Technical Assignment III:

2011 AE Senior Thesis
Office Building
Northeast, United States

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EXECUTIVE SUMMARY

While a design-build approach was utilized for the Office Building under investigation, the uniqueness of the site, owner requirements, and unforeseen conditions presented numerous constructability challenges that were not addressable through design techniques, and therefore demanded careful construction procedures to alleviate their impact on the construction process. The initial assumptions regarding the site's soil characteristics did not address the impact of the existing structures at the top of the slope upon which the new structure was to be located. Once excavation of the slope began, it became apparent that the force of the existing buildings on the soil above was causing the entire site to "slide" downhill. Additionally, the soils surrounding the existing central utility plant were highly contaminated with fly ash remnants from the time period during which the original central utility plant utilized coal burning boilers. This required the implementation of a contaminated soil abatement plan, which eventually led to the treatment and removal of approximately 280,000 cubic yards of contaminated soil.

Aside from existing site conditions, owner requirements and design changes also created constructability and project planning challenges. Most notably, preliminary coordination efforts between the owner and the future tenant did not effectively address the tenant's office logistics needs. Upon further investigation, the owner discovered that the tenants had spatial requirements that were drastically different from the preliminary assumptions. The realignment of these core areas, known as Blocking and Stacking because of the office logistic related purpose of the changes, led to many alterations of the original design. This process affected the coordination schedule by requiring the design firms to adjust their original designs to meet the updated owner requirements, which in turn affected the subcontractors' coordination processes, pushing the whole coordination process back by approximately 6 months, and resulted in change orders in the order of magnitude of $2.5M per floor.

Fortunately, the construction team was adamant about providing the owner with a best value product. Numerous value engineering approaches were taken to ensure that extraneous spending was minimized, such as designer specified materials that were not in line with the owner's expectations of the project, as well as some reductions in overdesigned building systems that resulted in the reduction of the overall project cost.

In addition to the aforementioned topics, the following technical assignment addresses a few oversights and missed opportunities regarding the Office Building Project. While 3D coordination was prevalent during the design development phase, these models were wholly underutilized in the field, creating numerous logistics issues. Prefabrication efforts, especially after the effects of Blocking and Stacking, were slightly under implemented.

Through participation in the PACE Roundtable event, many of the prominent issues on the Office Building project became ever apparent. The event also provided numerous options for remediating these issues, concerns and missed opportunities (which are expanded upon in the following report) in an effective and cost efficient manner.

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CONSTRUCTABILITY CHALLENGES

INTRODUCTION

While a design-build approach was utilized for the Office Building under investigation, the uniqueness of the site, owner requirements, and unforeseen conditions presented numerous constructability challenges that were missed during the initial design and coordination process, and demanded careful construction procedures to alleviate their impact on the construction process.

GLOBAL STABILITY

The initial assumptions regarding the site's soil characteristics did not address the impact of the existing structures at the top of the slope upon which the new structure was to be located. Once excavation of the slope began, it became apparent that the forces of the existing buildings on the soil above (see Figure #1) were causing the entire site to "slide" downhill. Even though extensive support of excavation systems were put in place around the excavated areas, they were not enough to prevent this movement, and other alternatives had to be explored.

Figure #1 – Existing Structures Affecting the Hillside

In order to effectively eliminate the load bearing issues associated with the site soils and reduce the risk of future differential settlement, Clark Construction completed a study that addressed the requirements necessary to effectively remediate these issues. Drilled samples were analyzed by the civil engineer who determined that concrete caissons were the only feasible method for providing the support needed to overcome the effects of the unstable hillside.

Fortunately, due to the phased nature of the project, the implementation of these caissons did not affect the project schedule. Additional excavation crews, as well as a specialty caisson contractor were directed to begin the work associated with the installation of the caissons while final grade levels were excavated for the Building One footprint. Other excavation efforts shifted from the footprint of Building Three to the areas surrounding the central utility plant and the parking garage, which made up for time in the schedule by interchanging the original time periods during which activities were supposed to take place around the central utility plant and the garage with the time allotted for the excavation of Building Three's footprint. This allowed the project team to handle the increased construction volume that resulted from the addition of the concrete caisson system without experiencing an increase in the scheduled project duration.

CONTAMINATED SOILS

In addition to being responsible for stability issues, the soils surrounding the existing central utility plant were highly contaminated with fly ash remnants from the time period during which the original central utility plant utilized coal burning boilers. This required the implementation of a contaminated soil abatement plan, which eventually led to the treatment and removal of 248,000 cubic yards of soil contaminated with fly ash. Additionally, there were approximately 10,500 cubic yards of soil contaminated with petroleum byproducts, and an additional 17,000 cubic yards of miscellaneous contaminated soils.

The process through which contaminated soils are abated depends on the nature of the contaminants within. The soils containing fly ash, a known carcinogen, were removed from the site by special container trucks and taken to an area where they were buried beneath several feet of clean soil. The disposal site was specifically chosen by the abatement contractor for its non-proximity to sensitive ecosystems and the relatively low likelihood that rain water would transport the carcinogenic materials into an aquifer that is utilized for human consumption. Similarly, the soils containing petroleum byproducts were transported to an area located at a distance from delicate natural resources and known water sources, and were spread out in a manner that dissipates the petroleum into the earth in concentrations that are below the legally acceptable levels. The additional 17,000 cubic yards of miscellaneous contaminated soils contained traces of lead and heavy metals, which were neutralized by the abatement contractor through various chemical methods.

While it was known to the project team that contaminated materials lay beneath the surface of the site, the amount of these earth borne contaminants was greatly underestimated by the geotechnical surveying firm responsible for preparing the initial soils report for the project. Due to the fact that this firm was contracted by the owner, the increase from the estimated amount of contaminated soils on the site was evaluated as a unit price change order, and was paid by the owner. Luckily, since there were already excavation and removal plans in place for the initially expected amounts of contaminated soils, the project team was able to rapidly adjust to the increased need for soil abatement. The abatement contractor was issued a change order that amplified their contract to include the additional soils requiring removal from the site. In order to eliminate negative effects on the project schedule, the excavation and abatement crews worked 6 days a week during the periods when contaminated areas were being excavated to ensure that the materials were removed from the site and dealt with in a timely manner. Fortunately, the contaminated areas were fairly concentrated (see Figure #2), increasing the ease at which they could be removed from the site. The petroleum and heavy metal riddled soils were located near the existing central utility plant, where nearly one hundred years of operation had left remnants of the processes through which the original buildings on the campus were heated. The coal byproducts (mainly fly ash) were relatively concentrated as well. It appeared that the operations staff of the original campus had designated an area around the future site of the rainwater collection pond as their waste area, and had dumped decades worth of coal burning remnants in this area.

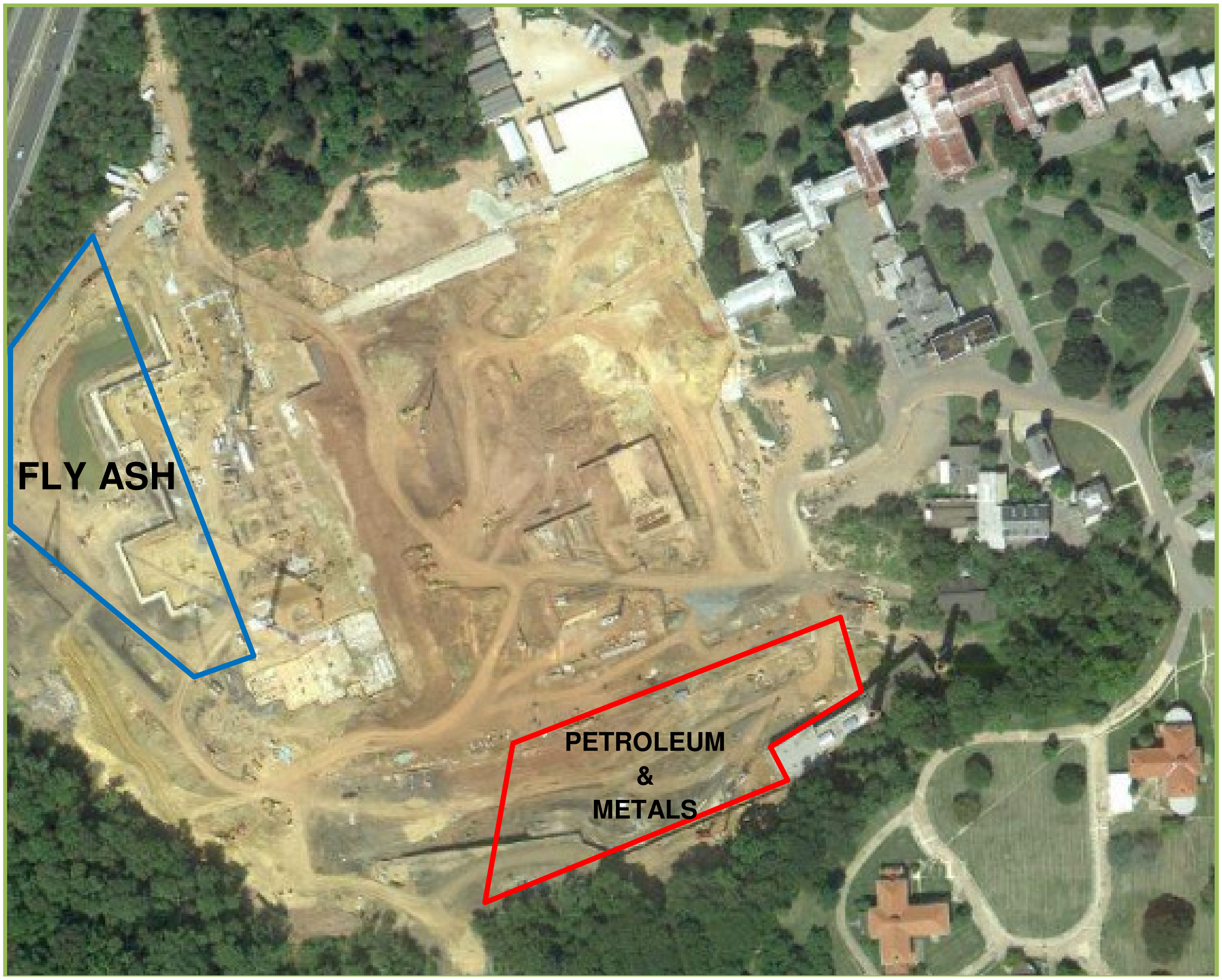

Figure #2 – Concentrations of Soil Contaminants

BLOCKING AND STACKING

Aside from existing site conditions, owner requirements and design changes also created constructability and project planning challenges. Most notably, preliminary coordination efforts between the owner and the future tenant did not effectively address the tenant's office logistics needs. Upon further investigation, the owner discovered that the tenants had spatial requirements that were drastically different from the preliminary assumptions. The realignment of these core areas, known as Blocking and Stacking because of the office logistic related purpose of the changes, led to many alterations of the original design. This process affected the coordination schedule by requiring the design firms to adjust their original designs to meet the updated owner requirements, which in turn affected the subcontractors' coordination processes, pushing the whole coordination process back by approximately 6 months, and resulted in change orders in the order of magnitude of $2.5M per floor.

These changes to the layout of the building's office, office support and specialized spaces (such as conference rooms and kitchenettes) lead to, as previously mentioned, millions of dollars worth of rework to the mechanical, electrical and plumbing systems that were already installed. Fortunately, work on the interior partition walls and finishes had not yet begun, and the costs associated with these trades amounted primarily to re-coordination and detailing efforts, which are minute in scale when compared to the demolition and reconstruction of duct lines, electrical cable tray and domestic water or HVAC piping.

Unlike the aforementioned constructability issues, the resulting rework associated with the Blocking and Stacking changes to the construction documents resulted not only in increased costs, but also extensions to the project schedule. Each floor of the building was expected to be delayed by approximately two months. However, Clark Construction and its subcontractors had the foresight to include the costs associated with increased crew sizes in their project change order estimates, which were approved by the owner. In order to effectively utilize this increased manpower, the owner was asked to finalize the layout designs on the floors that were currently under construction so that the subcontractor crews could continue to progress throughout the building as planned. The additional crews that were added to the project were then able to focus on demolition the existing mechanical systems in the lower levels while design was in progress. An aggressive re-coordination schedule was established and was met, almost exactly on time, by the subcontractor coordination staffs. This allowed the project team to minimize the effects on the project schedule by first addressing the mechanical systems on the floors that had been coordinated the first time around per the redesigned contract documents, and then backtrack to the floors below that underwent redesign and re-coordination afterwards.

Even though a dedicated effort was applied in order to minimize the negative effects on the project schedule due to the redesign of the building's layout, extensive core drilling and time consuming dismantling of welded HVAC, domestic and wastewater piping led to a six week delay in the project schedule. Most detrimental of all was the necessity to x-ray all locations where core drilling was to take place (see Figure #3). The original structural and mechanical designs were coordinated by Cagley and Girard Engineering (the structural and mechanical engineering firms) to ensure that floor penetrations did not compromise the structural integrity of the building. With a complete system redesign, save for the core mechanical shafts (see Figure #4), all floor penetrations had to be reevaluated to ensure that they did not affect the strength of the cast-in-place structural system already in place.

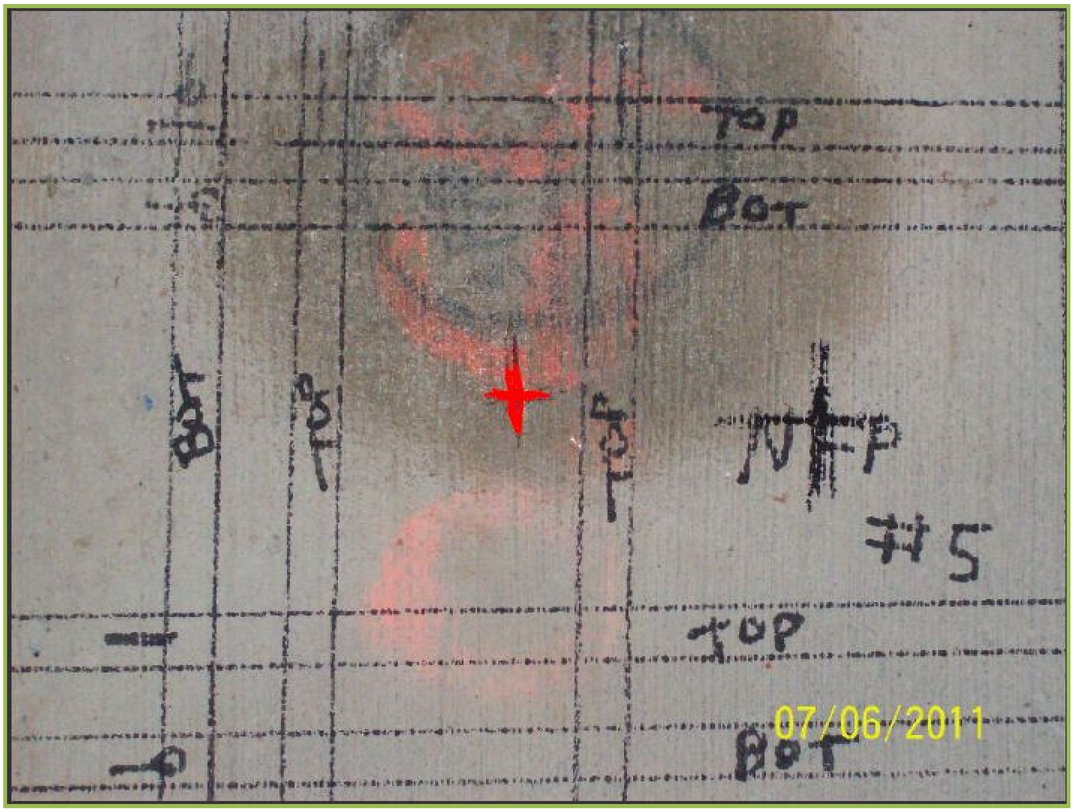

Figure #3 – Core Drilling Location Example – Courtesy of Clark Construction

Figure #4 – Unaffected Mechanical Shaft – Courtesy of Clark Construction

SCHEDULE ACCELERATION SCENARIOS

INTRODUCTION

While the owner anticipated that the quality and value of the finished product would benefit from a design-build approach, the main reasoning for implementing this type of project delivery method was to take advantage of the benefits stemming from ability to fast track the project by overlapping the design and construction phases.

SUPERSTRUCTURE CONCRETE

For a building complex of this size, the foundations and superstructure phases are commonly the driving forces behind the project schedule. The relationship between Clark Construction and Clark Concrete allowed for accurate schedule durations and phasing inputs at the start of the project that established a fairly lean superstructure schedule early in the project planning phase. With extraneous float time within the schedule minimized, the only possible source of acceleration for the superstructure phase of the project is the implementation of a larger concrete batch plant than the one currently in place. Unfortunately, an increased ability to produce concrete is not the only requirement for accelerating the superstructure schedule. Increased rebar and formwork crews would also be required, demanding greater commitments in labor, equipment and materials from Clark Concrete and the rebar subcontractor to keep up with the availability of concrete from the plant. A requirement for increased mechanical, electrical and plumbing (MEP) rough-in crews would also accompany an accelerated superstructure schedule in order to ensure that the in slab MEP materials are placed in a manner congruent with the rapid placement of structural concrete. The brief increase in labor costs associated with a temporary increase in manpower on the site would be justifiable only if the project schedule absolutely demanded an increase in cast in place activities.

The optimum size of the batch plant was determined by Clark Construction and Clark Concrete and is intended to meet the schedule requirements for most of the pour schedules. Some of the larger mat slabs require the importing of outside materials from 3rd party suppliers. While increasing the size of the batch plant would lead to an overall underutilization of its output potential, the added value of having additional concrete production capacity readily available may prove to be irreplaceable in the event of a schedule crisis. Relying on outside deliveries, especially on a controlled site, is not desirable. Additionally, the testing regiments on materials obtained from outside sources are more stringent than those placed on the concrete that is produced within the onsite batch plant. The increased convenience of material availability associated with an oversized batch plant would allow the project team to make on the fly decisions regarding the acceleration of the concrete schedule, and be able to support their decisions with an increased concrete production schedule that will allow the project to quickly react to these changes. The additional upfront costs of erecting a larger batch plant may never be offset through the utilization of the higher output capability, however, if the project runs the risk of not meeting its established date of substantial completion, the rewards of being capable of producing enough concrete to accelerate the superstructure schedule would far outweigh these initial costs. The added ability of being able to shorten the cast in place schedule could prove to be invaluable.

PREFABRICATION

As previously mentioned, the Blocking and Stacking events caused by the redesign of the interior layout of the building caused multiple setbacks in the mechanical, electrical and plumbing (MEP) schedule. The process of redesigning, re-coordinating and reworking the MEP systems set the project back by approximately 2 months. The process through which the existing systems are being removed, altered, and reinstalled are expected to set the project back even further due to decreased productivity rates associated with in-field modifications to major system components. In order to offset these delays, which may result in irreversible effects as the tradesmen work their way through the office complex, prefabrication efforts could be increased. The initial costs of coordinating this increased level of prefabrication would include intense coordination and staging planning, as well as the implementation of oversized material handling equipment. Fortunately, Clark Construction has completely realigned the coordination process to facilitate rapid coordination of the new building layout designs as they are completed by the design team. The subcontractor modeling and coordination teams were instructed to abandon the re-coordination of systems already in place, and focus on the coordination of the systems on the floors that were not yet reached by the tradesmen. This could allow for the implementation of increased prefabrication efforts at the onset of the coordination process. Installation activities could be focused on the areas that have not yet been completed, leaving the areas most adversely affected by Blocking and Stacking to be completed just in time for the interior finishing trades to perform wall and ceiling close in activities. Fortunately, there is a lot of float in the schedule for the interior activities, which tend to progress very rapidly.

Currently, the extent of prefabrication is limited mainly to ductwork and cable tray junctions. Due to the fact that all mechanical, domestic water, and wastewater piping has to be welded, rather than connected via Victaulic or Propress fittings, the process of dismantling and reinstalling these systems is extremely drawn out. In order to offset these affects on the schedule, the pipe fitting subcontractor could implement prefabrication techniques that allow them to fabricate complex piping junctions and crossovers in an offsite shop. This would allow them to focus on the connection of long piping runs, which is fairly simple compared to the labor intense work associated with piping junctions. While the costs incurred from intense coordination of these systems would be far from negligible, the project logistics and schedule duration returns would be immense.

VALUE ENGINEERING TOPICS

INTRODUCTION

Throughout their preconstruction and proposal process, Clark Construction explored and suggested the implementation of numerous value engineering options, some of which were applied to the project upon being awarded the construction contract.

GENERAL VALUE ENGINEERING

Many of the value engineering opportunities that were explored involved the central utility plant and the parking garage, which were determined to be overdesigned in the initial bridging documents, a mistake that carried over into the construction documents. Clark Construction facilitated a comprehensive review of the structural design, which lead to the redesign and ultimate reduction in the amount of concrete needed. Stair wells were realigned to provide shared access and egress points between the garage and the central utility plant, reducing the number of complex concrete forming and placement operations associated with stair wells. The owner's goals to reduce costs where extraneous spending was detected and reallocate these funds to other, more desirable, aspects of the building, such as the complex landscaping and fountain systems, were effectively addressed by the Clark Construction team. The project team also eliminated the requirement to paint all of the interior walls of the parking structure, a cost cutting opportunity that was heavily supported by the owner, further reducing the cost of the project. While the exterior of the parking garage matches the surrounding structures with its brick façade, the owner decided that the interior finishes of the garage, which would be seen by relatively few outsiders, were not a major concern. Therefore, the exposed cast in place concrete and concrete blocking was determined to be a satisfactory finish (see Figure #5).

Figure #5 – Unpainted Garage Interior – Courtesy of Clark Construction

BUILDING ONE VALUE ENGINEERING

Within Building One specifically, numerous "small" changes to the original design were made to further reduce the project costs. The strip windows in the Child Care area were originally anticipated to have 8" CMU block backing walls. In reality, the design professionals had intended for these walls to be 12" in thickness. While Clark Construction had bid the project with the assumption that these walls were 8" in thickness in mind, they were able to reduce the actual contract document requirements to match their initial assumptions, saving the owner approximately $40,000. The costs incurred by the team because of their oversight regarding the actual thickness of these blocks were offset by the increased productivity of both material deliveries and block laying activities.

Many of the savings associated with Building One were centered on the interior courtyard and the nearby storm water retaining pond walls. These areas demanded a high level of miscellaneous metal projects, all of which were originally specified by the architect. The owner decided to give Clark Construction the opportunity to suggest alternative products that would achieve the same results but minimize the costs associated with the originally specified materials. The originally specified material for the retaining pond walls was Corten Steel, which provides an aesthetic "weathered" look after it oxidizes (see Figure #6). Clark Construction determined that the owner could save upwards of $250,000 if blackened steel (see Figure #7) retaining walls were approved in lieu of the Corten Steel walls. The owner decided that the aesthetics of blackened steel were equal or greater than those of Corten Steel, and approved this change order.

Figure #6 – Corten Steel – Courtesy of lifeofanarchitect.com

Figure #7 – Blackened Steel – Courtesy of caliperstudio.com

Throughout the courtyard, the architect had specified stainless steel grating boardwalks (see figure #8) that demanded a high level of skilled fabrication and expensive materials. The project team advised the owner that not only the cost of materials and fabrication, but also the massive dead loads of the boardwalk that demanded bulky concrete pier foundations, were responsible for driving the project costs upwards. After reviewing the steel grating shop drawings, the owner also determined that the spacing between the steel grates would pose as a safety threat to users who were wearing high heeled shoes. Through advisement from Clark Construction, the owner approved a change order that replaced the steel grating boardwalks with an equally durable and aesthetically pleasing material, Ipe wood (see Figure #9). Ipe is prized for its outdoor durability, and is often used on boats and waterside docks. This attribute further convinced the owner that substituting the wood for the original steel grating design was both practical and economical, and savings of approximately $1.3M were achieved. The IPE wood utilized on the project was Forest Stewardship Council (FSC) approved, and therefore not only reduced the costs associated with the construction of the boardwalk, but also added to the sustainable aspects of the project.

Figure #8 – Steel Grating – Courtesy of interstategratings.com

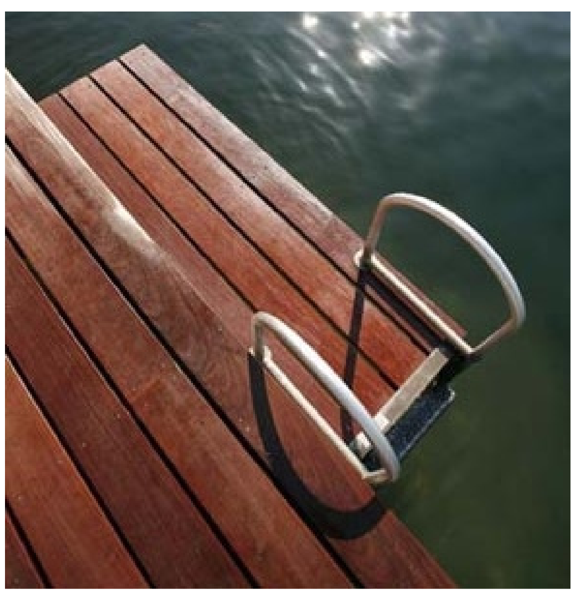

Figure #9 – Ipe Wood – Courtesy of edeck.com

UNPURSUED VALUE ENGINEERING

A plan for pursuing a precast parking garage structure in lieu of the cast in place structure that was designed underwent development and review, but was later dismissed due to multiple reasons.

Predominantly, the regionally accepted method of concrete construction is cast in place. Additionally, with a cast in place specialty contractor (Clark Concrete) already on board with the project team, it may have been easily discernable at the onset of research into the use of precast that the system would not assist in alleviating the project's logistics, schedule and costs concerns. However, there are multiple precast concrete detailers and fabricators in the area that perform work in surrounding construction markets, and could have provided the necessary services and materials for such an operation. While the cost of precast concrete members is substantially less than the financial obligations associated with forming, reinforcing and placing a cast in place concrete structure, it was determined that it would not be advantageous to ignore the presence of the multitude of tower cranes on site necessary for the placement of the cast in place office structure and instead utilize the services of truck or crawler mounted cranes capable of lifting bulky precast members into place. While the tower cranes COULD be phased from the office building to the garage, these cranes would have very limited areas of influence due to the increased weight of the precast members. Truck or crawler mounted cranes would need to be used in order to provide effective picking distances. The field management staff concluded that the sloped nature of the site, along with the less than ideal bearing capacities of the soil, would demand extensive staging, dunnage and safety planning in order to properly execute the use of truck or crawler mounted cranes. Conclusively, the project team decided that the costs associated with additional cranes on site, the logistical requirements of these cranes, and the uncertainty of relying on yet another subcontractor did not outweigh the costs savings associated with a precast structure, and the idea of implementing precast elements on the parking garage was abandoned.

CRITICAL INDUSTRY ISSUES

INTRODUCTION

The following summary of current prominent discussion topics within the building construction industry are a reflection of the discussions that took place during the 20th Annual PACE Roundtable Event, held on Wednesday, November 9th 2011 and the Penn Stater Conference Center located in State College, PA. The PACE Roundtable is a gathering of industry professionals, Penn State Architectural Engineering faculty and students that promotes an open discussion regarding key industry topics that have been selected by the faculty and professionals. Each year, students are given the opportunity to enrich their understanding of the industry by conversing with experienced professionals, who in turn gain valuable feedback from the students who may have drastically differing solutions to the prominent issues affecting the industry.

The topics of discussion (and the breakout session in which they were offered) this year were as follows:

- Sustainability/Green Building
    - Energy Management Services (1)
    - Learning Systems for Training a Sustainable Workforce (2)
- Process Innovation
    - Assembling/Procuring an Integrated Team (1)*
    - Integrated Decisions for High Performance Retrofit Projects (2)
- Technology
    - BIM Services for the Owner & the Role of the Design and Construction Professional (1)
    - Strategies and Opportunities for Taking BIM into the Field (2)*

*Topic of further discussion

Participants in this year's PACE Roundtable Event were given the opportunity to choose one of three discussions topics available during each of the two breakout sessions. Each breakout session, which lasted for roughly one hour, consisted of approximately 20-25 students, 5-10 industry professionals, and 1-3 faculty members. This particular reflection focuses on the discussions and conversations that took part in the Assembling/Procuring an Integrated Team and the Strategies and Opportunities for Taking BIM into the Field breakout sessions.

ASSEMBLING/PROCURING AN INTEGRATED TEAM

The process of *Procuring and Assembling an Integrated Project Team* was discussed during the first break out session. While the discussion began with individual opinions of how feasible a true Integrated Project Delivery method approach is, it was quickly agreed upon that until the companies and firms traditionally associated with a construction project take the necessary steps to equally share project risks and responsibilities, the Integrated Project Delivery method will not be able to realize its full potential. Additionally, insurance firms need to recognize and react to the need to move towards this type of project delivery method by providing insurance packages and programs that favor the division of risk and responsibility between each of the entities involved with a project. At this point in time, it is very difficult to find an insurance provider that effectively covers conglomerate entities. Until the means and methods, as well as the sociological mindsets that support integrated approaches to projects are solidified within the industry, it will continue to be a struggle to successfully assemble a truly integrated project team.

While the personal and legal barriers to the implementation of an integrated project delivery method that embraces the fair distribution of risk and reward are commonly out of reach at this time, the procurement and selection methods associated with an integrated project team can also be applied to traditional and design-build projects. Depending on the project type and the complexity of certain building systems, it may be advantageous to bring certain subcontractors onto the construction team early on in the project planning and development stage. It is imperative that the benefits of bringing a subcontractor on early in this process be carefully weighed against the disadvantages. For example, the money and time saved by carefully coordinating with a curtain wall manufacturer during the design development phase may not be significant when compared to the amount of money that could be saved by releasing a substantially completed curtain wall design for hard-bid, creating competition between the curtain wall subcontractors, driving the price of that scope of work down. This balancing act between the implementation of an integrated team and the promotion of competitive bidding can lead to uncertainty within the project planning process when deciding which trades to procure early on in the design process and which ones to secure upon issuing bid documents.

Each project in the building construction industry is unique and, as mentioned above, it is sometimes difficult to pinpoint the manner in which a project should be procured and developed. Additionally, it is sometimes equally difficult to convince the owner that the decisions regarding the project development approach, selected by the general contractor, architectural design and engineering team or whoever else may be responsible for these types of decisions, are the right ones. The struggle then becomes convincing the owner to agree with these decisions and effectively support these decisions, both financially and contractually. Since the integrated project delivery approach is relatively new to the industry and has yet to gain overwhelming support from industry professionals due to the small amounts of supportive evidence and research in its favor, it is often difficult to justify sacrificing the benefits of releasing work to the competitive bid process in order to reap the benefits of an integrated approach. During the PACE Roundtable breakout sessions, multiple industry members suggested that in order to overcome the propensity for owners to resist an integrated project approach, it is beneficial for a company to maintain related data from past projects that shows the financial, schedule, and quality gains associated with their integrated project delivery experiences. If companies can provide detailed evidence of the ways in which integrating a subcontractor onto the project team at an early point in time led to future cost and schedule benefits, an owner would be much more likely to support that company's decision to utilize a similar technique on their project.

In general, with the economy in its current state, where competitive bidding allows owners to reap the benefits of a work-hungry industry, and even while supportive evidence can be gathered on a case by case basis, it is a very difficult time to gather overwhelming support for the integrated project delivery approach to a construction project. The industry as a whole needs further, more conclusive, evidence of what types of teams work well together and why. Research that further investigates the various types of integration techniques and methods of subcontractor procurement in integrated project approaches is needed to compile a complete picture of the means and methods of integrated project delivery and project team dynamics that result in successfully delivered projects.

It was extremely surprising to see how weak the industry's grip is on the idea of integrated project delivery at this point in time. With the design/build contracting approach slowly gaining ground over its design/bid/build counterpart, one would think that the integrate project delivery method would also be slowly gaining ground behind design/build. Unfortunately, it seems that there are a lot of factors that have compounded against a true integrated project delivery approach, most significant of which being the current state of the economy, which promotes a hard-bid, competitive approach to construction project procurement. It seems that a lot of individuals in attendance at the breakout session were unaware of the fact that one of the major oppositional forces to the implementation of integrated project delivery is the absence of support from major builders and construction risk insurance companies. These companies are not prepared to handle the migration from individualized to shared risk on a construction project. The contracting and subcontracting companies themselves are not prepared to understand and address the need to share project risks fairly amongst one another. Until the industry as a whole begins to trust one another and promote the sharing of risk on a project, the advantages of implementing the integrated project delivery method will not be realized to their fullest potential.

STRATEGIES AND OPPORTUNITIES FOR IN-FIELD BIM IMPLEMENTATION

Many owners and project teams spend a lot of money on Building Information Modeling (BIM) operations that are utilized throughout a project's design and development stages, but are essentially forgotten about during the construction phase of that project. The *Strategies and Opportunities for In-Field BIM Implementation* breakout session focused on some of the ways in which BIM is being utilized throughout field operations as well as gave participants the chance to make suggestions in the way of how they envisioned BIM being used in the field. The other attendees provided constructive criticism and feedback to those that shared their ideas.

Initially, those in attendance quickly established the prerequisites for a successful in-field BIM implementation program. Most importantly, a dedicated BIM space is required in the field, whether this is simple a corner of the mobile office, or an entire room of a trailer complex dedicated to information modeling uses. After an information center is identified, computing power is necessary to provide the backbone through which all of the building construction information will travel. Once these two parameters are established, the project team or responsible firm needs to identify the manner in which they will utilize building information modeling on their project. Multiple opportunities for capitalizing on the advantages of an information modeling approach to field operations were discussed, the most general of which being the implementation of a "BIM Standard of Usage" that progresses throughout the project. Numerous industry professionals stressed the fact that in order to successfully implement BIM in the field, standards have to be established at an early point in the construction planning process to ensure that the proper BIM uses are identified and are pursued effectively. For example, if it is decided that detailed assembly modeling will be pursued on the project, the architectural and engineering teams need to be made aware of this as early as possible so that they may begin developing these models for future use in the field. If the planned usage for BIM in the field is not initially identified, the project team may find that the proper resources are not available at the point in time when they are required.

As mentioned above, virtual assembly modeling and prototyping (see Figure #10) was one of the biggest focuses of the breakout session. Those with personal experience, particularly Kurt Maldovan of Balfour Beatty, explained that it is commonly extremely effective to model the most complex and difficult assemblies on a project in detail in a manner that provides the subcontractors responsible for this work with a step by step, 3D model of the means and methods through which the assembly is to be installed. These detailed models essentiall provide a visual installation manual that details all of the components of an assembly, the order in which they are to be installed, and the tools and methods associated with each of these installation steps. This breakthrough approach to the installation of complex systems has assisted the project management team on numerous Balfour Beatty projects by allowing them to establish quality and consistency expectations early on in the construction process.

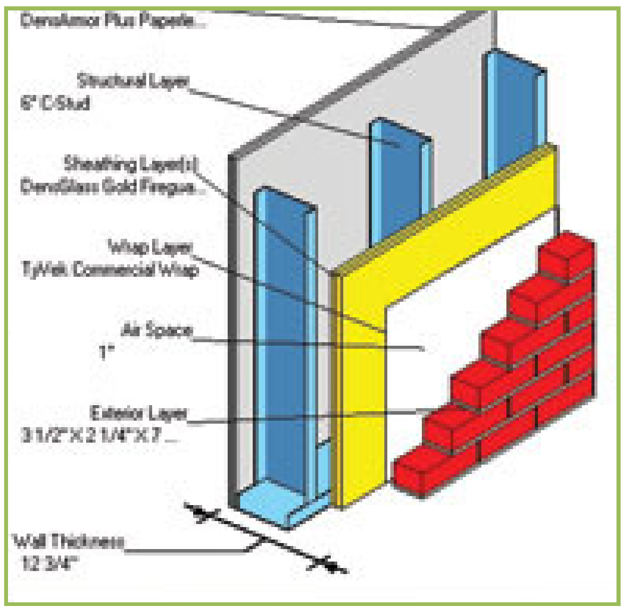

Figure #10 – 3D Prototyping – Courtesy of continuingeducation.construction.com

The implementation of Smartboards can provide a project team with an opportunity to convey complex construction phasing, exact locations on site where an activity is to take place or the proper techniques for material delivery, handling and installation in an interactive manner that is easily understood by all of the involved parties. Smartboards are wall mounted screens, with built in projectors that not only project an image onto the screen, but also pick up and record the user's movements when he or she is writing on the board with a special electronic marker. These recordings allow the user to make notes and document changes to the file being displayed on the board. For example, on the Office Building project, Clark Construction utilized Smart Boards in their field personnel meeting area. Every morning at 8:00 AM, all of the subcontractor foremen and the Clark office and field staff met in the field office to discuss the activities planned for the day. The assistant superintendent had a list of each subcontractor and the activities on the schedule that they were responsible for. After announcing these activities, where they were located, and what was involved, he would ask the remaining foremen if they knew of any direct conflicts with this work.

If concerns were raised, he would mark up the document by hand, noting these concerns. At the conclusion of the meeting, he would email the marked up list of the day's activities to all of the project managers, superintendents and foremen from each subcontractor.

In a related discussion, those in attendance discussed the implementation of BIM kiosks throughout the project site. These kiosks allow the construction personnel immediate access to the various BIM models associated with the project. This availability of information facilitates the constant back checking of work in complex and congested areas so that the tradesmen responsible for installing the work in these areas can be assured that their systems and assemblies are placed in accordance with the coordination models and drawings. If conflicts arise in the field, BIM kiosks make it possible to quickly and effectively check and confirm the source of these issues and make the necessary changes to allow for installations to continue without undergoing the lengthy process of contacting upper management within the subcontractors, who would ultimately contact the construction management staff for further direction. The time saving attributes associated with this ability are astronomical, as well as the increased level of quality and accuracy that the systems are installed.

Another common topic of discussion was the extent of detail of the operations and maintenance and as-built documents that are turned over to the owner at the conclusion of a project. Many industry members discussed the opportunities associated with providing owners with a complete digital record of all of the machinery and systems within their finished building, including the operations, maintenance and part ordering paperwork that accompanies this sometimes massive amount of data. A substantial amount of value can be added to a final product when a digital record of the operation and maintenance material is organized prior to turning it over to the owner. This makes it a lot easier for the facility's management staff to locate machinery, pin point any issues associated with that machinery, and order the necessary parts to ensure that the equipment is properly maintained and serviced throughout its lifetime.

While the most common method of providing owners with detailed and easily navigable documents at the conclusion of a project through the use of BIM is the traditional digital operations and maintenance data packages, the use of laser scans for detailed as-built models and drawings was also discussed. This approach to the creation of as-built documents is in its infancy, but holds powerful potential. If correctly executed, it is possible to perform laser scans at various intervals in the project's construction phase to effectively document the actual installed state of the systems and equipment within a building. At the conclusion of the project, these scans can be combined to paint a complete picture of the exact location of in-wall utilities, structural systems, and overhead assemblies. The details and means and methods of an undertaking of this magnitude are not yet clear, but most of the industry professionals agreed that an enormous amount of procedural planning would have to be implemented early in the project to establish the frequency, locations, and methods for providing accurate scans that could be later used to complete a full as-built building model.

The most promising implementation of BIM that was discussed focused on the digital linkage of project requests for information, architectural sketches and change order documents on a cloud server so that all affected parties could quickly access the most up-to-date construction documents. Essentially, all changes to the contract documents are digitally linked to the corresponding project drawings so that contractors can access the most current information at any point in time. This helps in the constant struggle to eliminate the improper installation of systems and equipment that have been subjected to a change for one reason or another. This industry is plagued by the constant risk of contractors not having access to the most recent versions of the construction documents, which commonly leads to the inappropriate installation of work. The monetary and time related ramifications of these mistakes are widespread, and commonly result in projects running over budget and schedule. If a system of virtual linkage between drawing updates and the documents that are being used to direct the work put in place is effectively instituted, project teams can reap the benefit of knowing that a high percentage of the installations on a project are in line with the most recent updates to the original contract drawings.

The most surprising aspect of the *Strategies and Opportunities for In-Field BIM Implementation* discussion was the relative unfamiliarity with in-field project management programs that are designed for use on tablet PC's. Very few attendees were familiar with the software available from Vela Systems, as well as the project management programs developed by Latista. The programs available through Vela Systems provide field staff with a method through which they can mark up drawings on the fly to document field coordination changes to the installed systems[4]. This aids greatly in the struggle to provide owners with an accurate record of the as-built state of building systems. Additionally, both Latista and Vela also provide that ability to track what equipment and systems have been installed, the quality control measures taken to ensure that they were installed properly, and the operations and maintenance data associated with these installations[6].

APPLICABILITY

While the Office Building project was delivered through a design-build approach which demanded early investments and inputs from the major subcontractors, some subcontractors provided far greater value to the project team than others. It is interesting to see how great the divide between the value-adding inputs of one subcontractor when compared to another truly is. Does one subcontractor have a greater propensity for collaborative work environments than the next? Or were the individuals assigned to the project from one contractor more dedicated to realizing the full potential of an integrated approach than those from another firm? These questions are a viable source for future exploration in the successes and shortcomings of the Office Building project that is the focus of this thesis project.

As documented in Technical Assignment II, the in-field usage of building information modeling techniques on the Office Building project were far removed from the intensity of the initial modeling and 3D coordination efforts pursued by the project team. While a fully coordinated, 3D model was available throughout the construction process, efforts to remediate unforeseen field conflicts resorted to the traditional, 2D drawing review and project management consultation methods. While the exact amount of time that could have been saved through the implementation of an in-field 3D coordination BIM tool is not fully understood at this point in time, it is safe to assume that time savings would be anything but negligible. This assumption is supported by the fact that the coordination models already existed per owner coordination requirements and the only additional commitments needed would include workforce training and portable computing hardware.

INDUSTRY CONTACTS

The following individuals were present and constructively contributed to the discussions that took place at the 20th Annual PACE Roundtable Event, held on Wednesday, November 9th 2011 and the Penn Stater Conference Center located in State College, PA. Their contributions to the breakout discussion sessions were documented and utilized in the above summary of said events.

Integrated Team Breakout
Chris Magent – Alexander Building Construction, LLC
Amanda Goolsby – Balfour Beatty
Jessica Wolford – Trammel Crow Company
Bill Moyer – Davis Construction

BIM Implementation Breakout
David Maser – Gilbane Building Company
Kurt Maldovan – Balfour Beatty
Tim Jones – Massaro Construction Management Services
Chris Taylor – Southland Industries

Focus Group: Student Research Topics
Amanda Goolsby – Balfour Beatty

RESEARCH TOPICS

INTRODUCTION

In the Spring semester, many of the constructability, value engineering and project scheduling concerns that were addressed above will be developed into in-depth analyses of the potential areas for improvement on these topics. The parameters and opportunities that were highlighted in Technical Assignments One, Two and Three will foster deeper thinking into the means and methods through which the project could be improved. Some of the industry issues that were discuss at the PACE Roundtable will be adapted to address some of these concerns. The following is a synopsis of potential areas of redesign, improvements and research that could be utilized to ensure that future projects take into account some of the design and construction process related decisions that affected this project.

SLAB EDGE COLUMNS

The current structural design places the exterior concrete columns approximately 4" from the interior faces of the concrete masonry and curtain wall assemblies (see Figure #11). This creates numerous issues pertaining to the work of the interior trades, who have to install their work within these confines. The productivity of metal studwork, insulation, air barrier taping, and drywall installation are all affected by close confines created by the proximity of the structural columns to the exterior façade.

Particularly, the metal studwork and drywall tradesmen are forced to focus the effort of two crew members in a small area in order to maneuver their materials into the tight space. This adversely affects the productivity of these subcontractors, as well as demands the implementation of atypical tools that are capable of operating in close quarters.

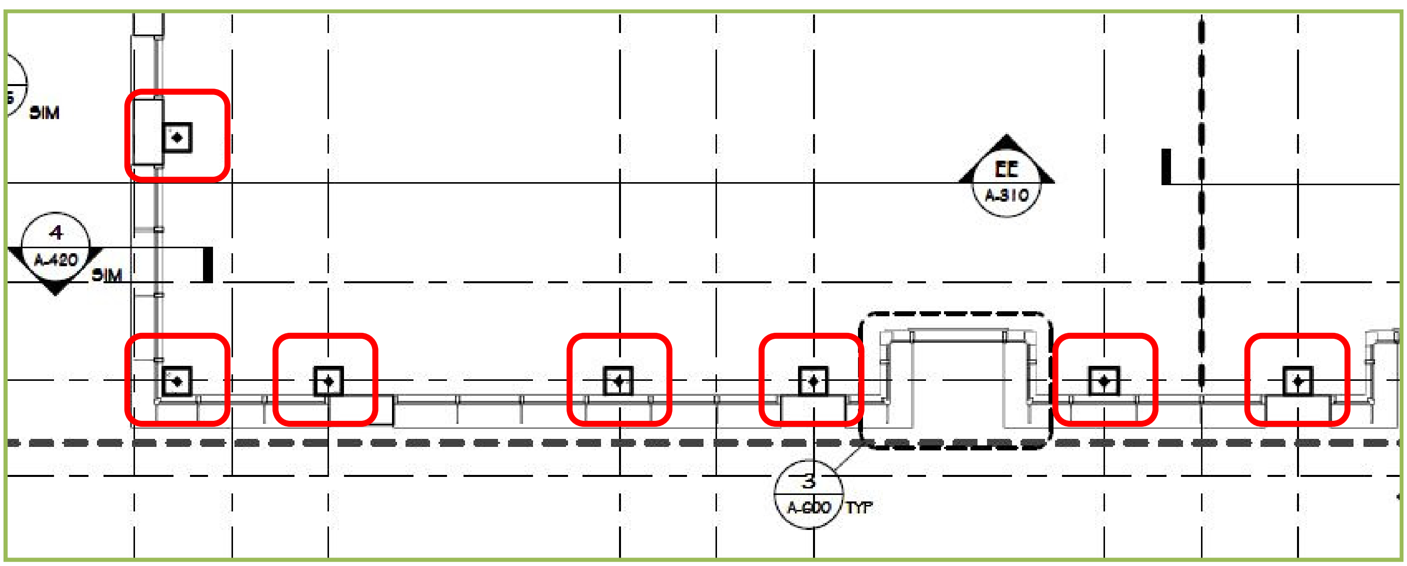

Figure #11 – Slab Edge Columns – Courtesy of Clark Construction

The problems associated with interior trade work between and around the exterior columns could be minimized if these columns were held back an additional 8” from the interior face of the façade. This would give tradesmen a full 12” within which to perform their duties, greatly increasing the quality and productivity with which they install their work.

Required Research

- Interview Workforce
  - What additional requirements are demanded due to the proximity of the exterior columns to the interior face of the columns?
  - Approximately how much productivity is sacrificed because of these confines?
  - Is the quality at which the work placed affected by the inability to properly navigate within the close confines?
- Structural Analysis
  - How much additional rebar would be needed at the slab edge to overcome the forces induced by a larger slab cantilever?
  - Would the blast rated mounts that attach the curtain wall to the structure need to be redesigned to accommodate the additional gap between the column and the slab edge?
- Architectural Analysis
  - Would holding the columns back an additional 8” affect the currently designed architectural casework?
- Cost Analysis
  - How much money is consumed by the need to employ two crew members in order to successfully place work behind and around the columns?

RECESSED FAÇADE FEATURES

At one point during the construction process, it was thought that the brick masonry contractor was not effectively maintaining the project schedule demands for façade brickwork. These initial assumptions were partially justified due to the fact that the brick masonry contractor had incurred numerous safety infractions early on in the project, and had lost a lot of their credibility. It was later determined that the losses in productivity could be attributed to the multiple recesses in the exterior façade, and the custom brickwork associated with wrapping the brickwork around these recesses (see Figure #13).

If the building were designed with a linear façade, the pitfalls associated with tedious brickwork could have been avoided. To date, the slow process at which the façade is being erected may negatively affect the schedule and delay the date of substantial completion.

Figure #13 – Recessed Façade Features – Courtesy Clark Construction

Required Research

- Interview Workforce
    - What custom work is involved with a brick corner?
    - How much extra time is required to complete a turn in the façade compared to linear brick laying?
- Structural Analysis
    - Could the existing foundations be realigned in a linear manner, or would they need to be resized or receive additional reinforcement?
- Cost Analysis
    - What trades are being held up by the slow brick laying process?
        - What are the costs incurred by these trades during standby?
    - Could the building have been less expensive if these brick returns were eliminated?

IN-FIELD BIM SHORTFALLS

Due to owner requirements, the entire project was modeled by the design, engineering and mechanical subcontractor teams. These models were used to detect clashes between the architectural features, structural systems and mechanical equipment. Unfortunately, these models were highly underutilized in the field, leaving contractors to facilitate information in a roundabout manner. If an in-field conflict that was overlooked during the coordination process was detected, contractor foremen were forced to first notify the project team, who would then review congested 2D coordination drawings in an attempt to discover the cause of the conflict. Occasionally, the necessary information could not be drawn from these overcrowded drawings, requiring the project team to solicit further information from the 3D coordination team. The process of obtaining an image from the 3D model usually took upwards of 2 or 3 days, leaving the field personnel to abandoned their current task and move on to another area until the required information was made available.

With 3D modeling files readily available in the form of NavisWorks and Revit files, the absence of an ability to open and review those files is mind boggling. At the very least, select personnel on the project team should have had the ability to rapidly access and review those files on site in order to quickly address problems in the field. Instead, the aforementioned 3 day process was initiated upon failing to obtain the required information from the 2D coordination drawings. An aggressive approach to this issue would have been to provide in field BIM kiosks, provide basic training to subcontractor foremen, and allow them to review the coordinated models themselves. While this may not have solved every conflict that arose, more often than not the 3D model screenshots provided by the coordination team provided solid evidence as to who had improperly installed their work, and the steps that needed to be taken in order to remedy the situation.

A possible area of research is an analysis of the hardware and training necessary to bring BIM to the field, whether it is within the project trailer, or on site in the form of a BIM kiosk.

Required Research

- Interview Workforce
  - How much training would be necessary to provide a rudimentary understanding of 3D model review software?
  - Would the workforce be receptive to the availability of BIM kiosks?
- Cost Analysis
  - Would the advantages of having instant access to 3D coordination models result in a financial gain on the project?
  - How much time and money is wasted waiting 3 days for a solution, when one could be easily obtained in a matter of hours?
  - What hardware needs are associated with a basic in-field BIM implementation and how much would these cost?

SOCIAL EFFECTS OF PROJECT CHANGE ORDERS

As documented in the *Constructability Challenges* section of this report, the effects of Blocking and Stacking on the project budget and schedule were detrimental. However, the emotional effects on the tradesmen responsible for removing and replacing previously completed work are often overlooked. It is widely known in the industry that quality and productivity diminishes when crews are directed to remove and replace work in place. Tradesmen take pride in their work and it is extremely demeaning to force them to tear out completed work due to changes in design.

Some owners do not recognize the true effects of their decisions beyond how much they cost and how long they will take. An analysis of the psychological effects on construction work forces that are required to perform rework on previously completed assemblies would provide a clear picture of the full extent of the effects that design changes have on a project.

Required Research

- Interview Workforce
    - Is quality sacrificed for the sake of getting back on schedule after a change order takes effect?
- Cost Analysis
    - What are the relative costs of reduced productivity associated with the effects of rework requirements?

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APPENDIX A – PACE ROUNDTABLE DELIVERABLE

Session #1
Topic: Assembling an Integrated Team

Research Ideas:

1.) What sociological events have to take place in order for project teams to facilitate trust amongst design and design assist partners? Is there a way to ensure that a bond of trust is built from day one and maintained throughout the project duration? Does this rely on the manner in which the team is chosen, and if so, what steps can be taken to ensure that the "right" team members are chosen?

2.) Why do some integrated project team members adapt to the mindset of a team based project approach better than others? What processes could facilitate an equal commitment from each and every subcontractor and design partner on a project?

Session #2
Topic: Taking BIM Into the Field

Research Ideas:

1.) What is the most effective manner, both financially and ease of use speaking, to take BIM into the field? What are the infrastructure and training requirements associated with this approach?

2.) In a virtual prototyping approach, what assemblies are most commonly provided to subcontractors and why? What are the most prominent benefits of providing subcontractors with digital models of complex assemblies; quality control, productivity? In what stage of design is virtual prototyping most applicable, and what steps need to be taken to ensure that is done properly and delivers the greatest advantage to the field?

Industry Panel: Differentiation in a Down Economy

Research Ideas:

1.) How does a down economy adversely affect the industry desire to implement design-build and integrated project delivery contracting methods? Does the ability for an owner to get a project at the lowest possible cost through a hard bid approach necessarily dominate their decision on which contracting and project delivery method to utilize?

2.) Once the government begins to settle down in the number of new buildings that have been constructed in the last decade, will the building construction market begin to decline? Will private investors and developers begin to develop the areas surrounding recently completed government infrastructure and office building projects?

Industry Member Discussion
Key Feedback: Which research topic is most relevant to industry? What is the scope of the topic?

With building information modeling at the front of most industry related discussions, the most relevant research topic that is applicable to the Office Building project is undoubtedly that of the implementation if in-field BIM efforts. Many design firms are embracing building information modeling technologies and techniques, however the benefits of these efforts are often short lived and are not properly transferred to field operations.

For the Office Building project specifically, an analysis of the most effective means and methods through which to bring BIM into the field is very fitting. This research would require assistance from industry members familiar with the field implementation of BIM, as well as cost and social analyses that take into account the financial, sociological and logistical commitments required to successfully implement BIM in the field.

Representatives from Balfour Beatty, Davis Construction and the Gilbane Building Company were present during the In-Field BIM Implementation break out session, and would undoubtedly serve as excellent points of contact for an analysis of this nature.

Suggested Resources:

Amanda Goolsby – Balfour Beatty

Bill Moyer – Davis Construction

David Maser – Gilbane Building Company

Kurt Maldovan – Balfour Beatty