe Laboratory
    - Incorporate equipment, cages, doors and other items
    - Model precise placement of utilities such as switches, outlets and sinks
- Use the Immersive Construction Laboratory to obtain feedback from the users in the layout and spatial plan of the rooms they will be utilizing in the future.
    - Evaluate adjacent Bio containment cabinets for enough space
    - Assess the space between and around corners for lab carts as well as the clearances between adjacent doors
- Impose design changes before the assembly of the field mockups

Resources and Tools

- Industry Professionals from PACE, internships and guest lecturers
- AE Faculty - Dr. Messner; Professor at the Pennsylvania State University
- Torcon – Construction Manager
- Cadnetics – BIM Coordinator
- Office of Physical Plant
    - Design and Construction Team
    - Engineering Services/ Design Services
- Supportive coursework
    - AE 597F
- Applicable Case Studies, Books, Online Publications

Expected Outcome

Case studies have shown that virtual mockups are feasible; they provide the same information to users, utilizing three dimensional modeling to convey information about the layout of a space. Through the use of VR and researchers input on possible design changes; a more cost effective as well as better designed room can be implemented, ultimately reducing the amount of field mockups constructed for the project. Along with the reduction of field mockups one benefit is the reduced waste on a project having the ability to score more points in the material and resources section of the project.

Analysis 3: Sustainability

Problem

Energy consumption for the Biological Research Laboratory is one area which limits the building from achieving a higher LEED certification. The eleven air handling units supply air to the four laboratory spaces, corridors, offices and stairwells as per the design conditions from the National Institutes of Health. Also the redundant boiler system de-contaminates cages and lab spaces after procedures and experiments. In the area of Energy and Atmosphere, on the LEED score card, the BRL facility achieves no points under Green Power or On-Site Renewable Energy. There is total of 9 points that could possibly be obtained if a renewable energy source was implemented.

Research Goal

The goal of the analysis is to implement a renewable energy system, evaluate the potential savings of the building as well as compose a financial strategy to fund the project. Through using either a geothermal system or a photovoltaic system, a certification of LEED Gold would be obtained from installing the new energy harvesting system. The photovoltaic system will be placed in multiple areas around and on the building serving multiple functions by have the possibility to charge alternative vehicles through car canopies to the traditional roof design. The Geothermal system if implemented could serve multiple purposes by lowering the cost to providing heating and cooling to providing partially heated water to the effluent decontamination system.

Methodology

- Research the Photovoltaics as well as Geothermal ground source heat pumps and heat sinks
    - Choose a system that will have the biggest impact on the building
- Contact local manufacturers about design factors for the location of installation
- Analyze the structural system of the existing building because of the added weight of each photovoltaic panels plus the racking system
    - Possible redesign of the K joist roof system to account for the additional dead load
- Evaluate design impacts of the electrical system (Photovoltaics)
    - Where to place the inverters (usually outside)
    - Where to integrate the power into the panel boards
- Evaluate design impacts of the mechanical system (Geothermal)
    - Where to place the additional equipment in the basement
    - Determine connection to the Boiler system
    - Incorporate a water to water system for the Air Conditioning
- Depending on the system chosen evaluate where LEED points could be obtained in order to acquire LEED Gold
- Compare the cost to value savings

Resources and Tools

- Industry Professionals from PACE, internships and guest lecturers
- Torcon – Construction Manager
- AE Faculty – Construction Management, Structural
- Office of Physical Plant
    - Design and Construction Team
    - Engineering Services/ Design Services
- Geothermal or Photovoltaic contractors
- Supportive coursework
    - AE 897A
- Architectural Engineering students with a focus in Structures
- Applicable Case Studies, Books, Online Publications

Expected Outcome

Through the design and installation of either a photovoltaic system or a geothermal recovery system, the Biological Research Facility will be able to reduce the overall energy consumed by the series of redundant mechanical systems. Adding the renewable energy system should also earn enough LEED credits making the Laboratory a LEED Gold structure. The financial feasibility on this systems is less of a concern compared to the Universities image on research. The Biological Research Laboratory is a one of a kind facility in which many researchers will visit once complete; just as the Penn State researcher did, to build this lab. The energy saving system has more value because it will advertise the green movement of The Pennsylvania State University combined with a state of the art Animal Biological Safe Laboratory. The installation of a renewable resource will be feasible with added bonuses in LEED certification as well as bettering the Green image of the University.

Analysis 4: Schedule Acceleration (Critical Path)

Problem

The Biological Research Laboratory is approximately two months into construction when permitting issues involving Labor and Industry set the project behind schedule. Problems permitting with the Labor and Industry and the inability to receive and start work caused the project to be delayed from the start. Another difficulty that imposed a scheduling delay was the weather in late August to the end of October, rain forced the excavation of the site to stop as well as the utility banks to be delayed. If the project does not finish on schedule both the owner and Torcon, the Construction Manager, would likely incur damages.

Research Goal

The goal of the analysis is to develop a schedule acceleration scenario while incorporating labor efficiency, and the added cost for overtime. An activity where time can be reduced was in steel erection and the placement of metal decking. Along with the increased number of crews re-sequencing will be evaluated in order to properly redistribute the crews so that their productivity remains higher than working a normal work week. Work flow on the project will also be evaluated because of the direct correlation to a crews inefficient work hours. The steel fabricating crews overall productivity ultimately determines a breakeven point, where working overtime is not beneficial and the acceleration of another activity may need to be assessed.

Methodology

- Research comparable schedule acceleration, work flow, and labor productivity techniques
- Evaluate the existing sequencing of work with added labor resources
    - Investigate the installation procedures of the steel and metal decking, can it be performed more efficiently
- Develop a new work week incorporating overtime for labor crews
    - Determine a breakeven point based on productivity and number of weeks worked
- Incorporate the crew levels to bring the project back to the scheduled completion date

Resources and Tools

- Industry Professionals from PACE, internships and guest lecturers
- Torcon – Construction Manager
- AE Faculty – Construction Management
- Office of Physical Plant
    - Design and Construction Team
    - Engineering Services/ Design Services
- Steel Sub Contractor
- Supportive coursework

  - AE 570
- Applicable Case Studies, Books, Online Publications

Expected Outcome

Through research and speaking with the project team, their sub-contractors and industrial professionals; develop a feasible acceleration scheduling scenario involving the steel sub-contractor. In the study, labor efficiency will be evaluated examining the earned value concept. The time to finish the super structure of the building has approximately a five week duration. Utilizing overtime for crews by implementing ten hour days as well as working on Saturdays for ten hours cuts one week off the project schedule. Allowing the steel crew to work overtime for the entire duration enables the crew to finish steel erection and metal decking in three weeks and two days compared to the original five week duration. This simple acceleration scenario without looking at inefficient work hours, labor productivity, or performance ratios places the project back on schedule.

Analysis Weight Matrix

The four technical analyses proposed on the Biological Research Laboratory integrate four primary areas which include Critical Issue Research, Value Engineering Analysis, Constructability Review and Schedule Acceleration. The table illustrated in Table 1, evaluates the weighted values of each study and the relation between the primary areas discussed above.

Analysis Description	Research	Value Engineering	Constructability Review	Schedule Acceleration	Total
Modularization	10%		10%	10%	30%
BIM Implementation	10%	10%	10%		30%
Sustainability		10%	5%	5%	20%
Structural Schedule Acceleration			10%	10%	20%
TOTAL	**30%**	**20%**	**30%**	**20%**	**100%**

Table 1: Weighted Analysis Matrix

Timetable

One requirement for the Capstone Senior Thesis project is to plan out a detailed schedule of work for Spring 2012. This timeline illustrates key dates and milestones which are used to balance a student's workload throughout the semester. Included in Appendix B, the preliminary table for the Spring Semester for the proposal can be referenced.

Conclusions

The in depth study of each analysis addressed above incorporate construction industry issues of today by recognizing problems and implementing the proposed solutions. Expected outcomes on all four analyses aid to develop a better quality Animal Biological Safe Laboratory on the Pennsylvania State University Campus. The incorporation of modularized spaces for the labs, holding and prep areas will not only decrease the schedule of the project but more importantly; the modular units would be of higher quality than if traditionally built. The implementation of virtual mockups provides more flexibility for the owners and a lower cost. Virtual Mockups also eliminates construction waste and provide more points to LEED scorecards. The addition of a sustainable energy system helps to lower the net energy usage of the facility as well as obtaining points toward LEED. Proposing a schedule acceleration of increased labor hours while evaluating their productivity will ensure the completion of the project.

This technical proposal on the Biological Research laboratory is ongoing and will continually be updated as the spring semester progresses. Design changes will be based upon research, additional feedback and industry professional's suggestions.

[APPENDIX A]

Breadth Topics and MAE Requirements

BREADTH Topics:

Structural Breadth: Pertains to Technical Analysis #1 & Technical Analysis #3

The building footprint sits on a series of reinforced spread footings for the steel columns where the spread footing reinforcement extends into the column footing. According to the geotechnical survey of the site, the wall footings and column footings must be 18 and 24 inches respectively to avoid punching shear failures. The first floor was comprised of a 2 inch metal composite deck with 2.5 inches of lightweight concrete. The steel throughout the structure will be comprised of both HSS4x4x4x3/8 as well as a series of wide flanged columns, W8x31 being the most commonly used. The beams in the structure are also supported by a series of hollow core structural steel as well as different types of wide flanged beams. The roof is comprised of a 1 1/2 inch metal decking that is supported by joists and the joists transfer the load to the beams and ultimately the columns.

Added dead load from the modularization of the laboratory spaces, in Technical Analysis 1, requires many of the structural components described above to be evaluated. The metal decking is one of the primary concerns as well as the connections between the beams and columns. One more area of concern is the size of the footing for the Biological Research facility. The Photovoltaic system which is outlined in Technical Analysis 3 imposes a significant amount of added dead load to the roof structure. The K joist system will need to be evaluated based on the additional load as well as other areas that could be affected within the structure.

Electrical Breadth: Pertains to Technical Analysis #1 and Technical Analysis #3

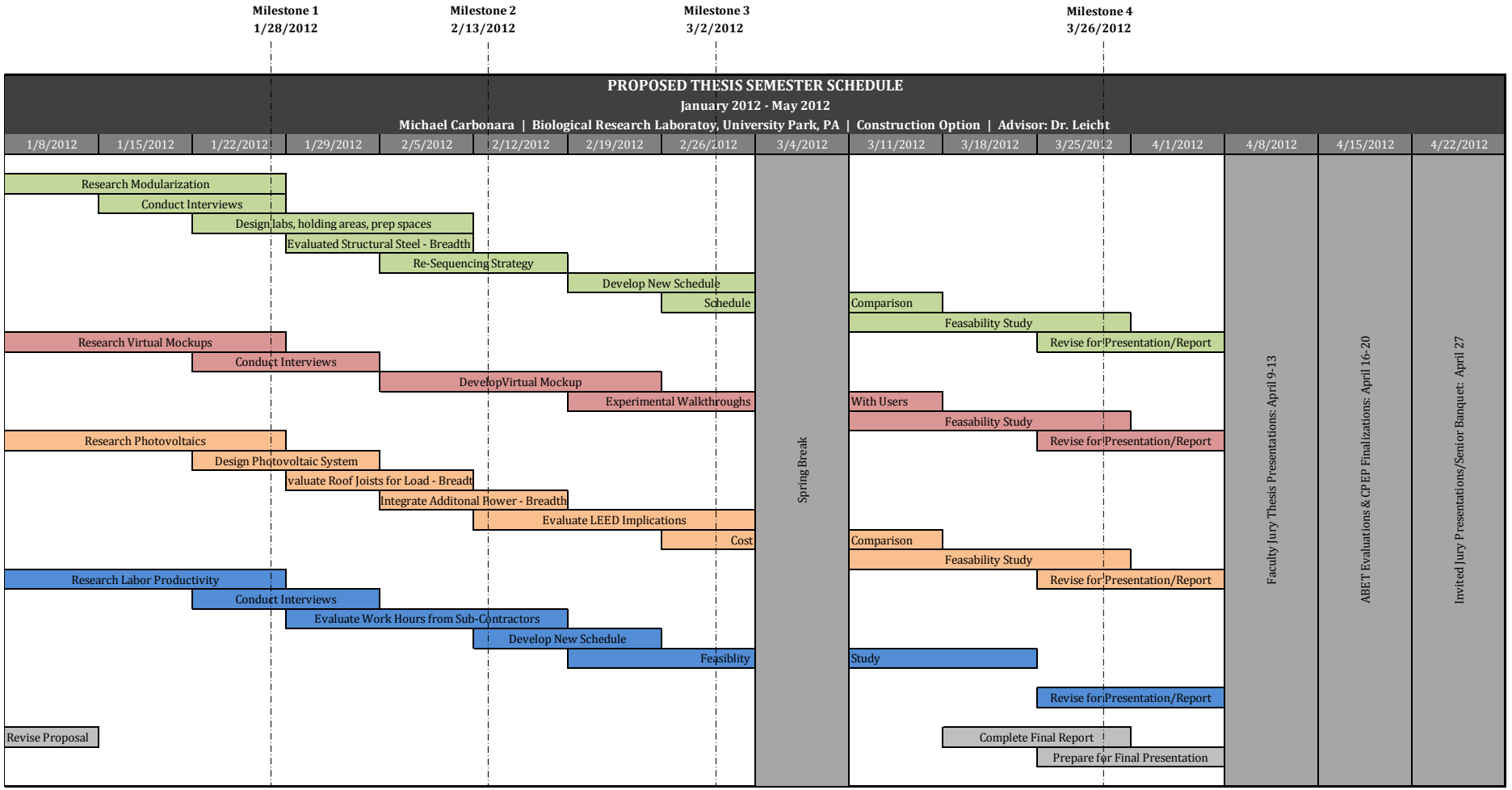
The electrical service into the building will be a 480Y/277 service that feeds a 1600 Amp double-ended switchgear. The power flows downstream to a pair of 1200 Amp switchboards which are fed from separate sides of the 1600 Amp double-ended switchgear. These two switch boards will supply the power to the mechanical, lighting and receptacle panel boards. The panels boards for the ABSL3 and BSL3 will be supplied from different panels located outside the containment barrier. The service for the facility will be calculated not only for the anticipated load but will include an additional 25% capacity for growth. A generator will also be placed on site for standby/Emergency and all life safety loads will be redundantly wired alongside with normal power in case of an emergency.
The Installation of the Photovoltaic system could pose several issues that need to be addressed in the location of equipment. Inverters many times are placed outside because of the heat and unfriendly noises, creating longer runs between PV components. Electrical feeders need to be sized and installed between the solar panels, the inverter, and the switch gear inside the building. How the added power is connected to the switchgear also needs to be examined along with the possibility of any constructability issues.

MAE Requirements

The MAE courses of senior thesis will be incorporated into the technical analyses for the Biological Research Laboratory as part of a requirement for the Integrated Program. Solar Project Development, AE 897A, was a class developed to design photovoltaic systems as well as develop financing, making the project feasible. Techniques learned in Solar Project Development will be used in Technical Analysis 3. Another analysis that will utilized the MAE course work is Technical Analysis 2 which shows the benefits of virtual mockups over field mocks. Virtual Facility prototyping, AE 597F, evaluates different ways to implement modeling bettering the construction process. The information learned in this Master level course will be implemented into the design and presentation of the virtual mockup for the Animal Biological Safe Laboratory.

[APPENDIX B]

Spring Semester Preliminary Timetable


Milestone 1
1/28/2012
Milestone 2
2/13/2012
Milestone 3
3/2/2012
Milestone 4
3/26/2012
PROPOSED THESIS SEMESTER SCHEDULE
January 2012 - May 2012
Michael Carbonara | Biological Research Laboratoy, University Park, PA | Construction Option | Advisor: Dr. Leicht
1/8/2012
1/15/2012
1/22/2012
1/29/2012
2/5/2012
2/12/2012
2/19/2012
2/26/2012
3/4/2012
3/11/2012
3/18/2012
3/25/2012
4/1/2012
4/8/2012
4/15/2012
4/22/2012
Research Modularization
Conduct Interviews
Design labs, holding areas, prep spaces
Evaluated Structural Steel - Breadth
Re-Sequencing Strategy
Develop New Schedule
Schedule
Comparison
Feasability Study
Revise for Presentation/Report
Research Virtual Mockups
Conduct Interviews
DevelopVirtual Mockup
Experimental Walkthroughs
With Users
Feasability Study
Revise for Presentation/Report
Research Photovoltaics
Design Photovoltaic System
valuate Roof Joists for Load - Breadt
Integrate Additonal Power - Breadth
Evaluate LEED Implications
Cost
Comparison
Feasability Study
Revise for Presentation/Report
Research Labor Productivity
Conduct Interviews
Evaluate Work Hours from Sub-Contractors
Develop New Schedule
Feasiblity
Study
Revise for Presentation/Report
Revise Proposal
Complete Final Report
Prepare for Final Presentation
Spring Break
Faculty Jury Thesis Presentations: April 9-13
ABET Evaluations & CPEP Finalizations: April 16-20
Invited Jury Presentations/Senior Banquet: April 27
Analysis 1: Modularization of Laboratory Spaces
Analysis 2: BIM Implementation (Virtual Mockups)
Analysis 3: Sustainability
Analysis 4: Schedule Acceleration (Labor Crews)
Milestone 1: 1/28/2012 - Research Completed
Milestone 2: 2/13/2012 - Designs Completed
Milestone 3: 3/2/2012 - Analysis 4 Completed
Milestone 4: 3/26/2012 - All Content Completed