April 7 2010

CARDEROCK SPRINGS ELEMENTARY SCHOOL

JOSEPH HIRSCH

CONSTRUCTION MANAGEMENT

FINAL RESEARCH REPORT

FACULTY ADVISER:
DR. CHRIS MAGENT

carderock springs elementary school
Bethesda, MD

Building Statistics

- Size: 80,121 sq. ft.
- CM: Hess Construction + Engineering
- Architect: BeeryRio Architect + Interiors
- Cost: $21,294,787
- Sustainability: LEED Silver
- MEP Engineer: Strickler Associates
- Civil/Structural: ADTEK Engineers
- Building Height: 3 Stories, 42 feet

Architecture

- Classroom Wing Located top left in above photo
- Gymnasium, Multipurpose Room, and Misc Space to bottom right
- Sloping grades along exterior for dynamic views of building elevations
- Brick veneer with CMU backup
- Curtainwall located at rear elbow of building to add great views from the media center

MEP Systems

- Geothermal heating & cooling
- 6 Rooftop ERU's to assist in heating & cooling and add outside air for ventilation
- Total electrical service is 1600A
- Energy Management system to monitor electrical usage for potential savings

Structural

- Steel superstructure
- Shallow foundations
- 5 ½" thick slabs on deck
- Long span joists in gymnasium and multipurpose room

JOSEPH HIRSCH / CM

http://www.engr.psu.edu/ae/thesis/portfolios/2010/jjh332/index.html

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I. ACKNOWLEDGEMENTS

The following individuals and organizations deserve special thanks for their support and help on my Thesis Project.

Professional:

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Montgomery County Public Schools

BeeryRio Architects + Interiors

Personal:

My parents, for all of their support during my collegiate career at Penn State

Meghan Graber

All of my friends who have helped out with my Thesis Project

Buck Harris

II. EXECUTIVE SUMMARY

This report encompasses four technical analyses and general project overview of Carderock Springs Elementary School in Bethesda, Maryland. This school has been selected for rebuilding as part of Montgomery County Public School's capital improvement program. The report provides an overview of the construction project including cost details, geographic information, project schedules, and structural estimates. Also included are four in depth analyses in 3D MEP Coordination, schedule acceleration, solar photovoltaic panels, and structural design.

The first analysis focuses on a current critical industry issue; Building Information Modeling (BIM), or, more specifically, 3D Mechanical, Electrical and Plumbing (MEP) Coordination processes. The analysis focuses on assessing the traditional and most widely used 2D coordination process used on majority of projects today. It then considers a generalized 3D process which, with proper planning, can be easily implemented to manage any project. Finally, it assesses the hypothetical application of the 3D process at Carderock Springs Elementary and reviews the potential benefits such as budget control, decreased amount of change orders, decreased amount of RFI's, and greater opportunity for quality control through pre-fabrication.

The second analysis focuses on decreasing the project budget through the relocation of an Underground Storm Water Retention System (UGS). The area where it is located requires deep excavations and setbacks for safety, eliminating access to other trades except the sitework contractor performing the work. Moving the system to a different location is analyzed. Possible benefits are better site utilization, opportunity for schedule acceleration, and more space for material staging and parking. The analysis shows that, by moving the system and adding crews to work in the restricted area, the schedule could be reduced by 20-30 days and saves about $94,000 of general condition costs.

The third analysis demonstrates breadth in structural systems by replacing a load bearing masonry wall system to a steel frame in two sections of the building. This analysis uses the LRFD method to size the new steel columns and beams. The same roof system is used. Also in this analysis it is shown that the steel system is $55,000 less than a masonry system and can save about 12 days on the critical path making this change potentially lucrative if pursued.

The final analysis, an electrical breadth, uses thin film solar photovoltaic panels made by Solyndra to help offset energy costs and add to the sustainability goal of the LEED program in place. By adding the panels, the addition to the budget would be about $800,000 while reducing the electrical utility bill by about $32,000 annually. The payback period will be 25 years making this a feasible option since, on average, a public school building will stand for 42 years in the United States.

III. PROJECT OVERVIEW

The previously existing Carderock Springs Elementary School was built in 1966 and was badly in need of modernization to meet the advancing educational needs of today's young Americans. This technical assignment will discuss various construction management topics including schedule, building systems, project costs, existing conditions, and project delivery and staffing.

The new 80,121 square feet Carderock Springs Elementary School is being built on the site of the previous school which has since been demolished. It will feature a new gymnasium, state of the art media center, high technology classrooms, as well as outdoor play spaces with basketball courts and ball fields. The project will cost approximately $21 million and is scheduled to be turned over to the owner, Montgomery County Publics Schools, July 7, 2010. It will open this coming fall for the beginning of the 2010-2011 school year.

The new elementary school is striving to achieve a LEED Silver rating from the U.S. Green Building Council under LEED for Schools guidelines. One of the unique sustainable features of this project is the closed-loop water Geothermal HVAC system which includes 120 wells drilled to a depth of 520 feet. The system will assist in providing efficient heating and cooling and significant electricity cost savings to the district. Other notable points being attempted are construction waste management, regional material extraction, and high indoor environmental quality. Montgomery County Public Schools is one of the largest owners of LEED accredited buildings in the state of Maryland.

The project is contracted under a Guaranteed Maximum Price format to HESS Construction + Engineering Services. It is being delivered utilizing a CM-at-Risk delivery method. HESS Construction has acquired a team of 36 subcontractors both from private and public bid. The architect of record is BeeryRio Architect+Interiors. They have consulted Strickler Associates for MEP systems and ADTEK Engineers for civil and structural design.

CLIENT INFORMATION

Montgomery County Public Schools (MCPS) is the owner of the new Carderock Springs Elementary School. They service the entire county and operate the 16th largest school district in the Unites States of America. The 2009-10 projected enrollment for the district is 142,000 students. The district operates over 200 schools.

The mission statement of MCPS reads "To provide a high-quality, world-class education that ensures success for every student through excellence in teaching and learning." One way they are meeting this goal is through the Capital Improvements Program which concentrates on modernizing old facilities or constructing new facilities for the students of the district. The approved modernization schedule has projects planned through 2018. For the fiscal years 2009-14 there is $1.271 billion allocated for the Capital Improvements Program.

The size of this school district requires very large scale project considerations and planning. Due to the high number of schools currently in planning or under construction, meeting budgets is extremely critical. HESS Construction + Engineering Services was hired as the Construction Manager early in preconstruction phases to offer value engineering suggestions to help meet these goals.

Since MCPS is an experienced owner, they expect top quality work to be completed on their sites. The MCPS Department of Construction is very committed to quality control. Since many schools are being built simultaneously or have been recently completed, MCPS has a very clear understanding of what they want on each project. It is not uncommon to receive owner change orders on components that have not lived up to performance on another school they have built.

Another aspect of the Capital Improvements Plan is the commitment to sustainable design. They have two values they expect out of each sustainable project. First, to have a student friendly facility that adds to the district's mission of high quality education. And second, they are interested in the long term cost savings sustainable design can achieve. Many of their new schools feature geothermal HVAC systems and intelligent building monitoring systems.

PROJECT DELIVERY METHOD

Montgomery County Public Schools (MCPS) hired HESS Construction + Engineering Services to provide preconstruction services and to be the construction manager for this project. HESS is assuming all construction risk in a Guaranteed Maximum Price (GMP) contract held with the school district. The GMP for this project is approximately $21 million. Since this project is public, certain scopes of the project were required to be public bid by law. All bid scopes were formulated by HESS with approval by MCPS. The scopes that were public bid included sitework, concrete, steel, roofing, drywall, fire suppression, geothermal, mechanical/plumbing, and electrical. Each contractor in the public bid had to be pre-qualified by MCPS in order to participate. They also must be bonded and insured and produce all necessary documentation. The rest of the scopes were privately bid directly to HESS. Once all bids were received, both public and private, HESS finalized the GMP which was reviewed and ultimately approved by the school district.

Each contract from the bid process is held by HESS. In total there are 36 subcontracts including the 9 subcontracts that were publicly bid. This number seems high, but the reason a General Contractor or Construction manager is hired is to gather skilled labor for high quality craftsmanship that meets owner’s expectations. Each bid scope is carefully developed based on the availability of expert construction services in the geographic area. HESS has developed strong relationships with many subcontractors allowing all parties to be competitive and successful in their ventures. These relationships provide increased value to the owner.

A unique relationship that exists on this project is between the commissioning agent and building controls engineer. The school district holds the contracts with these agents, although the agents’ work directly impacts construction on site. Collaboration and open communication has been critical in managing this relationship since each party has separate contractual requirements that sometimes intersect. These two independent contractors must work closely with MEP engineers to achieve the desired controls and automation of the mechanical and electrical systems of the building. The commissioning agent then, must carefully review the engineering of these systems to ensure the design intent is met.

All construction projects require high levels of organization and efficient communication. Carderock Springs Elementary School is a very good example of this. Overall this project has over 50 parties with a financial stake in the school. Each day the CM, HESS Construction +

Engineering Services, must ensure that all parties are receiving the information they need and that they are connecting parties together to ensure success of the project.

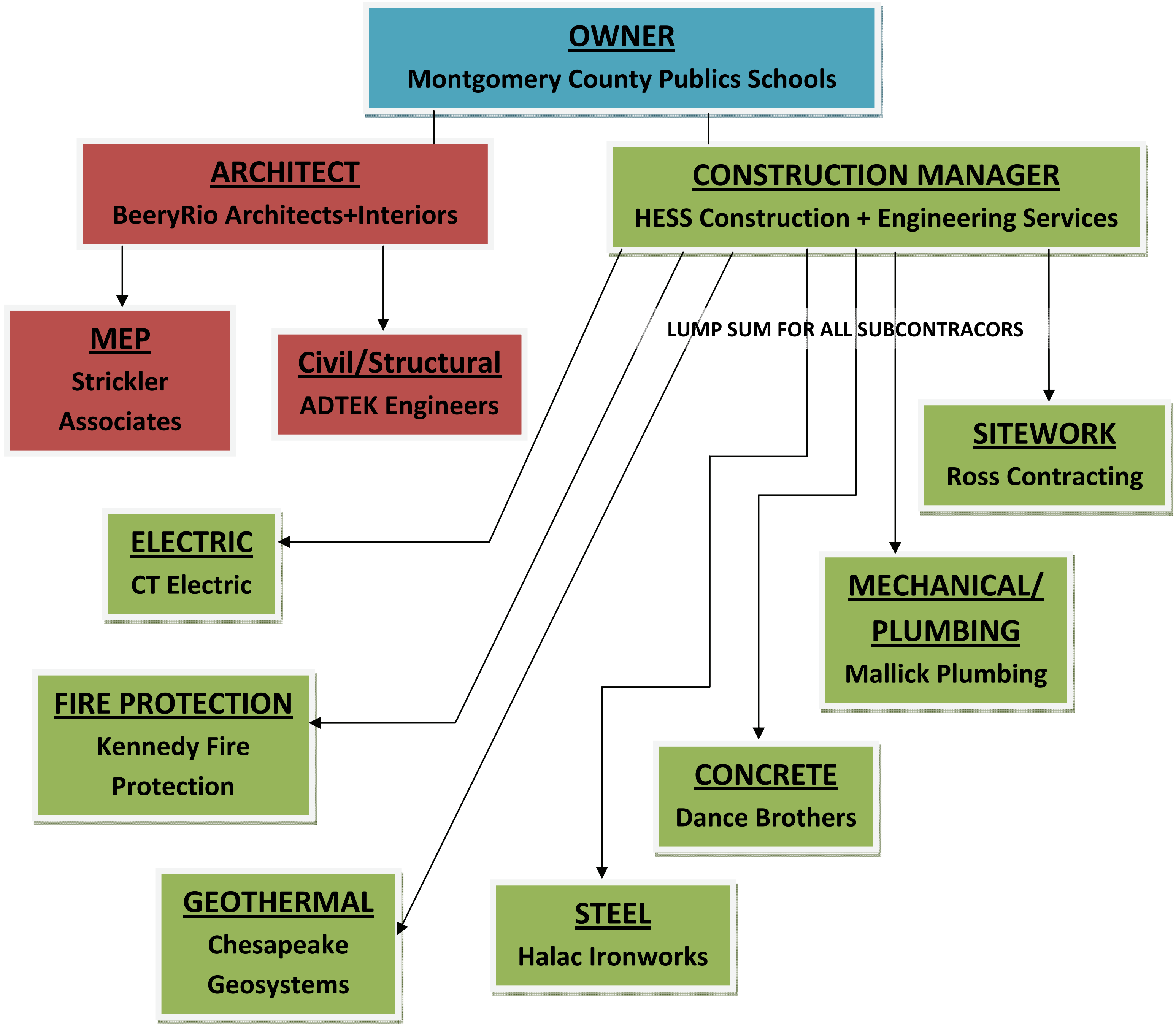


Figure 1 – Project Organization

STAFFING PLAN

HESS Construction + Engineering Services was hired as the Construction Manager for this project and is assuming all construction risk for the project. They assisted with preconstruction services and will oversee the project through closeout and commissioning. During the construction phase, the project is staffed by operations on site.

The site team consists of the Project Manager, Superintendent, Field Engineer, and Project Administrator. As is typical in the industry, the Project Manager is responsible the financials, approvals of documents, communication, and reporting. The Superintendent supervises field activity, updates the schedule, and is generally responsible for the means and methods of constructing the project. A Field Engineer will support the activities of the Project Manager and Superintendent. In this entry position, there is a focus on learning the responsibilities and participating in all the activities of a project. Finally, the project administrator is responsible for documenting and organizing the flow of information of the project. This position supports of the Project Manager. All site personnel are responsible for safety but the Superintendent runs the daily safety program since he is in the field. A Safety Manager also performs weekly audits with Superintendent.

The Project Executive and General Superintendent act as supervisors to the Project Manager and Superintendent. They generally support the activities of the site as required. They are responsible for a group of projects and generally are not involved on a daily basis.

Departments in the office such as Accounting, Marketing, and Estimating, support activities on site. They are utilized as needed. The top Executives at HESS are highly visible. It would not be uncommon to see each member visit the project in the same week to check progress. They generally focus on procurement of new work.

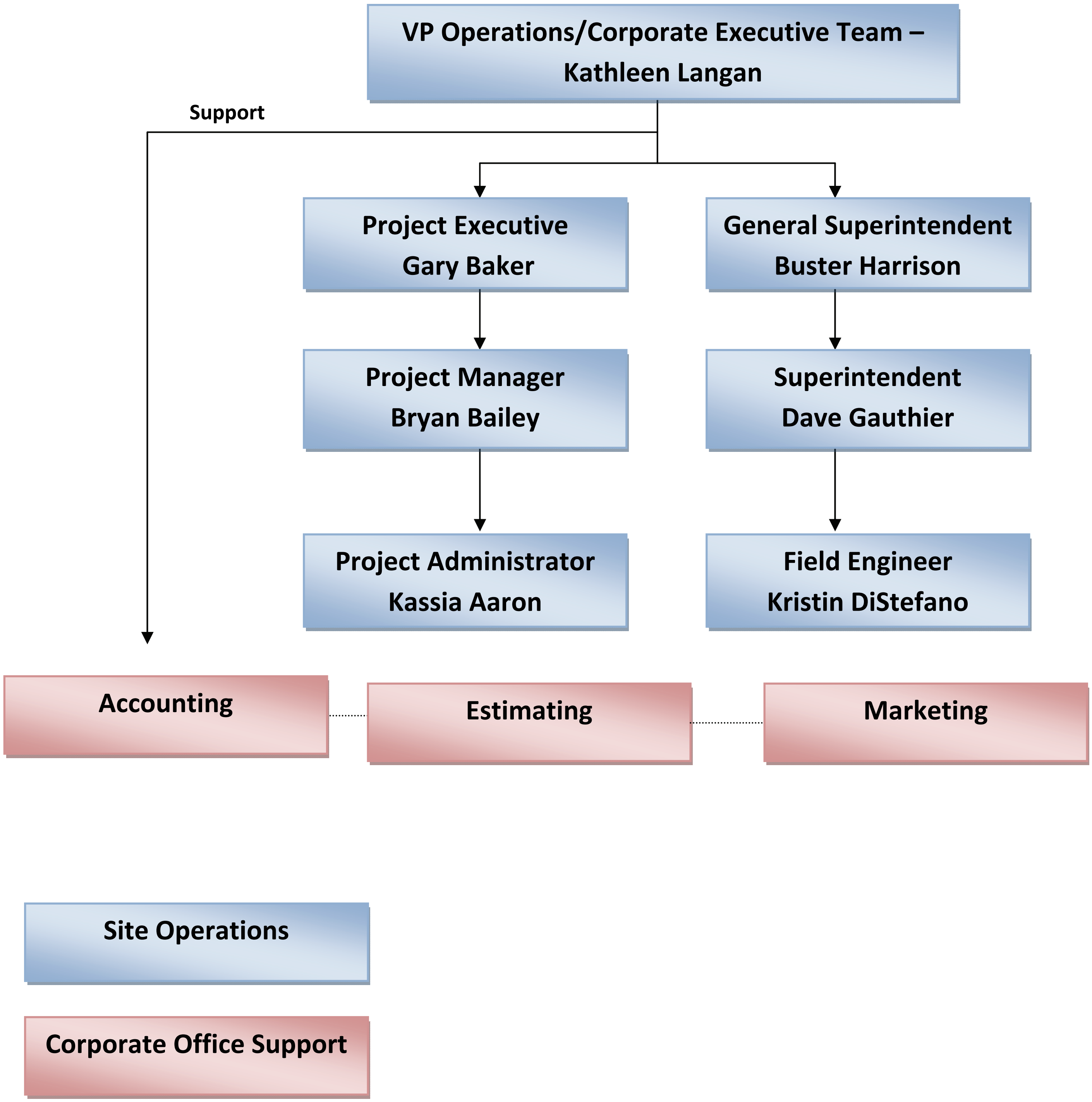


Figure 2 – Staff Structure

IV. DESIGN AND CONSTRUCTION OVERVIEW

Table 1 - Scope of Work

YES	NO	WORK SCOPE
x		Demolition
x		Structural Steel Frame
x		Cast in Place Concrete
	x	Precast Concrete
x		Mechanical System
x		Electrical System
x		Masonry
x		Curtain Wall
	x	Support of Excavation

Demolition:

To make way for the new building, the old elementary school was demolished. Asbestos was abated first to make the site safe for selective demolition. Next, the "guts" were taken out and salvaged if feasible. Items such as steel ducts and copper wires can be recycled by the demolition contractor. Following the demolition of the inside components, the building structure was demolished. Care was taken during this stage since steel and concrete can be recycled. Demolition was carefully organized since operators of the heavy equipment needed to keep some type of structural integrity while operating in close quarters to large structural elements. Next, foundations were demolished and crushed using impact hammers. The entire demolition of the existing structures lasted for just under three months.

Figure 3 – Existing Structure

Figure 4 - Demolition of Existing Building

Structural Steel Frame:

The frame of this building is structural steel. A combination of moment connections and free standing masonry structures (stairways & elevator shaft) provide the lateral resistance to loads. A Manitowoc 8500 crawler crane was used on this project. It has a capacity of 85 tons maximum load and a maximum swing radius of 200 feet. Columns in this building span all three floors. This saves time and money both in manufacturing and also erecting since there are less picks to make. The elevated slabs in this building are composite and are nominally 5 ½" thick. Long spans joists are used in the gymnasium and multipurpose rooms with spans reaching 72' and 78' respectively.

Figure 5 - Steel Frame at Carderock

Cast in Place Concrete:

Cast in place concrete was used for all concrete applications on this project. The retaining walls, foundations, slabs on grade, and slabs on deck were all cast in place. The concrete specified on this job was normal weight 3500 PSI compressive strength. Formwork was reusable plywood forms. On the slabs, steel pour stops were utilized. The concrete plant used for this project was located about 45 minutes away. However, due to the high volume of traffic in the Washington, D.C. area it took as long as 90 minutes for concrete to reach the project site. Any truck that did not begin its pour before the 90 minute limit was sent back to the plant. This situation was encountered multiple times over the course of the concrete work. Concrete pump trucks were utilized for many applications on this project including elevated slabs and areas that had restricted access to direct chute due to concurrent construction activities.

Figure 6 - Slab on Deck Pour

Mechanical System:

Figure 7 - Geothermal Well Drilling

A closed loop water Geothermal system was utilized on this project to support the LEED project goals and overall sustainability. There are 120 wells drilled to a depth of 540’ into the earth. These wells are in a series loop with the 49 water source heat pumps located throughout the building. In addition to geothermal there are six rooftop energy recovery units (ERU) that provide additional heating and cooling capacity as well as provide the necessary ventilation requirements. Larger rooms such as the gymnasium, media center and multipurpose room, receive its HVAC needs solely from its own respective ERU.

Electrical System:

The electrical service to the building is 265/460V, 3 phase, 4 wire rated at a total of 1600A. Secondary service is 120/208V and it primarily powers the lighting, computer, and small equipment loads. The building contains 21 panel boards and 7 transformers to step down the voltage to the appropriate level for the intended application. A 100 kW generator provides backup power to the lighting and life support systems throughout the building.

Masonry:

Figure 8 - Masonry Staging Area & Elevation

This building consists of an 8” CMU back-up wall with a 4” brick veneer on the exterior walls. Structural walls in the elevator shaft and stair towers are grouted and have reinforcing Z bars in corners to tie the structure together. Nearly all interior walls and partitions are 6” CMU walls. This was chosen to help with sound transmission goals. Since there is a lot of masonry work, detailed management and quality control of this contractor is critical for success of the project. During the enclosure phases, masonry considerations will drive the schedule on the critical path.

Curtainwall:

Curtainwall is utilized in key locations to achieve day lighting and outdoor views. The front entrance of the school is curtainwall to add architectural aesthetics to the design. At the elbow of the building the curtainwall spans 2.5 stories. This will provide the Media Center with expansive views and great day lighting. The curtainwall system being used is specifically engineered for low sound transmission since the Capital Beltway is located very close to the school. The architect has taken great care to ensure that noisy traffic will not be an issue inside of the building and affect the education of the children.

Media Center Located on Second floor with classrooms spaces on the lower level

BEERYRIO

Figure 9 - Elevation Featuring Curtain Wall

LOCAL CONDITIONS

Bethesda is located in Montgomery County, Maryland along the Capital Beltway Loop (I-495). It is located approximately 30 minutes northwest from Washington, D.C. and about an hour southwest of Baltimore, Maryland. Carderock Springs Elementary School is also located minutes away from the famed Congressional Country Club. This past summer Tiger Woods hosted the AT&T National Golf Tournament which brought in tens of thousands of visitors to the area, introducing traffic congestion problems for construction vehicles. Many of the surrounding roads are residential and restricted to large vehicles. Delivery routes and deliveries must be planned accordingly to maintain community relations.

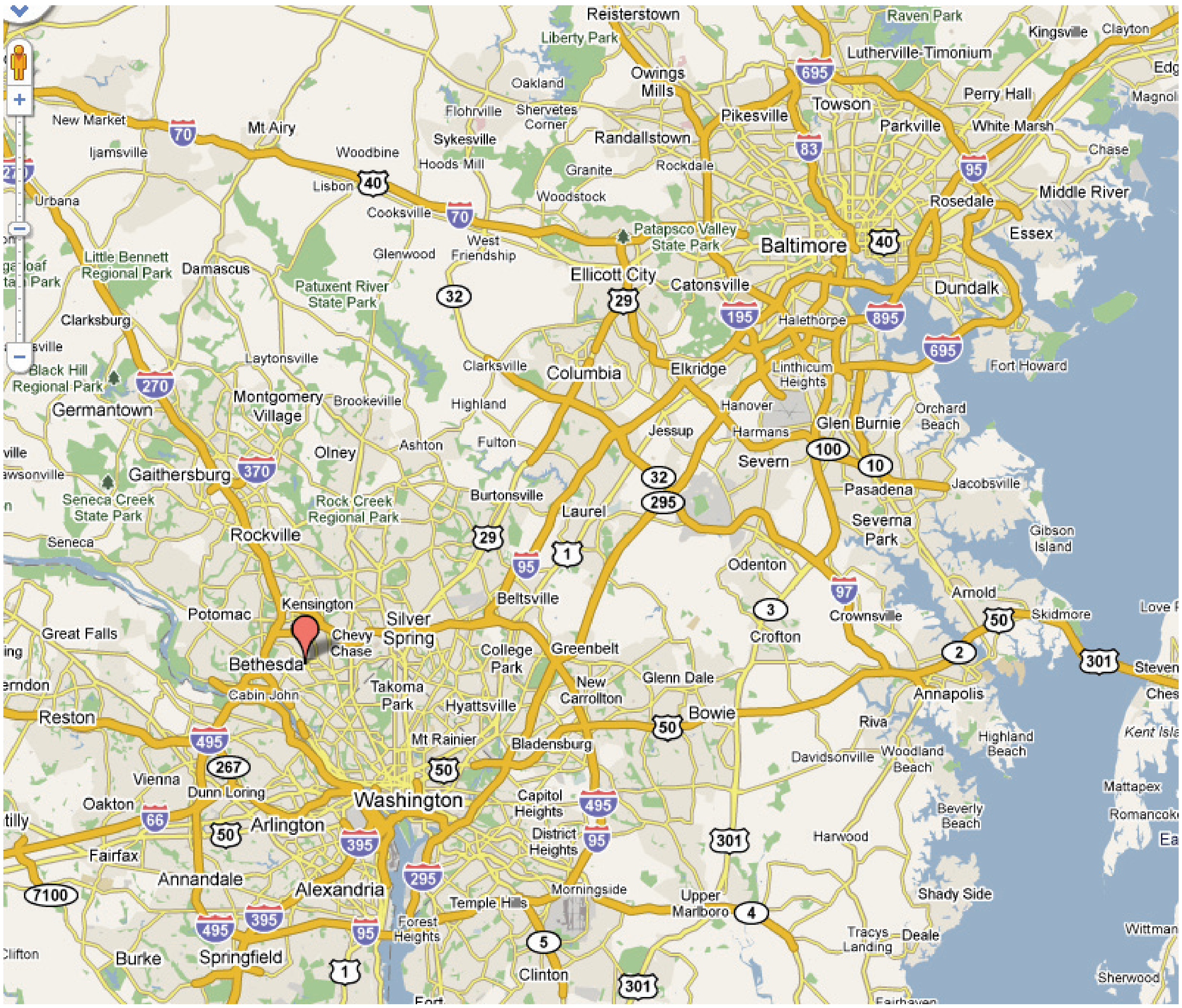


Figure 10 - Geographical Region (Google Maps)

Soils and Subsurface Conditions:

The existing soil and subsurface conditions on this site were good. Conclusions reached in the geotechnical report showed that the areas bored generally had firm silt and sand. There was no groundwater present that would complicate construction. The geotechnical engineer concluded that the use of spread footings with a soil bearing pressure of 3,000 PSF would be sufficient on the existing undisturbed soil or compacted fill. Other findings stated that the material found on site would be suitable for reuse as backfill if compacted correctly. The ability to reuse spoils had significant cost savings to the owner.

Figure 11 - Site Soil Picture

Construction Services and Workforce:

The availability of construction services is virtually unlimited due to the schools geographic location to Washington, D.C. Trash dumpsters in the area will generally be about $400 per pull for unsorted trash. Recycling and salvage is also readily available. This job is intended to receive a LEED silver rating which requires detailed management over the recycling program.

Parking in this area is extremely constricted. In order to save space on the site carpooling was emphasized to reduce cars on the site. Since the school was located in a residential area, parking on the street was not an option.

The construction workforce in this area is extremely diverse. Many of the workers were of a Latina decent from Central American countries. This introduced challenges due to the language barrier. Although all of the foremen were English speaking, the inability to communicate verbally to all site personnel created problems at times.

Overall, Montgomery County Public Schools expects great customer service and value on each of their projects. They have established relationships with many contractors, including HESS, which is very evident in the responsiveness they expect from each individual project team. It is important to maintain these relationships for both parties since the district will be building many schools in the future with construction planned through 2018.

SITE PLAN OF ORIGINAL CONDITIONS

The site utilization is extremely important during the early phases of construction. During the early phases beginning in December 2008 excavation began to prepare the building pad. In March of 2009, both foundations and drilling in the geothermal well field began. All of these

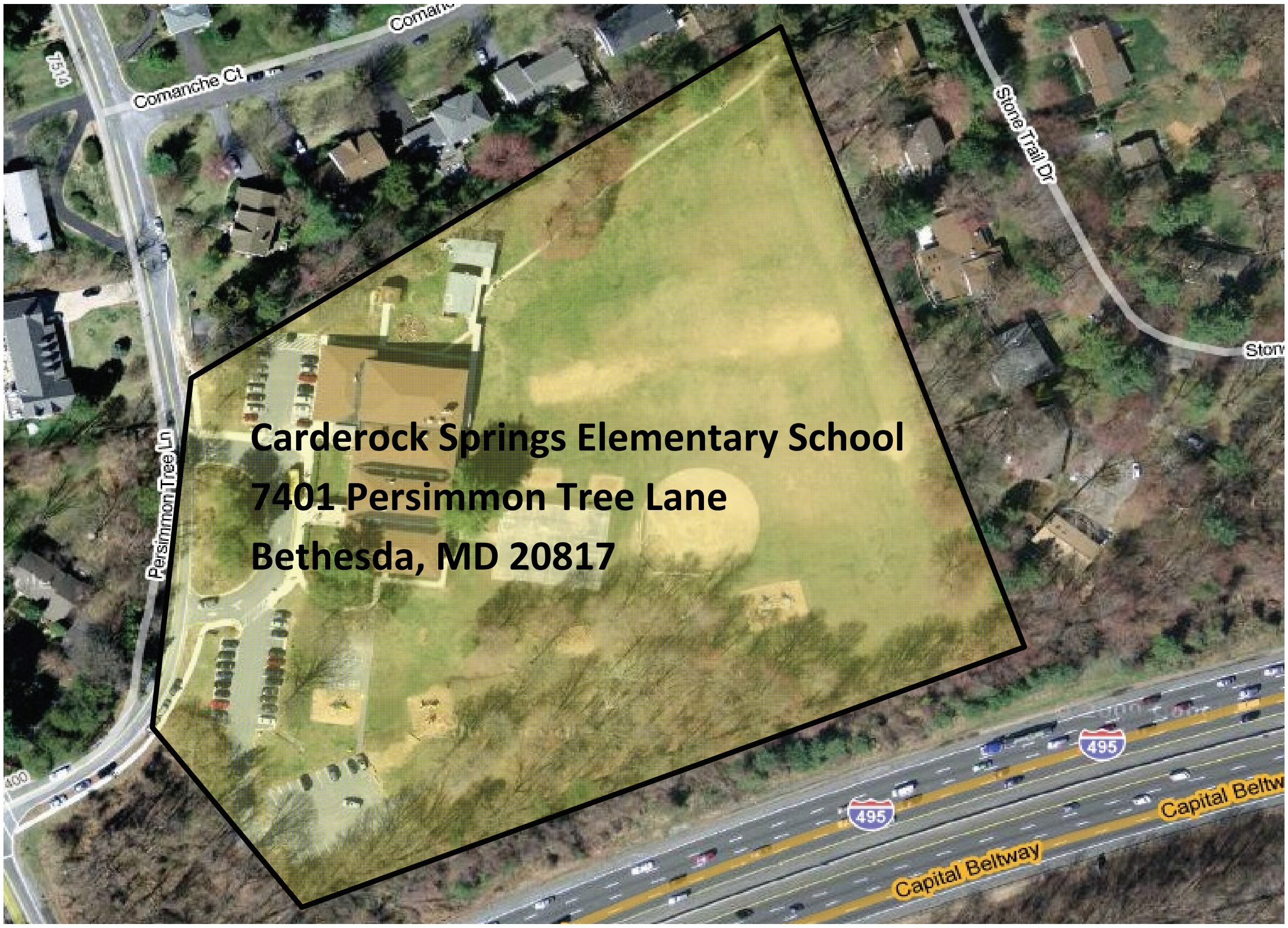


Figure 12 - Satellite Image of Site

activities required heavy equipment which needed ample room to operate. The high amounts of equipment on site required the temporary access roads to be maintained regularly to ensure easy movement of construction equipment including dump trucks, excavators, backhoes, and telescoping forklifts. This plan represents the early phases with congestion and later plans will reflect decongestion as activities are completed and more of the site is available for storage and parking.

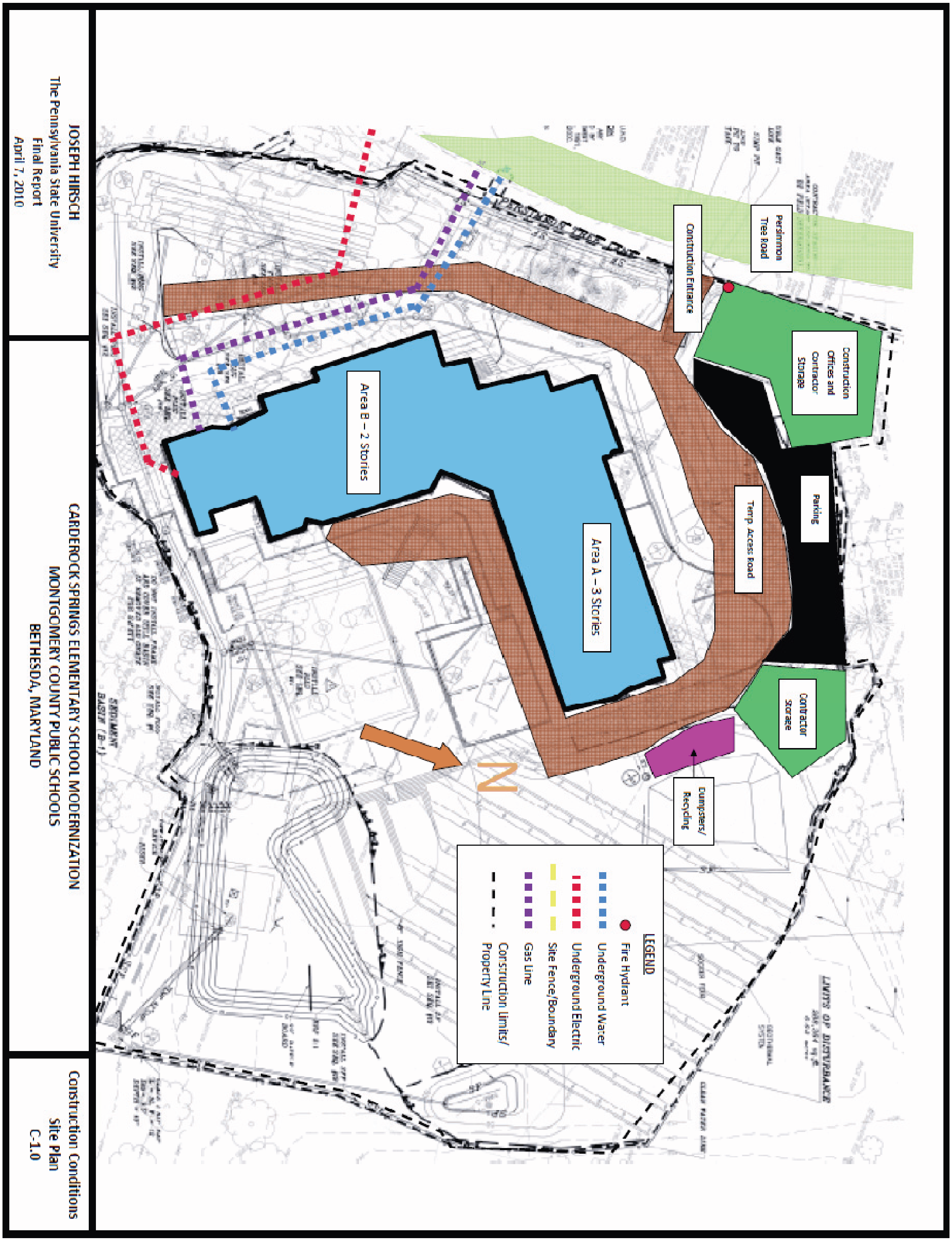


Figure 13 - Original Site Plan

V. PROJECT LOGISTICS

PROJECT COST

Table 2 - Project Costs

Total Project Cost and Square Foot Cost		
Building Systems	**Cost**	**Cost/SF**
General Conditions	$1,665,420	$20.79
Site Work	$3,412,850	$42.60
Concrete	$1,044,350	$13.03
Masonry	$1,974,625	$24.65
Structural	$1,952,070	$24.36
Moisture Protection	$669,000	$8.35
Carpentry	$310,600	$3.88
Openings	$1,758,436	$21.95
Finishes	$871,828	$10.88
Specialties	$221,025	$2.76
Equipment	$236,390	$2.95
Furnishings	$101,000	$1.26
Elevator	$95,000	$1.19
Mechanical	$3,894,487	$48.61
Electrical	$1,303,550	$16.27
Allowances	$975,036	$12.17
Total	**$21,304,667**	**$265.91**

This table reflects the actual costs of the project based on original contract bids. The price of the building however has gone up due to change orders and an owner request to fit out the 3rd floor which was originally slated to be a shell space for future expansion. The table includes costs of the project in its entirety including demolition and site work.

PROJECT SCHEDULE SUMMARY

Foundation Sequence:

The building is divided into two distinct sections, Area A and Area B. The primary scheduling and sequencing are based on Area A activities beginning before Area B. The foundation system consists of continuous strip footings along the exterior of the building to support walls and spread footings placed under all of the interior and exterior columns. Along with the footings, there are a couple of key retaining walls that were placed which required additional labor to form-up and support the walls during curing. The retaining walls were placed first since some of the foundations met up with the walls and required the wall to hold back soil for a logical construction sequence.

Structural Sequence:

The structural steel was delivered for Area A as foundations continued in Area B. Although the site seems relatively large, the amount of concurrent activities taking place simultaneously restricted lay down area for steel and other materials. This required some phasing of steel packages by the steel contractor. The erectors started with columns and proceeded throughout the whole Area A. Some columns spanned 3 floors which allowed for greater efficiency and allowed the steel erector to pick multiple beams at once. Once beams were erected, cross bracing was placed to support the structure from lateral forces. Once moment welds were completed, the bracing would be taken down. Before another level was started, decking would be dropped down and they could continue climbing vertically while placing deck. Once the deck was placed and welded in place, shear studs would be placed for the composite concrete decks. Then any other rough penetrations would be made which would allow the concrete to be poured. This sequence was repeated as the steel went around the building to Area B.

Finish Sequence:

The interior wall system of this building consists primarily of 6” CMU walls. Therefore once enough steel was laid out in front of the mason, their production would be critical to keep the schedule moving. While placing interior walls, MEP contractors coordinated penetrations and interior wall work to keep them from having to open up walls to make installations. Once the walls are in place and the building is enclosed final finishes can begin. First drywall will be placed followed by painting. After paint, ceiling grids can be hung allowing lighting fixtures to be placed and MEP trades to begin trim-out. Once this is complete tiles can be dropped in place. The next activities will include placing cabinets, fixtures, and additional equipment as necessary. The last thing that will happen is the punchlist and turnover of the building to the owner for occupancy. During the latter phases of construction and occupancy, building commissioning will take place to ensure the functionality of all MEP systems.

SEE APPENDIX A FOR DETAILED SCHEDULES

GENERAL CONDITIONS ESTIMATE

Assumptions:

- Location Factor for Silver Spring, MD of .895
- Project Duration is 21 months or 84 Weeks
- HESS maintains a fully staffed field office for the duration of the project
- Average unit costs were selected

The costs for this estimate were established using RS Means Building Construction Cost Data 2009. The general conditions estimate yielded a result of **$1,975,830** for the length of 21 months of the project. The tables below summarize the estimate.

Table 3 - General Conditions Calculations

Item	Location Adjusted Cost	% of GC	Cost/Month	Cost/Week
Staff	$405,596	21%	$19,314	$4,829
Temporary Utilities	$216,019	11%	$10,287	$2,572
Site Office Expenses	$18,532	1%	$882	$221
Site Security	$15,083	1%	$718	$180
Fee, Insurance, Bonds, and Permits	$1,155,893	59%	$55,043	$13,761
Miscellaneous	$164,708	8%	$7,843	$1,961
TOTAL	**$1,975,830**	**100%**	**$94,087**	**$23,522**

Table 4 - GC Summary

General Conditions	
Actual Budget	$1,665,420
RS Means	$1,975,830
Difference	($310,410)
% Difference	17%

After analyzing the above table, the Fee, Insurance, Bonds, and Permits encompass a large percentage of the General Conditions. The staffing probably will represent a high percentage of the actual budget in with the insurance, bonds and permits representing a smaller percentage. Despite that, the overall numbers are good ballpark figures to use in the analysis of cost savings that could result from reductions in schedule time.

SEE APPENDIX B FOR GC ESTIMATE

DETAILED STRUCTURAL ESTIMATE

Assumptions and Project Details:

- Takeoff was performed using logical modules.
- Logical modules extrapolated out to find total system values.
- Concrete strength is 3500 PSI Normal weight.
- Slab on Grade thickness is 4".
- Slab on Deck thickness is nominally 4.75".
- RS Means 2009 was used to obtain values
- Beams and Columns were matched to closest listed value of RS Means.

Table 5 - Detailed Structural Estimate Table

Detailed Structural System Estimate Summary							
Item	**Unit**	**Total Quantity**	**Total Material**	**Total Labor**	**Total Equipment**	**Total Cost**	**Unit Cost ($/ton)**
Structural Columns	Ton	65.87	$226,879	$6,993	$5,073	$238,945	$3,628
Structural Beams	Ton	270.83	$768,510	$70,240	$43,491	$882,241	$3,258
Structural Joists	Ton	72.48	$145,453	$32,142	$18,296	$195,890	$2,703
Steel Decking	Ton	118.50	$146,150	$22,120	$2,370	$170,640	$1,440
Total Structural Steel	***Ton***	***527.68***	***$1,286,992***	***$131,495***	***$69,229***	***$1,487,716***	***$2,819***
Item	**Unit**	**Total Quantity**	**Total Material**	**Total Labor**	**Total Equipment**	**Total Cost**	**Unit Cost ($/CY)**
Concrete	C.Y.	1568	$163,654	$44,057	$11,694	$219,405	$139.93
Concrete Reinforcing	C.Y.	1568	$63,972	$164,852	$0	$228,823	$145.93
Total Concrete	***C.Y.***	***1568***	***$227,626***	***$208,909***	***$11,694***	***$448,228***	***$285.87***

SEE APPENDIX C FOR DETAILED STRUCTURAL ESTIMATE

VI. 3D MEP COORDINATION (CRITICAL INDUSTRY ISSUE)

BACKGROUND:

Building Information Modeling can take many forms in the planning, design, construction, and facilities management after the building is complete. Many design firms, builders, and owners are embracing this trend in this use of BIM technology and are exploring BIM uses to assist them reach their project goals. As the industry becomes more familiar with the ways they intend to use BIM, efficiencies and cost of technology will continually decrease. Also resistance to change from traditional techniques will be overcome establishing this as the standard medium to view drawings.

Evidence of continued exploration of this topic, was Penn State's Computer Integrated Construction Research Program and their recent release of the BIM Project Execution Planning Guide. Research such as this will help the industry utilize different technology to help improve overall project planning and increase process efficiencies. The planning process will especially help to pinpoint exact BIM uses that would be the most effective to the reach goals of the project and the goals of the parties involved with its construction.

Understanding the project goals, and defining detailed plans for BIM will help make a project more efficient in its implementation of BIM. This is especially true of the capabilities of BIM when using 3D models to help coordinate the MEP system of a building. It is important for the entire team to be aware of their responsibilities and "on-board" for the entire coordination process. Working together as a team is integral in order for each participant to realize the efficiencies of 3D MEP coordination.

GOAL:

The goals of this analysis will be: to define the processes that need to occur to successfully coordinate the MEP systems in 3D; to analyze the hypothetical implementation of the process to the project compared to the traditional 2D method; to analyze overall advantages/disadvantages of the process; and to assess the final return on investment of implementing a 3D coordination process. Finally, a project specific plan will be generalized based on the best practices and capabilities of the Carderock project members.

TYPICAL 2D MEP COORDINATION:

On a typical Design/Bid/Build project, there are low levels of team integration and coordination to create the final product of a finished building. They traditionally rely on old, but proven processes and techniques to get the work completed on time. Whether it be a high technology lab building, office, or school, they will generally use the same 2D coordination processes using light tables or overlaying CAD drawings and time consuming meetings to coordinate the work. This process relies heaving on the experience and intuition of each team member to identify conflicts. However, this almost always results in conflicts in the field when the building is constructed.

After contracts are awarded on a Design/Bid/Build project, the specialty contractors involved with the MEP work will create detailed shop drawings of an area that will be used for coordination, fabrication, and installation. Typically, coordination of the systems will be prioritized in the following order: HVAC duct, HVAC pipes, plumbing, fire protection electrical, and telephone/data. Contractors will then lay a transparent drawing over a light table or use multiple layers within an AutoCAD software to look for clashes with the design. It is important to note that with this coordination technique there is no automated system to search for conflicts in the MEP systems. This process relies on the instincts and experience of the parties involved with process.

Typically, a building will be divided into zones with each area's coordination built into a Critical Path Method Schedule (CPM). This schedule should be followed to ensure that each area is coordinated and approved before being released for fabrication. Each zone will require at least one meeting to ensure the design is coordinated to minimize errors in the field. However one meeting per area is not commonplace in industry practice. Research published in the Journal of Architectural Engineering by Tatum and Korman said that a basement floor of a laboratory building required 15 coordination meetings over a 3 month period. It was estimated that it required about 520 work hours and cost around $260,000 to complete the coordination. This demonstrates that the amount of time required by key personnel, such as foreman, draftsman, and project managers, is extremely high for a 2D coordination process.

Clear observations of the 2D coordination process reveal its inefficiencies. As previously noted, the process requires large time commitments from critical project members. These time commitments come at a substantial cost to each contractor. The 2D process typically does not catch every coordination issue, leading to a high amount of RFI's, change orders, and re-work of installed assemblies. Re-works and change orders often come at a premium cost mark-up, inflating the project budget. In an interview conducted with a project manager, it was noted that he prioritized his time to deal with change order management which primarily stemmed from the issues in the coordination process and MEP conflicts. He noted that out of all of his responsibilities, change order management was the most time consuming. The following figure represents a generic process used for 2D coordination.

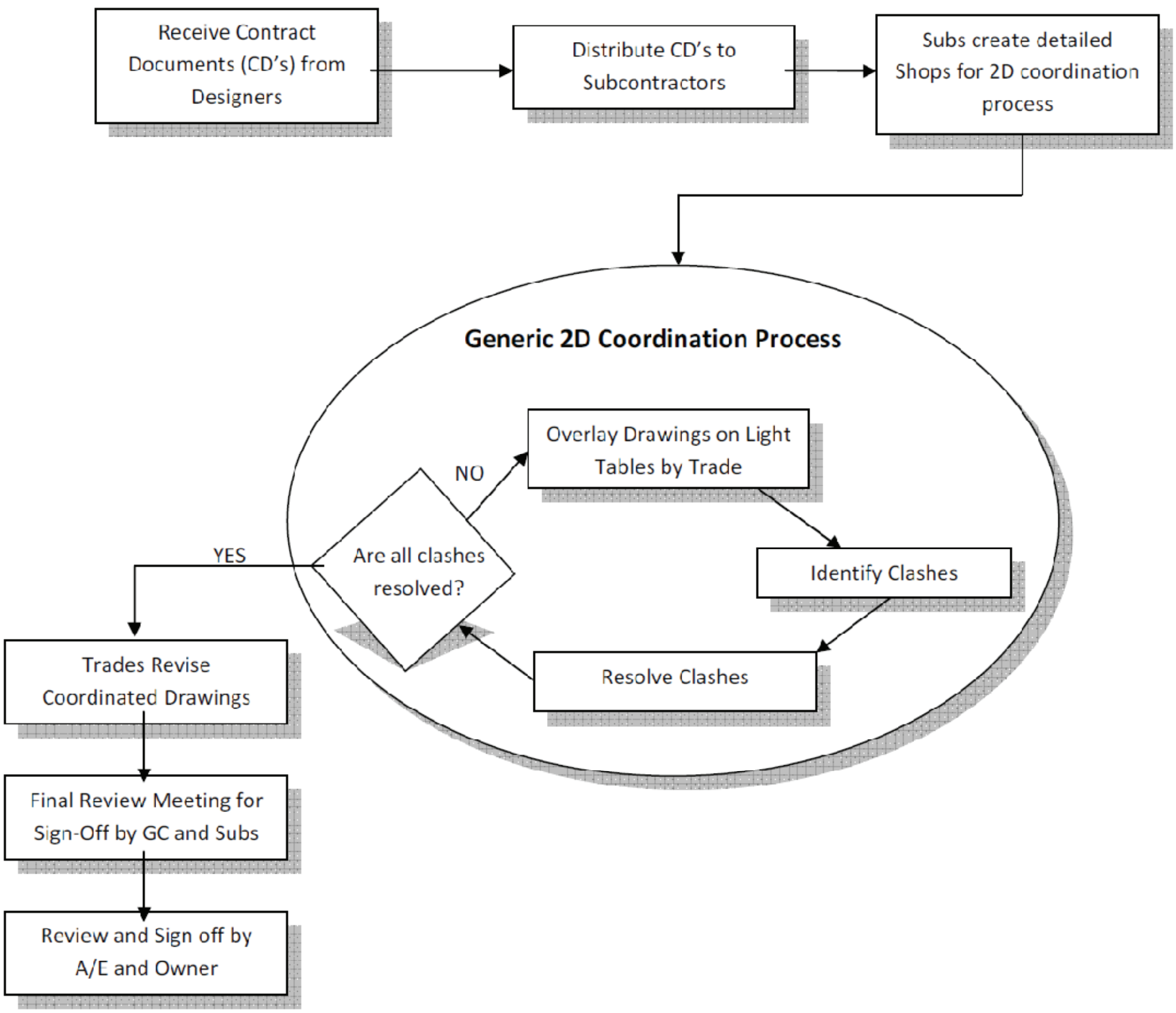


Figure 14 - Generic 2D MEP Coordination Process

2D Coordination Summary:

- Consumes large amount of time
- Generally does not identify all systems conflicts
- No clash reports are produced

- Requires multiple meetings for same areas
- Issues with MEP coordination lead to change orders and further consumption of time
- Change orders come with a cost premium to an owner causing the budget to grow

3D MEP COORDINATION:

Over the past 10 years, there has been a significant investment into BIM technology, both in industry and through institutional research. This investment has yielded significant results on actual projects and through the form of research publications. In the area of 3D MEP coordination, there have been numerous positive results that have improved the efficiency of the coordination on actual projects, thus saving time and money.

In practice, the largest benefits of 3D MEP coordination are achieved in a Design/Build or another type of integrated delivery approach. These delivery methods inherently increase the collaborative and team approach to the design and construction process. However, an integrated approach is not a necessity to use 3D coordination as a tool to achieve project efficiencies. It is possible to implement it in a Design/Bid/Build environment. The Design/Bid/Build approach will be the hypothetical study on Carderock Elementary School elaborated upon later in this section.

Before any process or BIM technology is applied to a project, a plan must be developed to guide the users through each step. This will help eliminate conflicts and will provide a reference to parties not familiar with the entire process. The following items from Staub-French and Khanzode were identified as essential steps in setting up a 3D design and coordination process. They were developed in researching a Design/Build project and are rooted in a more integrated delivery method. Each of these steps has its own set of processes and checklists that need to be completed to implement a 3D coordinated MEP systems process.

1. Identify the Potential Uses of 3D Models
2. Identify the Modeling Requirements
3. Establish the Drawing Protocol
4. Establish a Conflict Resolution Process
5. Develop a Protocol for Addressing Design Questions
6. Develop Discipline-specific 3D Models

7. Integrate Discipline-specific 3D Models
8. Identify Conflicts between Systems
9. Develop Solutions for the Conflicts Identified
10. Document Conflicts and Solutions

Although each step is important in the 3D MEP coordination process, defining each step in its entirety for application to Carderock is outside the scope and intent of this analysis. Instead a more generalist approach will be utilized. There is currently focused research being performed in each step of the list. The following figure is a graphical representation this approach.

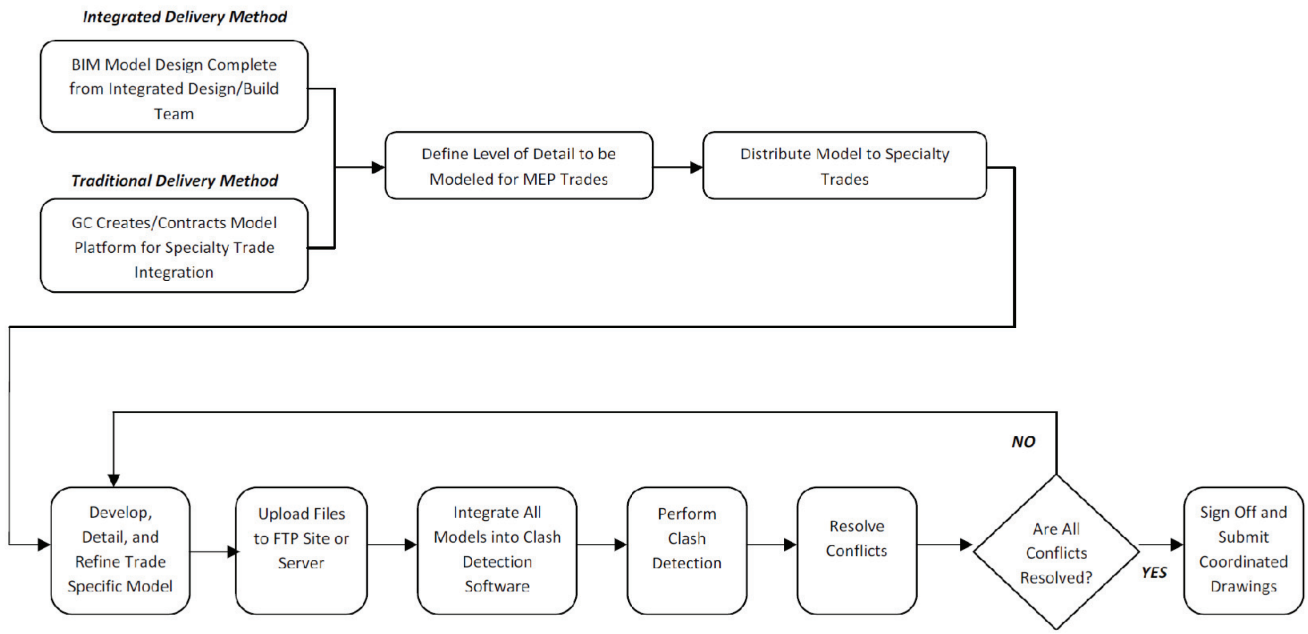


Figure 15 - Generic 3D MEP Coordination Process

The first step of this coordination process begins with the type of project delivery method that will be utilized. In an integrated approach, the owner is calling for the GC/CM and specialty trades to be involved early during the design stages. This would result in a substantially coordinated design in the contract document stage. A disadvantage in this approach is a longer design phase; however, the benefits from this approach, according to a case study by Staub-French and Khanzode, show less change orders and RFI's, less re-work, and enhanced cost control amongst other benefits.

A traditional method would begin coordination upon issuance of the 100% Construction Document stage. The GC/CM would lead this coordination process. When awarding contracts, specialty contractors would have additional 3D modeling and coordination requirements to go along with the traditional 2D submittal requirements. It is important to note that in this scenario, the 2D submission is the legal binding document since BIM was not utilized in the contract between the Owner, A/E, and GC/CM. The GC/CM is calling for additional capabilities of its subcontractors to obtain the benefits of BIM technologies specifically relating to 3D MEP coordination. It would be up to the GC/CM to identify the trades and the systems they would choose to coordinate in a 3D environment.

Also in these initial stages the level of detail must be determined. An example of defining detail would be the decision to model duct insulation or the corrugations of a metal deck. For clash detection purposes a duct could be modeled as a single entity that accounts for the insulation thickness or the insulation could be modeled separately. With the decking, the slab could be modeled at its nominal thickness and not include the corrugations. When creating models, file size and usability must always be considered. Incorporating more detail will slow the models and increase file sizes which could lead to technical issues such as slow file download speeds or computer compatibility issues. It is important to consider the hardware capabilities of each specialty contractor to ensure they can properly support the modeling software platform.

Next, in an integrated approach, the master model from the designers would be distributed to the specialty contractors to begin the detailing and refining stages. In a traditional delivery method, the GC/CM would have to create the initial architectural or spatial model. In a case study performed by Leicht and Messner at Penn State, it was found that the CM had created a spatial grid based on the surveys performed by the surveying contractor. Other options would be to create an architectural model "in house" or through a 3rd party contract. This would depend mostly on the capabilities of the GC/CM. It is safe to assume that in this situation, the GC/CM would have some type of capabilities in BIM modeling to choose to incorporate in their construction processes. This model would then be distributed to the specialty contractors involved in the 3D coordination.

Once the trades have received the base model, they would use this to model their respective scope to the appropriate level of detail. These detailed modeling phases would most likely take place by quadrant or area of the building. It is rare and unadvisable to coordinate an entire building at once since this requires extremely powerful computer hardware and would take an extremely long time to complete. Coordination is best performed using smaller sections of the building similar to a 2D process. These areas of coordination should be built into the Critical Path Method Schedule (CPM) if possible. The schedule should set specific milestones for area coordination, 3D model completion, upload to server/FTP website, and resolution of conflicts.

Next, the files must be compiled into a single clash detection program such as Navisworks. This would most likely be done by the GC/CM or the Mechanical contractor. The party responsible would have to be identified in the contract to avoid unnecessary disputes. In this stage, technical issues regarding file formatting can arise when combining different authoring software into a single model. It is critical that the contract spells out specific file formats or compatibility with the clash detection program. Once all of the MEP models are loaded, clash detections will be run to generate a report.

A clash detection report should be distributed to all MEP coordination parties prior to attempting to resolve the issues. This will give all parties a chance to review and note the collisions that arose to begin thinking how to address them. The meeting format must also be decided. This can take the form of teleconferencing, in-person, or independent coordination without any formal intervention. Although it may not be necessary to meet in-person during the resolution step of every collision report run, it is recommended that these face-to-face meetings do occur. Studies have shown that communication is richest and fullest in person.

Other things to consider regarding the meeting place and format are travel times, ensuring attendance commitments from all critical personnel, and technology capabilities. Through speaking with industry members, it was said that trailers with projector screens and adequate computer hardware tend to work best. This ensures that coordination team members are all on the same page and can lead to more efficient meetings. It also lends to the opportunity of physically entering the building area to further visualize the model information in the field.

Clashes can occur in different forms when using 3D BIM technologies. One type of conflict could arise from lack of model detail. An example of this could be a pipe going through a wall that does not require a sleeve. This type of clash should be noted and ignored in future reports. The next type of collision is a coordination issue such as a piece of duct that runs through a plumbing pipe. In this scenario, the specialty trades would have to determine a solution. Last, there are collisions that occur due to design issues. This type of clash would occur if a pipe of a certain diameter did not fit within a chase. This would have to be submitted to the designer as a RFI for further clarification or design changes.

In this stage it is extremely important to document and log the results of the meetings. The minutes along with the clash report and proposed solutions should be distributed to all parties as a reference in the event field issues arise or further clarification is needed.

When all of the areas have been coordinated and clash detection has yielded no collisions, the process is complete. During this step the final coordinated plans will be submitted to the designers for approval. Most likely each section was submitted individually after each quadrant or area was coordinated with no clashes detected.

Implementing 3D MEP Coordination at Carderock:

Much of this section will take lessons and processes derived from other research for application to this project in a hypothetical sense. It will describe the general method to implement a 3D coordination process utilizing BIM technologies.

It has been shown that utilizing BIM technologies such as 3D coordination utilizing an integrated project team delivery has the maximum benefits and efficiencies. Although this is true, a Design/Bid/Build project such as Carderock Springs Elementary School can also obtain some of the benefits of 3D MEP Coordination as well. In this implementation, Hess Construction + Engineering Services assume the lead role in the process since they hold all subcontracts.

In order to implement this process, specific requirements for 3D modeling will have to be implemented into the contractual language that will supplement the owner's requirements of a 2D process. This means that the specialty contractors will build their models from the 2D contract documents since there will be no preceding 3D model from the architect and consulting engineers. It is critical to note that 2D shop drawings and submittals will still be necessary to meet contract requirements. 3D modeling software will only be used to increase the efficiency of the coordination process. In order for the contractors to obtain the maximum benefit they should use the 3D software to obtain their 2D required drawing submittals. However this does not always occur, in the Dickinson School of Law Case Study by Leicht and Messner, they reported some contractors had hired a 3rd party modeling company to perform the 3D requirements of the contract with the CM. They then took the results of the 3D modeling and coordination process to maintain their own 2D drawing set. This was inefficient since the same drawings were created twice.

Technology capabilities and limitations should be considered when choosing the contractors to work on the project. Often, a pre-qualification method would be used with metrics based, not only on past performance, but also in 3D coordination and BIM capabilities. Considering this when awarding contracts would be important since you would want commitment to the 3D coordination process. Another important aspect of this would be to reach out to the subcontractors to attempt for them to assemble teams with experience with BIM technologies. This would help to decrease the learning curve compared to team members who have no experience. Having no experience does not necessarily disqualify a contractor. In the BIM Execution Plan by the Computer Integrated Construction Research Program at Penn State, they highlight the importance of identifying capabilities and supplementing inexperienced members with training to put them on a level with the rest of the construction team.

At this stage it would be important to identify which contractors would be required to model in 3D and implant the 3D MEP coordination requirements within their contract. At Carderock, the traditional MEP trades and Steel contract would be required to model in 3D for coordination purposes. These trades would be the following:

- Steel
- Mechanical/HVAC
- Plumbing
- Electrical
- Fire Protection

The contractors that were actually chosen at Carderock had some exposure to 3D modeling, although not all had participated in a truly 3D MEP Coordination process. The steel contractor had used a 3D model of the structure for shop drawing and detailing purposes. That would make their inputs into the process relatively minimal. It is also important to note that the steel contractor does not fully participate in the process since their system is of the highest priority. The mechanical and plumbing contracts were awarded to the same company. This introduces an added efficiency to the process since there are be less variables to consider and less points of contact to maintain. This contractor already has 3D modeling capabilities that they use to produce shop drawings and automated fabrication within their shop. This is typical of mechanical contractors of the Washington, D.C. area. Their inputs into the process would also be minimal. The fire protection contractor also has significant modeling experience and would need little training if any to participate in the modeling process.

The contractor of primary concern would be the electrical contractor. This contractor had the least amount of 3D modeling experience and would need the most amount of investment into the project. In this scenario they would have the option to invest in software and train personnel or hire a consultant to perform the modeling.

Once all the contracts were awarded, it would be important to establish a clear and well documented execution plan for the project. This would benefit the project since none of the contractors have had experience with a true 3D MEP Coordination process in the past. This would follow similar conventions to figure 15 found previously in this section. For example, in defining the level of detail, it would have to be spelled out that a duct should be modeled including the thickness of its insulation. Another example of this would be to say that all hangars and seismic supports should be modeled for all systems. Also, in the early stages it would be determined which file formats and software compatibility requirements would be necessary to ensure interoperability of MEP models.

After the requirements of the models and compatibility concerns are addressed, a process for sharing the files needs to be established. Through interviews with industry members about the ease of sharing files it was reported the best method is through a FTP site. They said that these sites have the least technical issues and allow for large files to be shared with faster upload and download speeds. They explicitly noted that e-mail was to be avoided at all costs since large files often get rejected by companies e-mail filters or takes a long time to send and receive.

Once all details regarding the technical software and information technology are understood, the building can finally be analyzed for coordination. To begin, the building should be broken down into logical sections that correspond with the CPM schedule. This will allow for modeling and coordination requirements to be built into the schedule by area to ensure that all areas are coordinated and released for fabrication as early as possible so that the contractors can realize the maximum benefit of the 3D MEP coordination process and make their investment worthwhile.

Table 6 - Building Area Breakdown

<table>
<tr><th>Area</th><th colspan="3">Components of the Area</th></tr>
<tr><td>Area 'A'</td><td>A Lower Level</td><td>A Main Level</td><td>A Upper Level</td></tr>
<tr><td>Area 'B'</td><td>B Lower Level</td><td colspan="2">B Main Level</td></tr>
<tr><td>Gym</td><td colspan="3">One Logical Area</td></tr>
<tr><td>Multipurpose Room</td><td colspan="3">One Logical Area</td></tr>
</table>

Table 6 demonstrates how Carderock was broken down into different areas. The construction schedule should then be adjusted to reflect when areas should be coordinated according to when construction activities will take place. This will drive the meeting and the clash detection cycle of the process.

At Carderock, for Areas ‘A’ and ‘B’, meetings were held on the first Wednesday of the month approximately a month and half before the first MEP trades were schedule to begin work. The schedule typically followed Area ‘A’ Lower to Upper, followed by ‘B’ Lower to Main, and then the Gym and last the MPR. Once again, to maximize the benefits of a 3D coordination process, the contractors would be required to begin modeling almost as soon as they are awarded the contract. This would provide them with two primary benefits. First, a learning curve will most likely exist, therefore running a “mock-up” type coordination process would benefit the team to test the process and refine steps if necessary. Next, it creates opportunities for prefabrication which can improve the efficiency of work output and even accelerate the schedule without any direct inputs to schedule acceleration scenarios.

Once the modeling is complete, the models will be uploaded to the FTP site and Hess would compile the models and run clash detection for the area being coordinated. The collision report would be distributed and a meeting would be scheduled. The best place would either be the construction field office or the corporate office of Hess. If the corporate office is used, no additional technology such as computers and projectors. If the field office is chosen, then an investment into a computer that can handle the collision software and projector will be needed. At this meeting the collisions would be assessed and solutions to the problems would be proposed. Again, the collisions would either yield a detail issue, a coordination issue, or a design issue. The contractors would then be given time to refine their models.

The coordination meetings at Carderock using the 2D AutoCAD overlay process lasted 4-6 hours. They were very time consuming and not every contractor had actively participated. The 3D process would allow for the meetings to concentrate only on the detected clashes and less on the searching of conflicts within the 2D drawing set. They were given 3 weeks to make changes and compile the coordinated drawing set. This was the responsibility of the Mechanical contractor. Using a 3D process it is realistic to accomplish revisions in half the time. After this time, the refined drawings would be loaded into the clash detection software and reports would be distributed. At this stage, a majority of the conflicts should be resolved. It is safe to assume that another in-person meeting will not be required and that the coordination toward zero conflicts can take place using phone calls and emails between the specialty trades.

After the initial coordination meeting for each area, a review cycle should be set up for the collision detection of the specific areas. For example, after five working days, the models are posted back to the FTP site to be compiled for another clash report. This would provide feedback as to whether there is significant improvement in the conflicts within the models. The collision report can be sent to the contractors for comparison to the original coordination meeting. If necessary another meeting could be required in person to discuss the new results. This would have to be a judgment call based on the severity and depth of the conflicts that occur. For example, a main supply duct branch conflicting with a large and critical structural member could require a meeting to discuss potential solutions.

Once the zero conflict milestone is reached, a 2D set would be exported from the 3D model for approval from the A/E designers. When approved, the specialty contractors can begin pre-fabrication plans to benefit from the enhanced quality control of their shops. This should increase the quality and tolerances of the workmanship. It would also cut down on labor within the field with the opportunity to finish ahead of schedule.

Summary of Implementation Strategy:

The goal of this analysis is to identify best practice techniques to establish a process for 3D MEP Coordination on a project that was not initially set up to support such a procedure. The analysis is created through critical industry research relating to the topic. Using the results and recommendations of industry professionals and researchers, a plan was derived that strived to achieve the maximum benefits of time, efficiency, and budget: while minimizing risk and inefficient practices.

It is impossible to say whether or not the 3D coordination plan would prove to be better in practice than the 2D method employed on the project since there is no way to apply a new process and analyze it without actually performing the steps. The best way to analyze its impact is to make generalizations from case study projects and find similarities that can support evidence of a 3D MEP Coordination plans effectiveness compared to a 2D process.

Currently, there is research that supports the case for using a 3D MEP Coordination process on construction projects. In research performed by Staub-French and Khanzode, they highlighted many benefits of the process including increased cost control, fewer change orders, and increased quality and efficiency due to prefabrication. In another publication by Leicht and Messner, they also noted the reduction in change orders and RFI's specifically related to MEP systems. They also reported that there was increased cost control due to fewer field conflicts as a result of implementing MEP systems. Each report concluded that the overall 3D MEP Coordination process and experience was positive for all parties involved.

The main barrier to success using this process is a lack of thorough initial planning. Each step in the process must be documented carefully. Therefore, it is a recommended that a project specific manual be made to guide the project. This should include details regarding all aspects of the coordination process such as file compatibility to conflict resolution processes as was discussed earlier in this section. Perhaps the most important aspect of the manual should be to define the goals of using BIM technologies on the project. For Carderock Springs Elementary School, an example of a project goal relating to this analysis would be "To enhance the efficiency of the project through commitment to the 3D MEP Coordination process." It is important to think about what the expected output and end goal would be. In this case it would be to reduce coordination conflicts that could result in RFI's, Change Orders, and Re-work in the field. All of these activities are very time consuming for all parties, from the specialty contractor to the owner, who must review all changes to the original contract scope.

The last recommendation is a commitment to the refinement of the MEP coordination processes. Within any industry, new technology provides an opportunity for innovation and creativity. It must be understood that there will be inherent difficulties that arise from using a new technology. This is especially true in the architecture, engineering, and construction industries, since there is no project that is identical to another. No precedent can be truly established. The uniqueness of each project lends itself to innovation as managers and project team members must refine "best practice" type guidelines to work on their own unique project. This commitment to the overall goals of the project would allow each team member to realize the efficiencies of the 3D MEP Coordination process and save time and money while gaining experience and knowledge that can be applied to future projects.

Section Specific References:

C. B. Tatum, T. K. (2000). Coordinating Building Systems: Process and Knowledge. *Journal of Architectural Engineering , Vol. 6* (No. 4).

Computer Integrated Construction Research Program. (2009). "BIM Project Execution Planning Guide – Version 1.0." October 8, The Pennsylvania State University, University Park, PA, USA.

Messner, J., & Leicht, R. (2008). Moving Towarrd an Intelligent Shop Modeling Process. *Journal of Information Technology in Constrcution , Vol. 13*, pg. 286-302.

Staub-French, S., & Khanzode, A. (2007). 3D and 4D Modeling for Design and Construction Coordination: Issues and Lessons Learned. *Journal of Information Technology in Constrcution , Vol. 12*, pg. 381-406.

VII. RELOCATION OF UNDERGROUND STORM RETAINAGE SYSTEM (UGS)

BACKGROUND:

Carderock Springs Elementary School has an underground storm water retainage system (UGS) to manage volumetric flow of water from its site to the public storm sewers. At the current location the UGS is located about 18 feet below one of the highest points on the site. This requires deep excavations that are more costly and take longer to dig. Also at its current location, it cuts off a very critical access point to the site and building during critical stages of the construction sequence.

This analysis will look to relocate the system to a lower location saving on installation costs. The primary benefits will come from greater site utilization. This will allow more crews to work on substructure components simultaneously at different parts of the building. This will help to accelerate the schedule. It is important that substructure and superstructure activities, such as the installation of footings, slabs on grade, and steel structure, be monitored closely since they are on the critical path and can affect the schedule duration many months later.

METHODOLOGY AND STEPS:

This analysis will first highlight the proposed relocation area of the site. Next it will analyze the cost difference between placing the system at different elevations of the site. It will then review areas of the schedule that can benefit from achieving access to ‘area B’ of the building earlier. Last a new site utilization plan will be created to take advantage of greater amounts of space.

RELOCATION OF UGS:

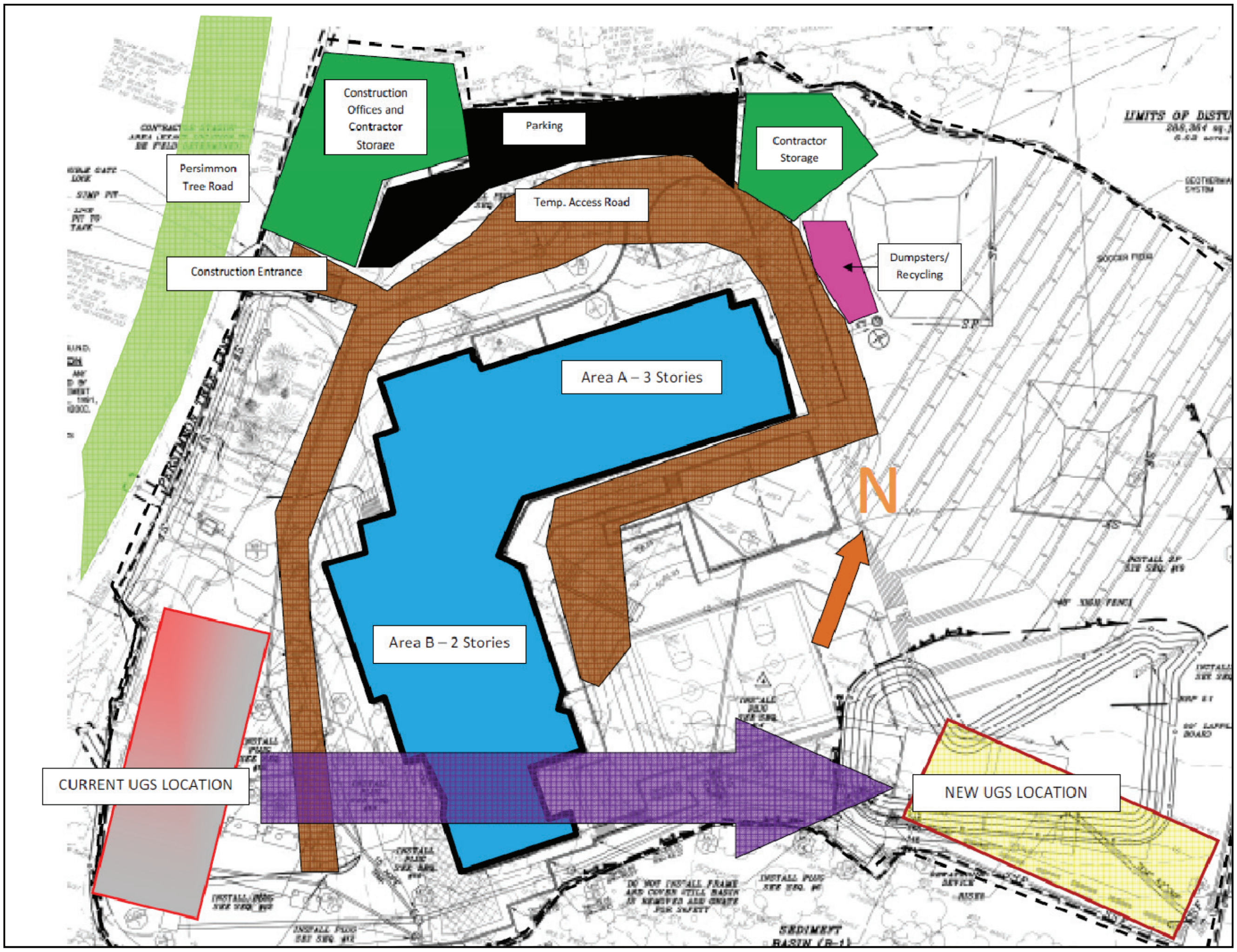


Figure 16 - Relocation of UGS Plan

The figure above shows the new location of the UGS. It will move from being very close to Area B of the building footprint to an unused corner of the site. This new location will be on the edge of the site conservation area where trees must be preserved. This new location will allow for a greater utilization of the site near Area B for material storage, parking, and material staging.

COST COMPARISON:

This comparison is being made by simply "lifting up" the system and moving it to a new location. This means that there will be no difference in the actual cost of the system as it is engineered. The following assumptions were made:

- The engineering of the system would not be affected by relocation
- The new location would not require any additional storm structures
- There are no unknown soil conditions in the area that could affect the structural support
- Identical crew sizes will be used at the new location
- RS Means 2010 was used to find cost and labor output or duration
- The excavation totals were calculated using 45 degree slopes on the excavation limits to adhere to safety regulations. This was common practice on this site. At times, trench boxes were also used to protect the workers.

Table 7 - Excavation Takeoff Summary

Location	Quantity	Description	Daily Output	Duration (8h work days)	Labor Hours	Unit	Mtrl.	Labor	Equip.	Total	Labor Total	Equip Total	TOTAL COST
ORIGINAL	7286	Excavating, bulk bank measure, 3 C.Y. capacity, backhoe, hydraulic, crawler mounted	2080	7.3	0.008	CY	$ -	$ 0.23	$ 1.13	$ 1.36	$ 1,676	$ 8,233	$ 9,909
NEW	3643	Excavating, bulk bank measure, 3 C.Y. capacity, backhoe, hydraulic, crawler mounted	2080	3.6	0.008	CY	$ -	$ 0.23	$ 1.13	$ 1.36	$ 838	$ 4,117	$ 4,954
										DIFFERENCE	**$ 838**	**$ 4,117**	**$ 4,954**

Cost Results:

- The difference between the excavations is about $5,000.
- There is no savings in general conditions since relocating this work would take it off the critical path.

NEW SITE UTILIZATION PLAN:

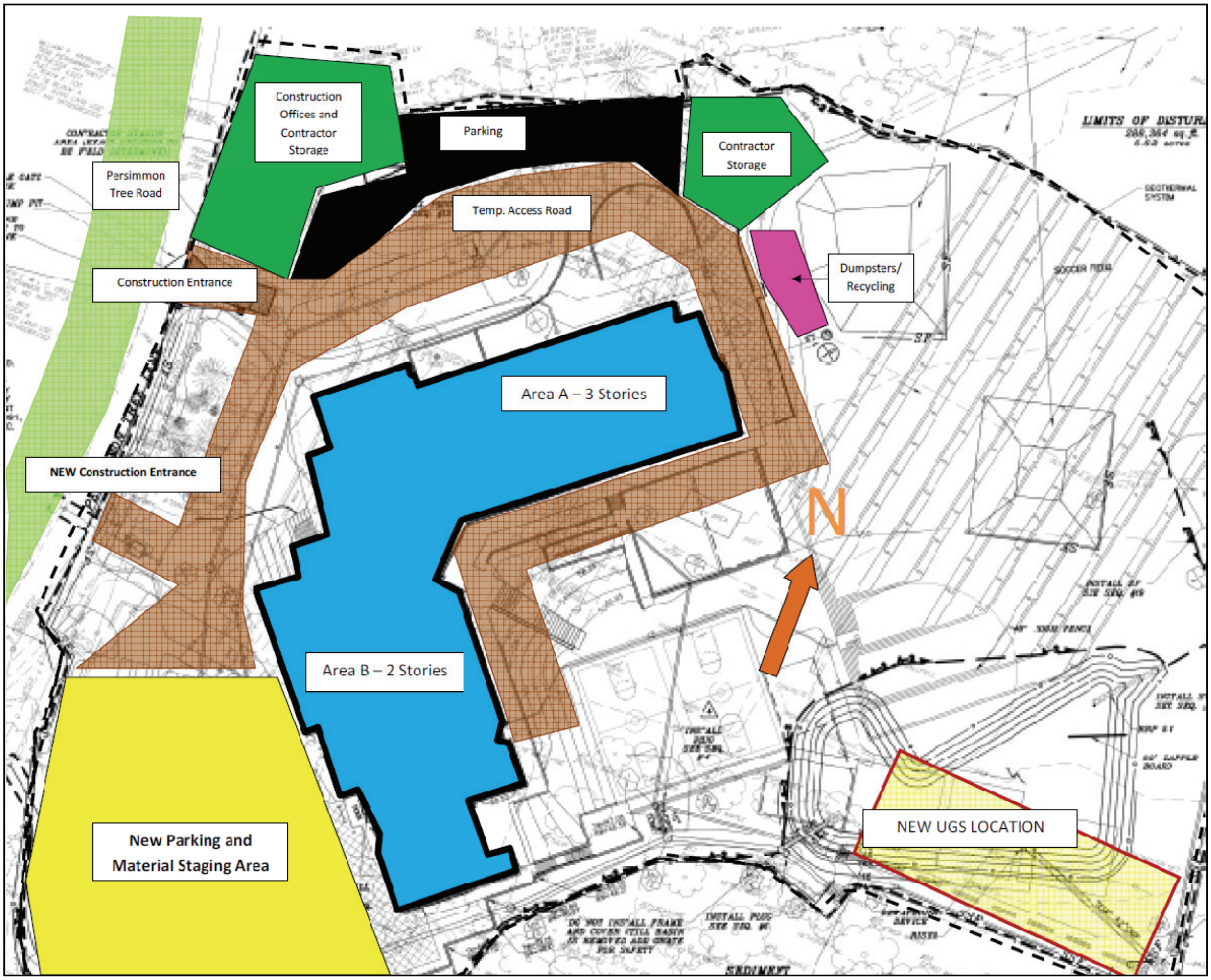
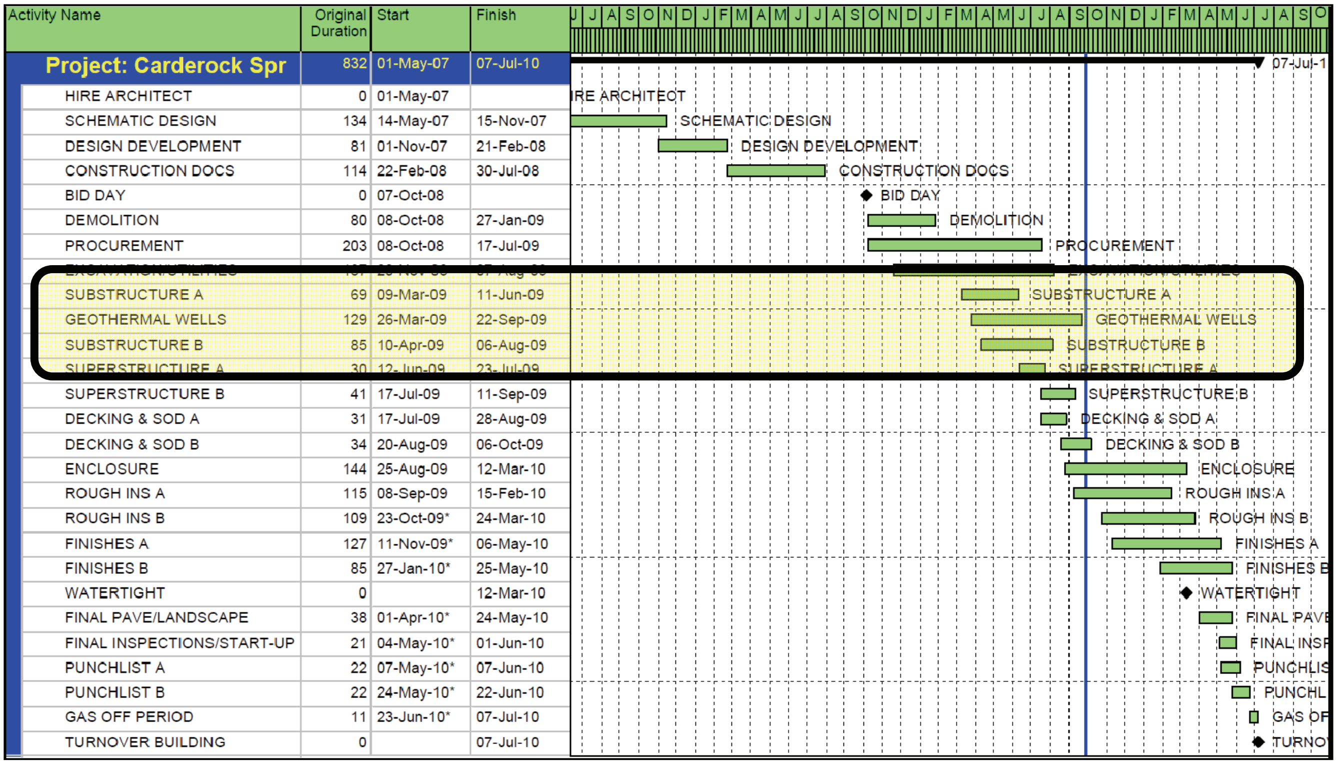


Figure 17 - UGS Relocation Site Utilization Plan

The new site plan opens up a generous area that was previously allocated only for the sitework contractor during the installation of the UGS. This area will also allow for more parking and material storage. During this phase, the masonry contractor began delivering CMU for foundation walls and exterior wall systems. Previously shipments had to equal only about 2-3 days work. With more storage they can receive larger deliveries saving them valuable time in material staging. The greatest benefit will be unrestricted access to Area B by the concrete contractor who will install foundations and slabs on grade. With access to this area they can add another crew and work in Area A and B simultaneously to do slab work and finish foundations. This will allow them to pour both areas at the same time which will them to save money. Concrete pours also take precedent on the site over deliveries and construction traffic. Pouring at the same time will limit restricted traffic patterns on site.

SCHEDULE ANALYSIS:

In order to accelerate the schedule in this scenario, additional crews will have to be used to work simultaneously in different areas. This will be possible since the restrictions that were on Area B will be lifted by relocating the UGS to the new location. The relocation will allow for other contractors such as the concrete contractor to get their equipment into the area to prepare the substructure and slabs. By doing so, and working simultaneously in two areas they can achieve a 20-30 work day schedule reduction.



Activity Name	Original Duration	Start	Finish
Project: Carderock Spr	832	01-May-07	07-Jul-10
HIRE ARCHITECT	0	01-May-07	
SCHEMATIC DESIGN	134	14-May-07	15-Nov-07
DESIGN DEVELOPMENT	81	01-Nov-07	21-Feb-08
CONSTRUCTION DOCS	114	22-Feb-08	30-Jul-08
BID DAY	0	07-Oct-08	
DEMOLITION	80	08-Oct-08	27-Jan-09
PROCUREMENT	203	08-Oct-08	17-Jul-09
EXCAVATION/UTILITIES	[illegible]	[illegible]	[illegible]
SUBSTRUCTURE A	69	09-Mar-09	11-Jun-09
GEOTHERMAL WELLS	129	26-Mar-09	22-Sep-09
SUBSTRUCTURE B	85	10-Apr-09	06-Aug-09
SUPERSTRUCTURE A	30	12-Jun-09	23-Jul-09
SUPERSTRUCTURE B	41	17-Jul-09	11-Sep-09
DECKING & SOD A	31	17-Jul-09	28-Aug-09
DECKING & SOD B	34	20-Aug-09	06-Oct-09
ENCLOSURE	144	25-Aug-09	12-Mar-10
ROUGH INS A	115	08-Sep-09	15-Feb-10
ROUGH INS B	109	23-Oct-09*	24-Mar-10
FINISHES A	127	11-Nov-09*	06-May-10
FINISHES B	85	27-Jan-10*	25-May-10
WATERTIGHT	0		12-Mar-10
FINAL PAVE/LANDSCAPE	38	01-Apr-10*	24-May-10
FINAL INSPECTIONS/START-UP	21	04-May-10*	01-Jun-10
PUNCHLIST A	22	07-May-10*	07-Jun-10
PUNCHLIST B	22	24-May-10*	22-Jun-10
GAS OFF PERIOD	11	23-Jun-10*	07-Jul-10
TURNOVER BUILDING	0		07-Jul-10

Figure 18 - UGS Schedule Analysis

The primary activities to be monitored during this period will be footings, underground rough-ins, poured concrete and CMU foundation walls, slab pours, and exterior CMU course patterns. Another important consideration in the success of this scenario will be the need for close coordination by the superintendent. It will be critical that close supervision and extensive quality control be utilized to prevent any problems from arising. It will be important to maintain a team atmosphere during this stage since multiple contractors will be working together to accelerate the schedule by a month. They will also have to be very diligent that all of their work is planned for and installed to the specification's quality and performance standards. By referencing the General Conditions estimate (pg. 21), saving a month of time correlates to a budget savings of about $94,000. Also, starting from the beginning of demolition to building turnover, this acceleration represents a duration reduction of 9.1%.

CONCLUSION:

This analysis shows how building design greatly affects the construction process. By moving the UGS (with assumptions noted), it is shown how greater access to areas of the site can reveal opportunities for schedule acceleration. This translates to significant cost savings, especially in the general conditions. Although the difference in excavation costs is negligible, the CM Hess Construction + Engineering Services, could increase their margins on this project significantly by utilizing increased manpower from the trades on site.

In summary the results show that about $94,000 can be saved in general conditions costs from a schedule reduction of about 9.1%. This makes this scenario extremely desirable if it could be applied to the project. The variables that could negatively impact the scenario include: supervising more trade members at the same time; coordinating larger deliveries of materials and concrete; maintaining quality control in multiple areas; and managing contractors' interactions in close working areas. This would require planning up front but could provide great benefits on the back end of the project by saving time and money.

SEE APPENDIX D FOR RS MEANS SUPPORT

VIII. STRUCTURAL WALL CHANGE (STRUCTURAL BREADTH)

BACKGROUND:

The gymnasium and multipurpose room at Carderock Springs were designed as load bearing CMU walls with joists resting over top of the wall to carry the roof load. The rest of the building's typical construction is a steel frame. In the two areas where the typical steel frame meets these two rooms, there needs to be increased coordination to ensure joists can be set on time to go with the flow of the structural steel. This work requires two contractors to work in the same area, which is not ideal.

Figure 19 - Picture of Gymnasium

Figure 20 - Picture of Multipurpose Room

GOAL:

The goal of this analysis is to change the structure of these two areas to steel so that they can be erected independently of another contractor's work. This should increase the efficiency of the steel crew and allow the critical path to move faster, since a steel column and beams are faster to erect than building a load bearing masonry wall. In addition, there would be less constructability and coordination issues which would minimize potential risk.

RESEARCH STEPS:

To begin this analysis, a cost estimate will be done to estimate the cost of the original construction. This will be used later to compare costs to the steel structure. The next aspect will be the re-design of the two areas using structural steel. After the design is complete, estimates for the new cost and schedule will be made. These will then be used to compare to the original schedule which will be used as the baseline and the original estimated costs for the construction. Finally, advantages and disadvantages will be assessed for use in the final recommendation.

RESOURCES:

The primary resource used was the AISC Steel Construction manual. Other resources included online joist catalogs and the assistance of other students. RS means was used for cost estimates.

DESIGN:

The design was completed using Load and Resistance Factor Design (LRFD) method. The gravity design was the only design considered within the scope of this analysis. In general the design followed these steps:

1. Determine roof loads using drawings and ASCE 7-05.
2. Perform preliminary layout and spacing of columns and beams.
3. Determine loads to columns and beams using original roof and joist plan.
4. Size beams and columns.

To determine the sizes of beams and columns, a simplified method was used. Instead of designing each beam and column independently, the maximum load condition was found. This condition was then repeated at the regular intervals of the new design. These two spaces are rectangular and benefit from a simple repeating design. Masonry will still be used in these spaces as partitions to separate them either from the exterior or other interior spaces.

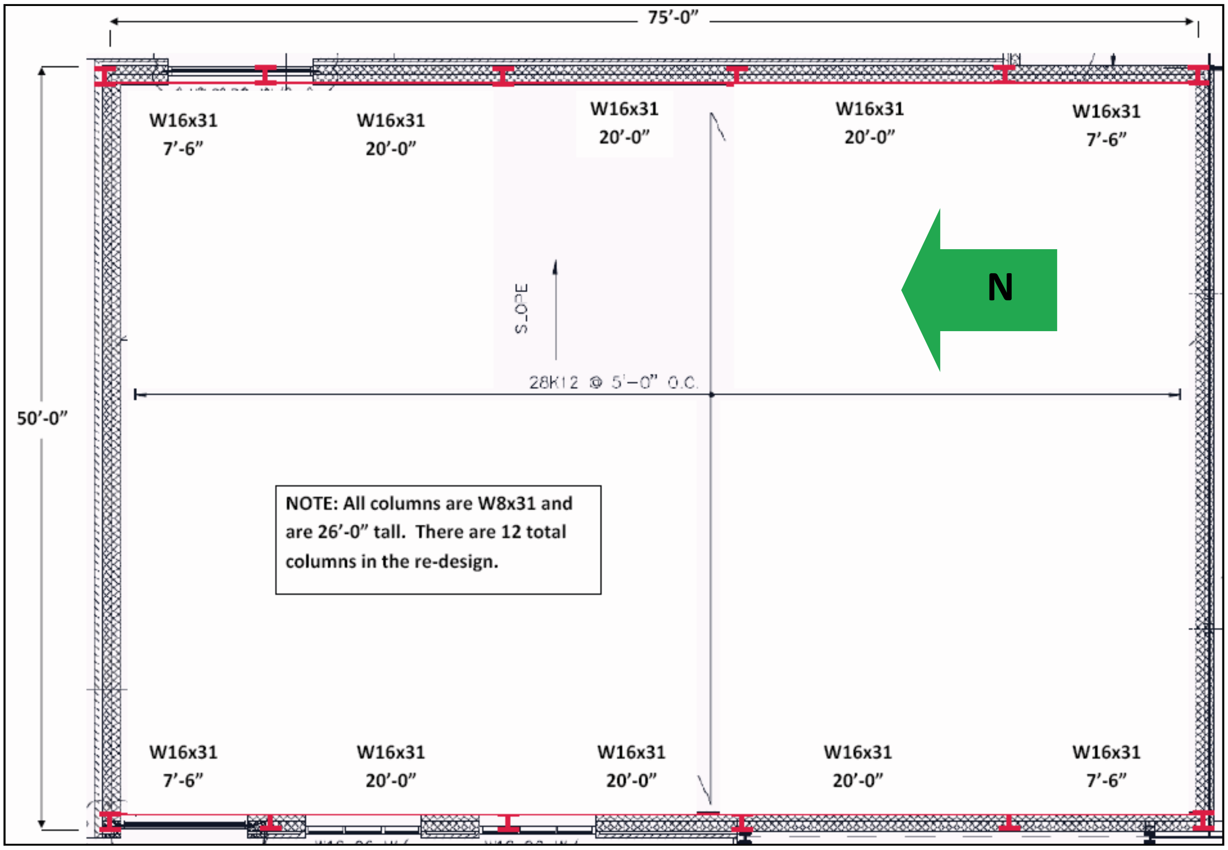


Figure 21 - New Gym Structural Design

The above figure represents the final design of the gymnasium space. Detailed hand calculations can be found in the attached appendix E. The gym is 75 by 50 feet and will utilize W16x31 beams and W8x31 columns with 50 KSI steel. The plan north and south walls are partially exposed to the exterior as well as the entire plan west wall. This type of partition will be a 12" thick CMU exterior wall. The remaining areas will be interior walls which will be 8" CMU with a painted final finish.

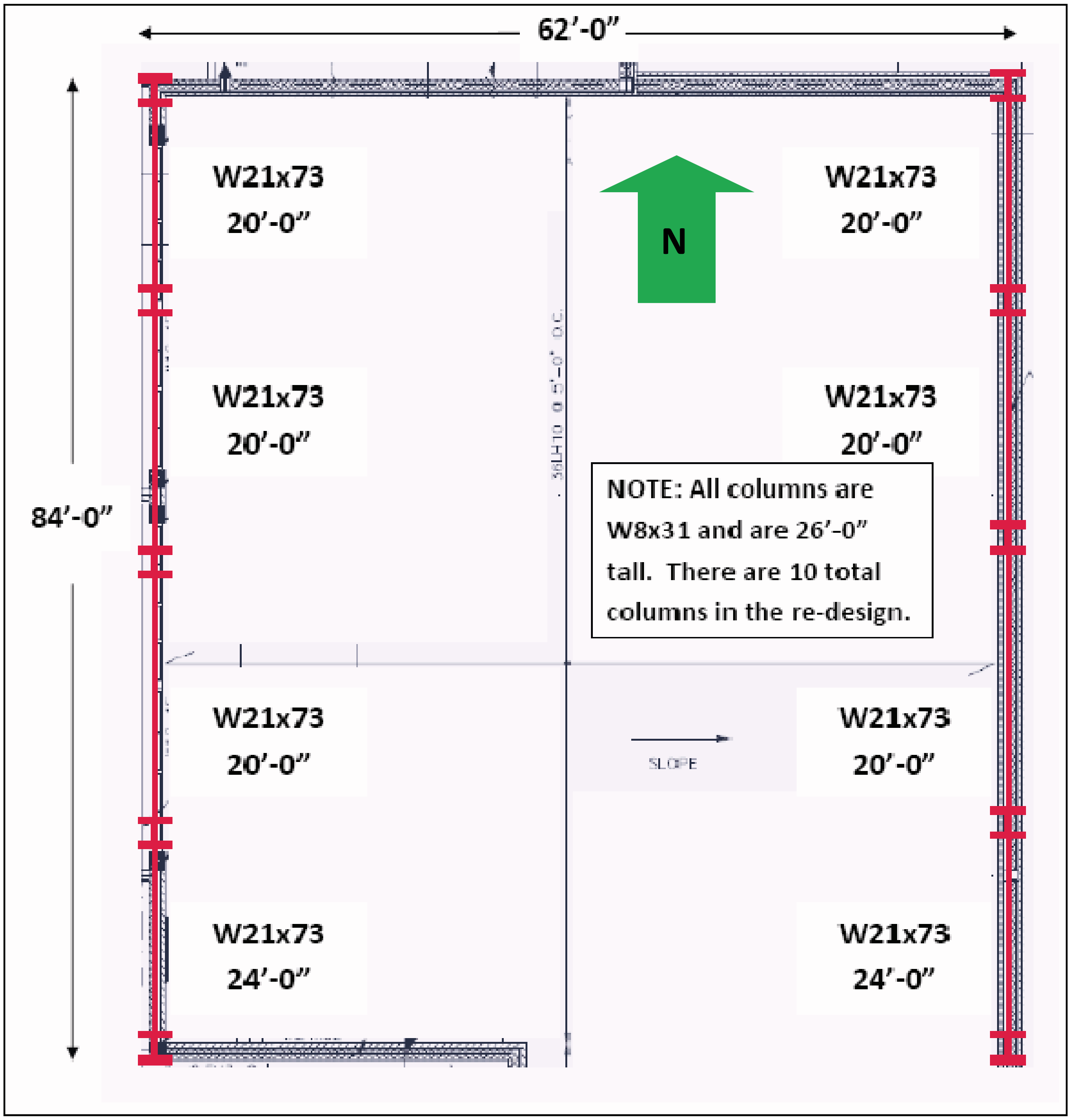


Figure 22 - New MPR Structural Design

The above figure represents the final design of the multipurpose room space (MPR). Detailed hand calculations can be found in the attached appendix ?. The MPR is 62 by 84 feet and will utilize W16x73 beams and W8x31 columns with 50 KSI steel. All of the walls with the exception of the plan east walls are interior. The interior walls will be 8” with a painted finish. The exterior walls will be 12” CMU with painted interior finish and a brick ledge on the outside façade.

CONSTRUCTABILITY & SCHEDULE:

The constructability and coordination of the original design was a very detailed scenario. The original construction called for steel joists to rest on a masonry load bearing CMU wall. This schedule calls for the steel erector and masonry company to work very closely together to coordinate placing the steel joists immediately after the masonry is complete and the grouted walls are cured. The construction schedule called for the joists to be placed upon completion of the walls. See the detail to the right for the specific connection requirements.

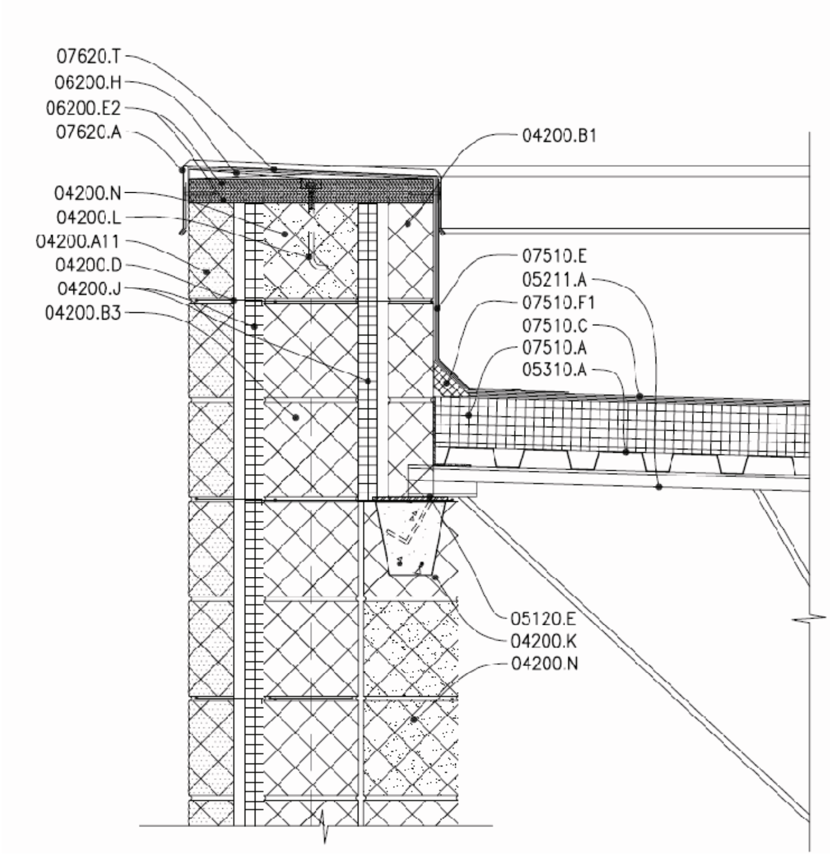


Figure 23 - Typical Masonry Bearing Wall Joist Bearing Detail

Issues can arise in multiple scenarios with the original design. One scenario is that the masonry is lagging while the steel erector stays on schedule. This would mean that the joists would be on site and ready to be erected but the masonry walls would not be ready. In this scenario the steel erector would be slowed down and a new plan would have to be developed to keep the steel erector's working. This would most likely cause conflict since contractors do not like to be slowed or delayed by another contractor. Most schedules and construction plans account for this and allow contractors to work in specific areas for specific durations. However in a scenario such as this, there is no choice but to have to closely coordinate the work.

All different combinations of the masonry lagging or the steel being ahead would cause a disruption to the original schedule. The only good scenario would be that the masonry crews are ahead of schedule.

With the steel structure, these problems would be eliminated. The steel contractor would be ahead of the masonry contractor (as is typical for a primarily steel superstructure) and would not have to worry about syncing their schedule with the mason's schedule. They could complete the work with a little more leeway and freedom. In this scenario, the mason crew would follow behind the steel erector and neither would affect each other's work.

Also in the steel scenario, time can be saved on the critical path. The original schedule calls for 20 days to complete the gym walls which are on the critical path (The multipurpose room is not on critical path). Steel can generally be erected faster than masons can build load bearing CMU walls. On this project, this is the case since only typical construction techniques. Using steel, the schedule is reduced by 12 days moving the finish date from July 7, 2010 to June 21, 2010. These calculations were performed using the following technique:

1. Use original schedule to determine steel erection rates of other similar portions of the project. Result = 45 pieces of steel (beams and columns) can be erected in 5 days.

2. Use proportions to estimate new steel duration.

    a. 45 pieces/5 days = # steel pieces in Gym or MPR/x days

3. Use original masonry duration for load bearing walls in both spaces to find difference.

4. Subtract durations to get new duration and find schedule savings.

Table 8 - Schedule Savings from Structure Change

Room	Original Duration	New Duration	Work Days Saved
Gym	20	8	**12**
MPR	10	6	**4**

Note: Only Gym on the Critical Path

Original Project Finish: July 7,2010
New Project Finish: June 21, 2010

COST

Building with masonry is a very labor intensive activity. The process of moving bricks, concrete masonry units, and mortar is very difficult and requires many men skilled and unskilled. Erecting steel requires less labor in comparison to masonry. The labor inputs of steel erection are the crane operators, riggers, and setters. Then after setting, a bolt up or welding crew to finish the connections. The following tables show the differences in cost of the two systems.

Table 9 - Cost of Original Gym Structure

Gymnasium - Original Construction									
				Cost Per SF			Total Cost Per SF		
Wall Type	SF of Wall	CMU Size	Core Fill	Material	Installation	Total	Material	Installation	Total
Interior	3380	12x8x16	Grout	$4.70	$8.80	$13.50	$15,886	$29,744	$45,630
Exterior	3120	12x8x16	Grout	$4.70	$8.80	$13.50	$14,664	$27,456	$42,120
								Final Cost:	*$87,750*

Table 10 - Cost of Original Multipurpose Room Structure

Multipurpose Room - Original Construction									
				Cost Per SF			Total Cost Per SF		
Wall Type	SF of Wall	CMU Size	Core Fill	Material	Installation	Total	Material	Installation	Total
Interior	7592	12x8x16	Grout	$4.70	$8.80	$13.50	$35,682	$66,810	$102,492
Exterior	2184	12x8x16	Grout	$4.70	$8.80	$13.50	$10,265	$19,219	$29,484
								Final Cost:	*$131,976*

Table 11 - Cost of New Gym Structure

Gymnasium - Redesigned Structure									
				Cost Per SF			Total Cost Per SF		
Wall Type	SF of Wall	CMU Size	Core Fill	Material	Installation	Total	Material	Installation	Total
Interior	3380	8x8x16	Hollow	$2.55	$6.20	$8.75	$8,619	$20,956	$29,575
Exterior	3120	8x8x16	Grout	$3.05	$6.60	$9.65	$9,516	$20,592	$30,108
								Final Cost:	*$59,683*

Table 12 - Cost of New Multipurpose Room Structure

Multipurpose Room - Redesigned Structure									
				Cost Per SF			Total Cost Per SF		
Wall Type	SF of Wall	CMU Size	Core Fill	Material	Installation	Total	Material	Installation	Total
Interior	7592	8x8x16	Hollow	$2.55	$6.20	$8.75	$19,360	$47,070	$66,430
Exterior	2184	8x8x16	Grout	$3.05	$6.60	$9.65	$6,661	$14,414	$21,076
								Final Cost:	*$87,506*

Table 13 - Summary of Structural Change Costs

Structural Steel Cost for both Areas						
Member Size	Area	Function	Linear Feet	Weight (ton)	Cost/Ton	Total Cost
W16x31	Gym	Column	312	4.84	$2,819	$13,633
W8x31	Gym	Beam	150	2.33	$2,819	$6,554
W21x73	MPR	Column	168	6.13	$2,819	$17,286
W8x31	MPR	Beam	260	4.03	$2,819	$11,361
					Totals:	***$48,834***

The previous tables demonstrate the cost differences, especially in labor, for a reinforced CMU load bearing wall. These walls take considerably more time to build than a standard CMU partition with no load bearing ratings. It is seen that in both rooms, money is saved in both materials and labor to only construct standard partition and exterior walls for the spaces. The masonry costs were derived from RS Means Assemblies guide. The last table shows the costs for the additional steel. These costs were found from using the detailed takeoff of steel on the project to find the price per ton of steel with installation included.

Table 14 - Overall Cost Summary for Structural Change

	Original			Redesign					
				Masonry		Steel			
Room	Material	Labor	General Cond.	Material	Labor	Mat. + Install	General Cond.	Percent Difference	Total Savings
Gym	$30,550	$57,200	$52,860	$18,135	$41,548	$20,187	$21,144	50.28%	$39,596
MPR	$45,947	$86,029	x x x x x	$26,021	$61,485	$28,647	x x x x x	12.75%	$15,824
Totals	*$76,497*	*$143,229*	*$52,860*	*$44,156*	*$103,033*	*$48,834*	*$21,144*	*22.63%*	*$55,420*

Notes: Multipurpose room not on the Critical Path, therefore no G.C. savings
General Conditions derived from actual budget in General Conditions Estimate section of report

This last table shows the total dollar savings from the new system with general conditions included. Although, $55,420 is a small savings compared to the $21 million total cost of the project, it would still be appreciated by any owner. That dollar amount could relate to a pure cost savings or could allow for the owner to upgrade equipment or enhance the project with an add-alternate. One particular item on this project was an outdoor sustainable garden space with a small amphitheatre design that was selected to be constructed by the owner after the bid. A small savings such as this could help offset or completely pay for a space such as this.

BIM OPPORTUNITIES

BIM could play a role in various aspects of this re-design scenario or original design. Areas of potential use could be 3D design coordination, engineering analysis, phase planning, and cost estimation.

The engineering analysis is one area where the potential for comparing two systems could be effective. Using structural modeling software, designers could compare and contrast the designs to choose the design with the best potential. They could then use these two models to compare costs, allowing the owner to make an informed decision.

In the construction phase, a 4D model could be used to sequence the construction activities for maximum efficiency and to evaluate constructability and risk for particular rooms or construction sequences. A 3D visualization activity could help to generate new ways of approaching a particular space. There would be many opportunities to utilize BIM on this small section that could enhance the project from the design, construction, and owner's perspective.

RECCOMENDATION

This analysis indicates that a construction management perspective makes this re-design very lucrative. The new steel design helps minimize risks and increases the overall efficiency of the superstructure schedule. The three main points of interest are constructability, schedule, and cost.

Constructability is easier since there is less coordination required. The steel contractor and masonry contractor could work independently of each other without their critical paths meetings at any intersection. The schedule is reduced by 10 working days. Although this seems very small, it can provide a nice cushion if problems were to arise on the project. The K-12 educational market is extremely competitive which correlates to very small profits on these types of projects. More importantly, a contractor will never complain if they can find ways to shorten the critical path. Finally, the savings in cost must be noted although it does not correlate to a significant benefit when compared to the magnitude of the overall project cost.

SEE APPENDIX E FOR DETAILED CALCULATIONS AND RS MEANS

IX. ADDITION OF SOLYNDRA SOLAR PANELS (ELECTRICAL BREADTH)

BACKGROUND

Carderock Springs Elementary is striving to achieve a LEED Silver rating from the USGBC. The school's design is part of the Montgomery County Publics schools commitment to build sustainable buildings to help reduce environmental impact and to save in their energy budget through energy efficient systems. This analysis will assess the feasibility in adding solar panels to further offset energy demand and decrease the overall energy bills for this particular facility.

GOAL

The goal of this analysis is to identify the feasibility and potential output of a solar PV system. It will attempt to produce enough power to supply the lights and receptacles independent of the grid. It will also look into LEED points rating of the building and help to increase the school district's goals of sustainable buildings.

RESEARCH STEPS

Research began on the solar photovoltaic systems to attempt to identify a highly efficient system to incorporate to the design. Once a system was selected, a layout was identified using the most favorable and accessible areas of the roof. The next step will be to identify what the energy output will be and costs of installation. Last, payback and life cycle analysis will be done to determine recommendations of the analysis.

RESOURCES

Resources that will be used are industry contacts as well as technical product data from the manufacturer. Also, various government websites will also be used to help to estimate the amount of sun that can be expected to shine on the site to estimate power output.

PRODUCT SELECTION

The product used in this analysis is a photovoltaic system from Solyndra. Solyndra is a relatively new company that introduced a product using cylindrical tubes instead of a flat plate-like system. It utilizes thin film photovoltaic technology which is cheaper to produce than crystalline cells. They are also extremely thin and light which can make for a more versatile panel design. This product also takes advantage of "cool roof" designs such as the one that is being implemented at Carderock Springs Elementary School.

The cylindrical shape takes advantage of the reflectivity of the white roof to capture reflected sunlight from the white surface on the bottom side of the cylinder. This capability also means it is positioned differently than traditional PV systems. They lay horizontal to the surface as opposed to being positioned at an angle facing the south. This allows for better use of the area of the roof. You can fit more panels in a smaller area since there is no need to worry about shadows compared to a traditional panel system. Solyndra data reports that only minimal losses of small percentages (less than 3%) occur when they can not be oriented toward the southern exposure.

Another advantage of this system is the ability for air to flow through the cylinders. This allows for lower air resistance and uplift force. This is done without structural attachments to the roof or penetrations. It is a self ballasting system which makes for a very easy installation process.

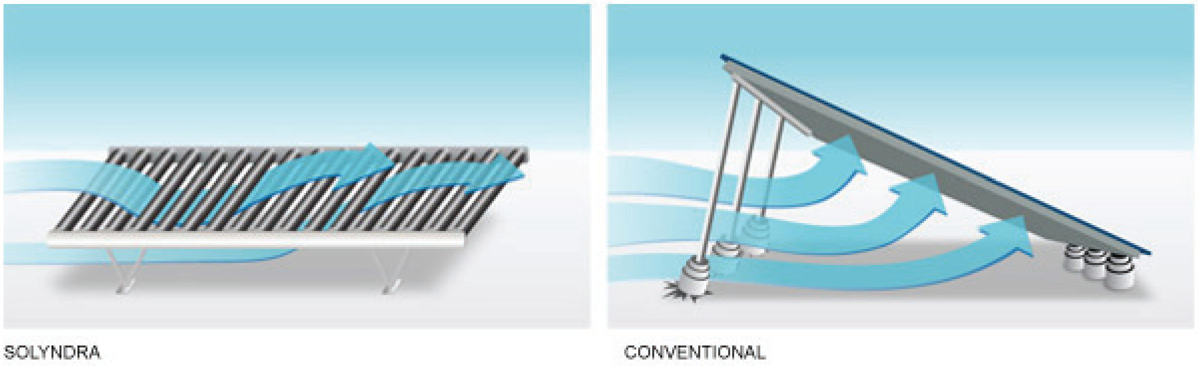


Figure 24 - Solyndra Wind Diagram

The panel that was selected from the product data was the SL-001-191. It has a power rating of 191 watts. The highlighted data will be used to produce the results of power output and cost calculations.

Product Specifications

Electrical Data

Measured at Standard Test Conditions (STC) irradiance of 1000 W/m², air mass 1.5, and cell temperature 25° C

Model Number		SL-001-150	SL-001-157	SL-001-165	SL-001-173	SL-001-182	SL-001-191	SL-001-200 Release Date TBD
PowerRating (P_{mp})	Wp	150 Wp	157 Wp	165 Wp	173 Wp	182 Wp	191 Wp	200 Wp
Power Tolerance (%)	%/Wp	+4, -5	+/-4	+/-4	+/-4	+/-4	+/-4	+/-4
V_{mp} (Voltage at Maximum Power)	Volts	65.7 V	67.5 V	69.6 V	71.7 V	73.9 V	76.1 V	78.3 V
I_{mp} (Current at Maximum Power)	Amps	2.28 A	2.33 A	2.37 A	2.41 A	2.46 A	2.51 A	2.55 A
V_{oc} (Open Circuit Voltage)	Volts	91.4 V	92.5 V	93.9 V	95.2 V	96.7 V	98.2 V	99.7 V
I_{sc} (Short Ciruit Current)	Amps	2.72 A	2.73 A	2.74 A	2.75 A	2.76 A	2.77 A	2.78 A
Temp. Coefficient of V_{oc}	%/°C	-.24						
Temp. Coefficient of I_{sc}	%/°C	-.02						
Temp. Coefficient of Power	%/°C	-.26						

System Information

Cell type	Cylindrical CIGS
Maximum System Voltage	Universal design: 1000V (IEC) & 600V (UL) systems
Dimensions	Panel: 1.82 m x 1.08 m x 0.05 m Height: 0.3 m to top of panel on mounts
Mounts	Non-penetrating, powder-coated Aluminum Up to 2.17 mounts per panel
Connectors	4 Tyco Solarlok; 0.20 m cable
Series Fuse Rating	23 Amps
Roof Load	16 kg/m² (3.3 lb/ft²) panel and mounts
Panel Weight	31 kg (68 lb) without mounts
Snow Load Maximum	2800 Pa (58.5 lb/ft²)
Wind Performance	208 km/h (130 mph) maximum Self-ballasting with no attachments
Operating and Storage Temp	-40°C to +85°C
Normal Operating Cell Temperature (NOCT)	41.7°C at 800 W/m², Temp = 20°C, Wind = 1m/s
Certifications/Listings	UL1703, IEC 61646, CEC listing IEC 61730, IEC 61646, CE Mark Application Class A per IEC 61730-2 Fire Class C
Warranty	25 year limited power warranty 5 year limited product warranty

Solyndra's panels come with all of the mounts, grounding connectors, lateral clips, and fasteners required to build a standard array.

Specifications subject to change without notice.

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Revision: 3 / Released: 2/11/09

Figure 25 - Solyndra Product Specifications Sheet

DESIGN

The first step was to determine the areas of the roof that can be utilized for the panels. Luckily, the school is located on its open site without surrounding buildings. This will allow a large portion of the roof to be utilized for placement of panels. The major obstacles would be protrusions and leaving room for maintenance to occur if necessary.

Space on Area A, Area B, and the gymnasium roof were optimal for placement of solar panels. The total area calculated and highlighted below was 22,861 SF. Then a reduction of 10% was used to account for maintenance alleys and protrusions in the roof where a panel could not be placed. This brought the total area to 20,575 SF. Given a panel size of about 21 SF, the maximum amount of panels that can be placed on the roof is about 1,089.

Figure 26 - Location of Solar Panels on Roof

The design of this system follows these steps:

1. Determine electricity load from drawings for the lighting and receptacles which were 75.2 kW and 93.3 kW respectively. The total is 170 kW which represents about 16% of the entire building demand load.

2. A 75kW inverter from PVPowered was selected (see appendix F for data sheet). Two inverters will be used splitting the load in half.

3. Using the PVPowered string calculator, the total number of panels needed was determined. See the charts below for the system information.

Table 15 - PVPowered Configuration Report

PVPowered

Selected Configurations for PVP 75K-208

Project Specifications

Module Manufacturer	Solyndra
Module Model	SL-001-191U
Mounting Type	Roof
Correction Factor	NEC (2008)
Temperaure Scale	Celsius
Local Temperature Range	From -.6 to 25.1
Inverter	PVP 75K-208

Module Specifications

Manufacturer	Solyndra	Model	SL-001-191U
STC Watts	191.0 watts	VOC Temp Coefficient	-0.2357 V/Deg C
PTC Watts	179.9 watts	Max Power Temp Coefficient	n/a
VOC	98.2 vdc	Coldest Day VOC	108.0 vdc
VMP	76.1 vdc	Warmest Day VMP	71.0 vdc
IMP	2.51 A		

Inverter Specifications: PVP 75K-208

Maximum DC Input Voltage	600 V	Continuous Power Output	75,000 W
DC Peak Power Tracking Range	295 - 500 V	Weighted CEC Efficiency	95.5%
DC IMP Nominal Current	267 A	AC Nominal Voltage	208 V
AC Operating Range	183 - 228 V	AC Frequency	60 Hz
AC Maximum Continuous Current	208 A		

Selected Configurations

Parallel Strings	Series Modules	STC Watts	PTC Watts	Inverter AC Watts	STC VOC	Coldest Day VOC	STC VMP	Warmest Day VMP	STC IMP
66	5	63,030 W	59,367 W	56,695 W	491 vdc	541 vdc	381 vdc	355 vdc	165.66 A

4. The results yielded the use of 990 Panels (66 Parallel Strings*5 panels/string*3 arrays) to meet the load of 170kW. Reduction factors for inefficiencies in the solar panels, inverters, and conductors are considered in this calculation.

5. Three arrays of 330 panels will be used. There can be 5 panels to a series string with 66 strings connected in parallel.

6. A panel board must be sized to handle the electrical load and distribute power to the building lighting and receptacle loads. The load that needs to be met is 56,695 W per inverter. Using a 175A panel, 63 kW can be supported. It will also leave room for future growth.

a. (175 A) x (208 V) x (√3) = 63,046W or 63kW

7. Next combiner boxes need to be sized to group strings together. This box then runs to the inverter. A combiner box from Amtec Solar can support up to 36 strings with a max load of 540A. This systems max load will be 165.66A. Two combiner boxes will be needed per inverter array. A total of 6 combiner boxes will be used.

8. Using the data from the combiner boxes and the current of the configuration, conductors need to be sized. Each conductor will support a load of 82.83A.

a. #2 AWG THHW conductors will carry 106.6A with a reduction for ambient temperature betweens 114-122 degrees Fahrenheit.

b. The max distance of the run to the electrical room panel is around 175 feet so voltage drop should not be an issue for this size of conductor.

c. ½” EMT conduit can be used to support each of the #2 AWG conductors from the 6 combiner box feeds to the inverter and then to the panel.

The next step was to collect data relating to the solar radiation that the site will receive during a typical year. This data was collected from www.gaisma.com which taps into resources such as the U.S. Geological Survey and NASA. The following data reflects general solar and meteorological data for Bethesda, Maryland. The following table will be used to determine the output of the solar panels from the solar radiation received at the site for the designed system.

Table 16 - Insolation Valued for Bethesda, MD

Bethesda, Maryland - Solar Radiation Received												
Month->	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Insolation (kWh/m^2-day)	1.87	2.61	3.58	4.61	5.27	5.75	5.65	5.08	4.11	3.14	2.10	1.64

The next table shows calculations by month for energy output for a 191W Solyndra solar panel. The energy rate was found using the U.S. Bureau of Labor Statistics average energy rates for the Bethesda, MD region. Another factor in the chart is the adjustment for roof reflectivity and the inverter inefficiencies. It is also important to note that over time, dirt and debris could affect output if the roof is not cleaned further reducing the system output.

Table 17 - Energy Output of PV System

ENERGY OUTPUT AND ENERGY COST SAVINGS									
Month	**Days in Month**	**Insolation Value**	**Energy Rates**	**Panel Output PTC (W)**	**Adj. for Roof Reflectivity**	**Adj. for Inverter Efficiency**	**Number of Panels**	**Energy Output (kWh)**	**Energy Cost Savings**
January	31	1.87	$0.137	180	0.95	0.96	980	9,715	$1,331
February	28	2.61	$0.137	180	0.95	0.96	980	12,247	$1,678
March	31	3.58	$0.137	180	0.95	0.96	980	18,598	$2,548
April	30	4.61	$0.137	180	0.95	0.96	980	23,176	$3,175
May	31	5.27	$0.137	180	0.95	0.96	980	27,378	$3,751
June	30	5.75	$0.137	180	0.95	0.96	980	28,908	$3,960
July	31	5.65	$0.137	180	0.95	0.96	980	29,352	$4,021
August	31	5.08	$0.137	180	0.95	0.96	980	26,390	$3,615
September	30	4.11	$0.137	180	0.95	0.96	980	20,663	$2,831
October	31	3.14	$0.137	180	0.95	0.96	980	16,312	$2,235
November	30	2.10	$0.137	180	0.95	0.96	980	10,558	$1,446
December	31	1.64	$0.137	180	0.95	0.96	980	8,520	$1,167
							Totals:	**231,815**	**$31,759**

COST & PAYBACK

Through communication with a Solyndra agent, the costs of the system could range from $5.00 to $7.00 per Watt with installation. However since every system that they sell is independent of any other project, they do not issue exact numbers for a general inquiry. Despite not having exact numbers, the following chart represents possible costs and payback scenarios. Another factor in the cost is a Federal Government issued rebates of up to 30 percent of the systems costs for investment in clean energy sources such as photovoltaic systems. A range of costs was evaluated to get clear idea of the payback and cost scenarios.

Table 18 - Payback of Solyndra PV System

COST AND PAYBACK						
Cost/W (Installed)	Total Output STC (W)	Additional Project Cost	Federal Gov. Tax Incentive (30%)	Adjusted Cost	Yearly Savings	Payback (Years)
$7.00	187,180	$1,310,260	$393,078	$917,182	$31,759	28.9
$6.00	187,180	$1,123,080	$336,924	$786,156	$31,759	24.8
$5.00	187,180	$935,900	$280,770	$655,130	$31,759	20.6

LEED

Carderock Springs Elementary is striving to achieve a LEED Silver rating from the USGBC. According to the checklist (see appendix F), they are attempting to obtain 39 points with 5 points in question. Adding solar energy potentially add a credit in the Energy and Atmosphere under On-Site Renewable Energy category. There is also a potential to add a point in the “Optimize Energy Performance” as well. Adding an additional 2 credits will put 7 potential points in questions and a possibility to enter the LEED Gold category (44-57 points). This would be a great deliverable to the owner since they aim to achieve a LEED rating with the USGBC for their new construction projects.

CONSTRUCTABILITY

Before adding any new aspects to a project, the schedule, costs, and installation challenges must be considered to ensure it will integrate into the intended goals of the project. This system, compared to other systems is very easy to install and comes with small structural considerations. Solyndra Panels weigh approximately 68 lbs and with all mounts and hardware adds an additional 3.3 lbs/SF to the roof load.

The weight of the panel makes it easy to install since they can be handled easily by one person on a crew. Another large advantage of the system is that it does not have any structural connections penetrating through the roof membrane. It is a self ballasting system and can withstand a wind load of 130 MPH. This adds to the possibility of incorporating it with minimal structural considerations after a design has been made. It also lends itself to the ability to retrofit.

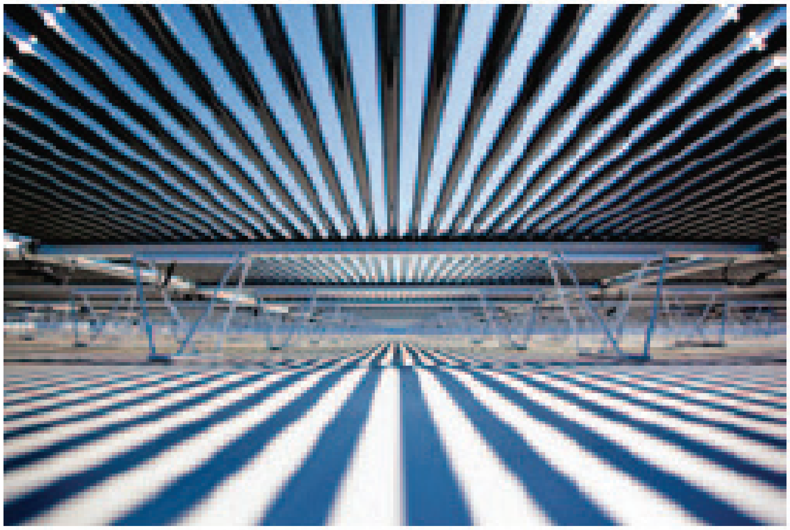

Figure 27 - Roof Picture with Solyndra System

Large considerations to be made are the electrical wiring, inverter, and utility considerations. With a system of this size, it would be beneficial to tie this into the grid to be credited for electricity when the building itself is not consuming. This could be a high probability since the most radiation will be received in the summer months when school is out. These lower summer loads might allow the district to sell power back to the utility company. The construction team would have to notify the utility of this intent to gain approvals. There can sometimes be long wait times for approvals and work orders when dealing with utility companies.

Considering schedule, this system could be easily implemented with minimal considerations to other aspects of the project. Since this activity would be off the critical path, work would begin around mid February when the roofing and roof activities are finished. Using a labor rate of around 15/panels per hour, the system can be installed in about 8-9 days. This would be very attainable to achieve. The system then would need another 1-2 days for testing and start-up to ensure proper working order with the rest of the building systems.

BIM OPPORTUNITIES

Installation and planning of this system could benefit from using 3D modeling. The primary areas of use would be initial layout of the PV panels to maximize space and avoid any obstacles on the roof such as drains, roof curbs, and other protrusions. It can also be utilized to create a panel installation sequence for material staging and pathways to install the panels. Furthermore, advanced electrical modeling could be done if desired from the design team to help predict energy usage and the functionality of the addition of the system. This type of analysis is not within the scope of this particular analysis, but is highlighted to identify potential uses of building information modeling on a construction project.

RECCOMENDATION

With the addition of Solyndra solar panels, Carderock Elementary can further attain its goal of sustainability while also offsetting energy costs. With a payback between 21-29 years (depending on actual system cost), it would be feasible since public school buildings on average stand 42 years according to a 1998 study done by National Center for Education Statistics. The system also comes with a 25 year warranty covering it over the average payback period of about 25 years.

The output of the system is about 231,815 kWh which saves about $31,759 annually. These are considerable numbers and support the feasibility of the PV system.

Another factor to consider is the trend of deregulation of utility companies and the rising cost of energy. Although this study does not adjust for inflation and future estimates of utility costs, it is safe to say the utility rates will rise faster in the coming years than they have in the past. When factoring in a higher utility rate, the payback period would be accelerated, further justifying the installation of on-site renewable energy, such as a Solyndra photovoltaic system. Having independent on-site energy sources will help stabilize some of the volatility in the energy market.

Adding the solar PV system would raise the cost of the project from $21.3 million to about $22.1 million ± $0.1 million. Adding an additional cost of about $800,000 would minimally impact the school district's budget considering they have $1.27 billion allocated toward capital improvement projects such as this new school construction through fiscal year 2014. Using the average use of a public school building of 42 years, the school district would make a return on their original investment while enhancing the sustainability program with the Montgomery County Public School system. The addition of Solyndra PV panels at Carderock Elementary school is feasible.

SEE APPENDIX F FOR SPECS AND LEED CHECK LIST