FINAL THESIS REPORT

Philip J. Corrie
Construction Management
AE Faculty Advisor: Dr. Horman

Aloft & Element Hotels at Arundel Mills
Hanover, Maryland

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David Riley	Associate Professor – CM
Kevin Parfitt	Associate Professor – Structural
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James Freihaut	Associate Professor – Mechanical
Linda Hanagan	Associate Professor – Structural
Robert Leicht	Graduate Student - CM
Craig Dubler	Graduate Student – CM

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Tom Shumaker	Vice President - Holder Construction Company
Jason Ellenberg	Project Manager - Holder Construction Company
David Epps	Senior Engineer of BIM - Holder Construction Company
Richard Gates	Project Engineer - Holder Construction Company
Michael Arnold	Vice President - Foreman Program and Construction Managers
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Megan Wortman	Construction Management
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William Tang	Mechanical

I would also like to thank my family and friends for their help and support throughout.

II. Executive Summary

The following thesis report examines the Aloft and Element Hotel Project at Arundel Mills. In addition to background information in the form of a project overview, this report includes research into a critical industry issue that could potentially improve the Aloft and Element project. It also includes analysis into two other areas of the project where there is potential improvement. Each topic includes an outline of a statement to identify the problem, the goal of examining the analysis topic, the steps that will be taken to achieve the goal stated, and the expected outcome of the analyses. The topics then go on to examine each problem in depth and propose a potential solution to each problem.

The research topic develops a methodology to evaluate the effectiveness of BIM, particularly with regards to three-dimensional MEP coordination and clash detection. After a method has been developed, the report then goes on to apply the method to real life projects in the form of a case study.

The first of the two technical analyses examines the potential benefits from redesigning the HVAC system of the hotel buildings to include PTAC units rather than a forced air system. Initially, a PTAC unit is sized and selected for typical guestroom of the Aloft and Element. From there, implications to cost, schedule, constructability, and other aspects are examined.

The second technical analysis delves into the parking structure of the Aloft and Element project. The schedule and any potential float time are investigated. Furthermore, a potential sequencing of construction and design of formwork are proposed. The analysis then continues on to identify potential cost saving by moving the start of construction of the parking structure to mid-March of 2008 rather than early December of 2007.

III. Project Overview

A. Project Background

The Aloft and Element hotels are a new brand of hotels specific to Starwood Hotels and Resorts Worldwide. The project entails the construction of two seven story hotels, as well as, a two story parking structure. The Aloft hotel, totaling 76,883 square feet, is a vision of W Hotels and includes 142 guestrooms. The Element hotel, totaling 97,923 square feet, is an extended stay hotel and consists of 147 guestrooms. The parking structure includes 118 total spaces and totals 34,700 square feet. The hotels' designers have taken a stab at sustainability by incorporating a few building components typical to green design. The project team, however, will not attempt to obtain a LEED rating. The overall cost of the project totals less than $40 million. Construction was scheduled to begin in May of 2007 and finish in January of 2009.

The Aloft and Element project has been challenged early on with incomplete construction documents and escalated construction costs. Regardless of the challenges faced, the project team continues to press forward as they attempt to successfully complete their mission. Among others topics, the following will describe several aspects of the Aloft and Element Hotel project at Arundel Mills including the project's schedule, costs, and teams.

B. Project Team

Owner – LTD Management Company, LLC
Architect – Jonathan Nehmer & Associates, Inc.
Civil Engineer – Kimley-Horn & Associates, Inc.
M/E/P Engineer – Karpinski Engineering
Structural Engineer – Holbert Apple Associates, Inc.
Contractor – The Whiting-Turner Contracting Co.

C. Client Information

LTD Management, LLC is no stranger to construction. With the addition of several new hotel properties to its assets, LTD plans to expand its revenue to nearly $1 billion. The addition of the Aloft & Element Hotels will consequently assist them in achieving their goal.

LTD has recently had an extensive list of hotel projects were they have assumed the owner's role. Previously, LTD had brought Whiting-Turner on board as the GC for a hotel project in Fredrick, Maryland. The key to WT landing the Aloft & Element project was WT's mission to treat LTD fairly throughout the previous project, specifically with regards to change orders. As was also the case with the project in Fredrick, LTD has strived to reduce the costs of the Aloft & Element projects with several rounds of value engineering. In order to satisfy LTD, Whiting-Turner had made it their mission to cut costs, keep to a tight schedule, and coordinate with LTD's FF&E installation.

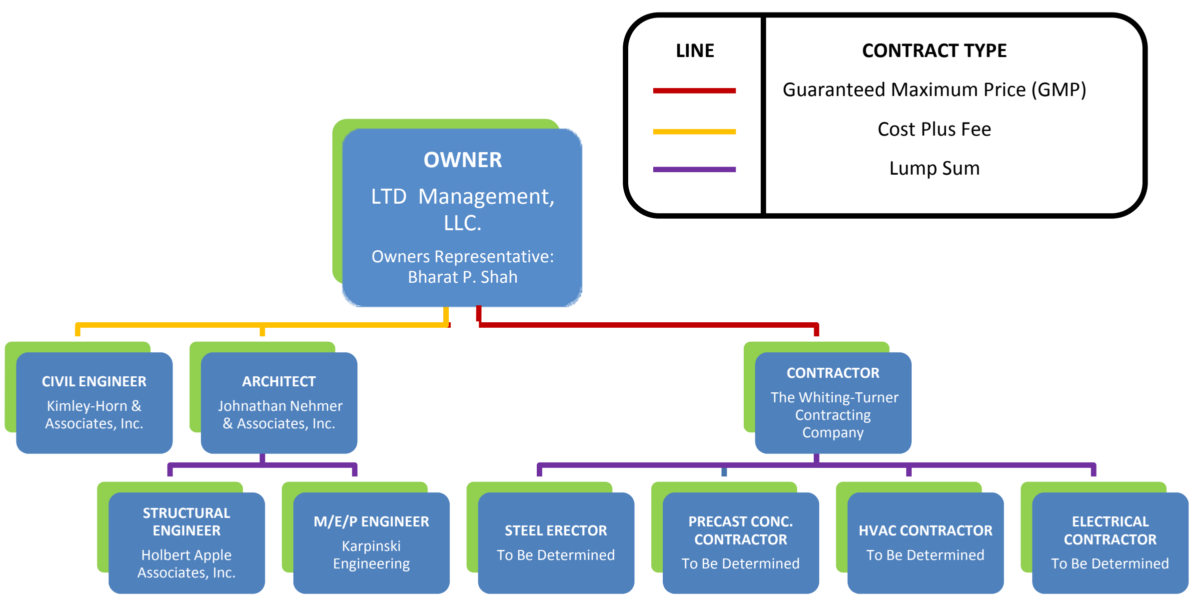
D. Project Delivery System

After LTD and Whiting-Turner established a good working relationship from a previous project, LTD came to WT with a plan to build the Aloft & Element hotels. WT gladly assumed the role of a construction manager at risk after they negotiated their fee for constructing the project. By adding their fee to subcontractors' bid proposals, WT will eventually establish a guaranteed maximum price (GMP) for the project. Currently, WT is negotiating prices with subcontractors and will partner up with LTD to award the work of the construction trades. In order to reduce project costs, subcontractors will not be required to obtain a bond and were originally contacted to bid based on their reputation. The selected subcontractors will, however, be required to obtain insurance with limits typical to the Aloft & Element project size.

Aside from the construction side of the project, LTD also holds separate contracts with designers. In an attempt to begin site work early in the project and cut the schedule, LTD contracted with both a civil engineer (Kimley-Horn & Associates, Inc.) and an architect (Jonathan Nehmer & Associates, Inc.).

Figure III-1 below visually depicts the construction manager at risk delivery method implemented in this project. Both the designers and GC have subcontracted out much of the work for the project.

Figure III-1. Project Organizational Chart

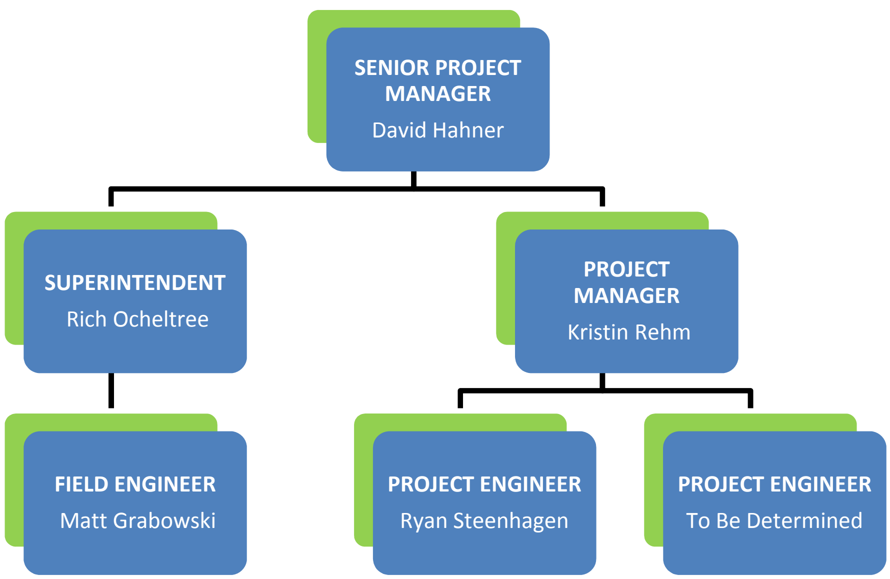


E. Staffing Plan

Typical to many Whiting-Turner projects, the senior project manager (SPM) took charge and set out to obtain the Aloft & Element Hotel project at Arundel Mills. Originally the SPM negotiated WT's fee and obligations and later initiated the bidding process. Later, the project manager (PM) took charge of not only the bidding process, but also other aspects including scheduling. Under the supervision of the PM, WT's project and field engineers have assumed the responsibility of bidding out the majority of the trades. Throughout the project, the SPM will oversee construction with biweekly site visits keeping a close eye on progress. The superintendent and PM will work hand in hand during construction. The superintendent will oversee all on site activities, while the PM will manage the cost, schedule, and other activities and will be the primary contact for the owner. The field engineer will provide assistance to the superintendent, while the project engineers will alleviate some of the PM's workload. Please refer to Figure III-2 for a chart of Whiting-Turners project staff.

Figure III-2. Project Staff of Whiting-Turner

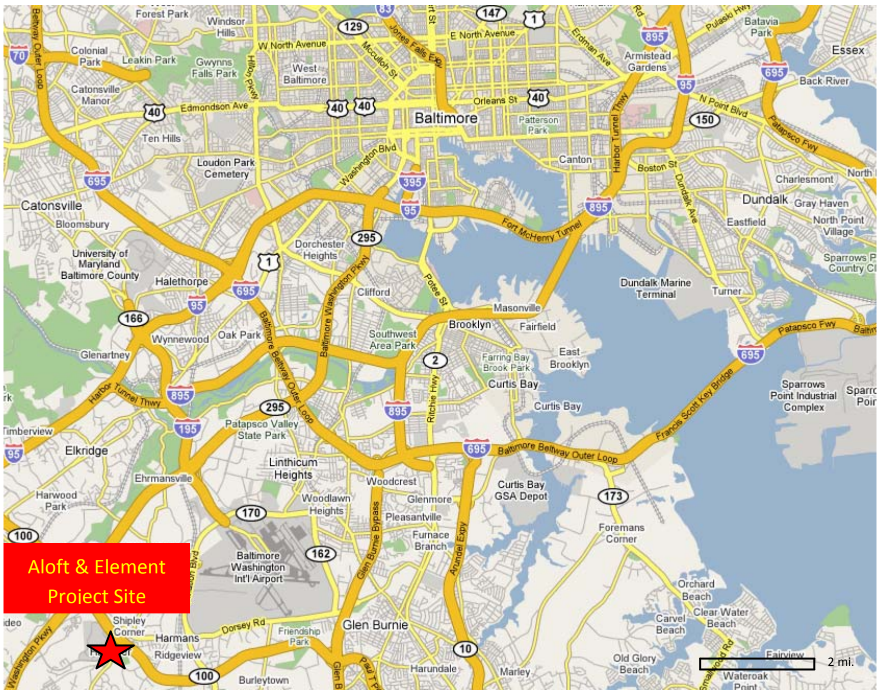
WHITING-TURNER



F. Site

With future addresses of 7520 and 7522 Teague Road in Hanover, Maryland, the Aloft and Element Hotels at Arundel Mills will be located south of Baltimore across from Arundel Mills Mall, which is in close proximity to the Baltimore-Washington International Airport. The following figures provide a visual description of the exact location of the project.

Figure III-3. Location of Hanover, Maryland Relative to Baltimore, Maryland



Courtesy of Google

Figure III-4. Location of Site Relative to Arundel Mills Mall

Courtesy of Google

Figure III-5. Enlarged Bird's Eye View of Existing Site

Courtesy of Google

Figure III-6. View from East of Site

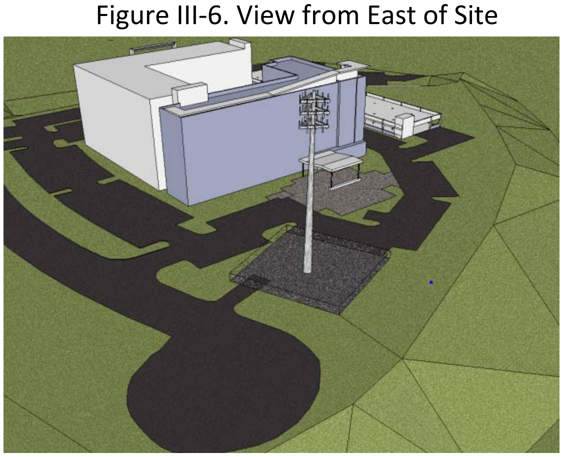


Figure III-7. View from West of Site

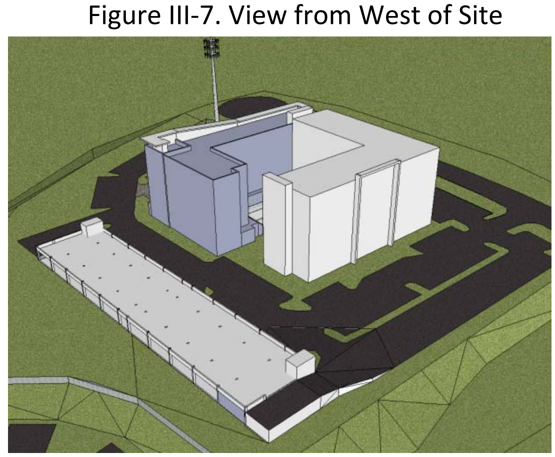
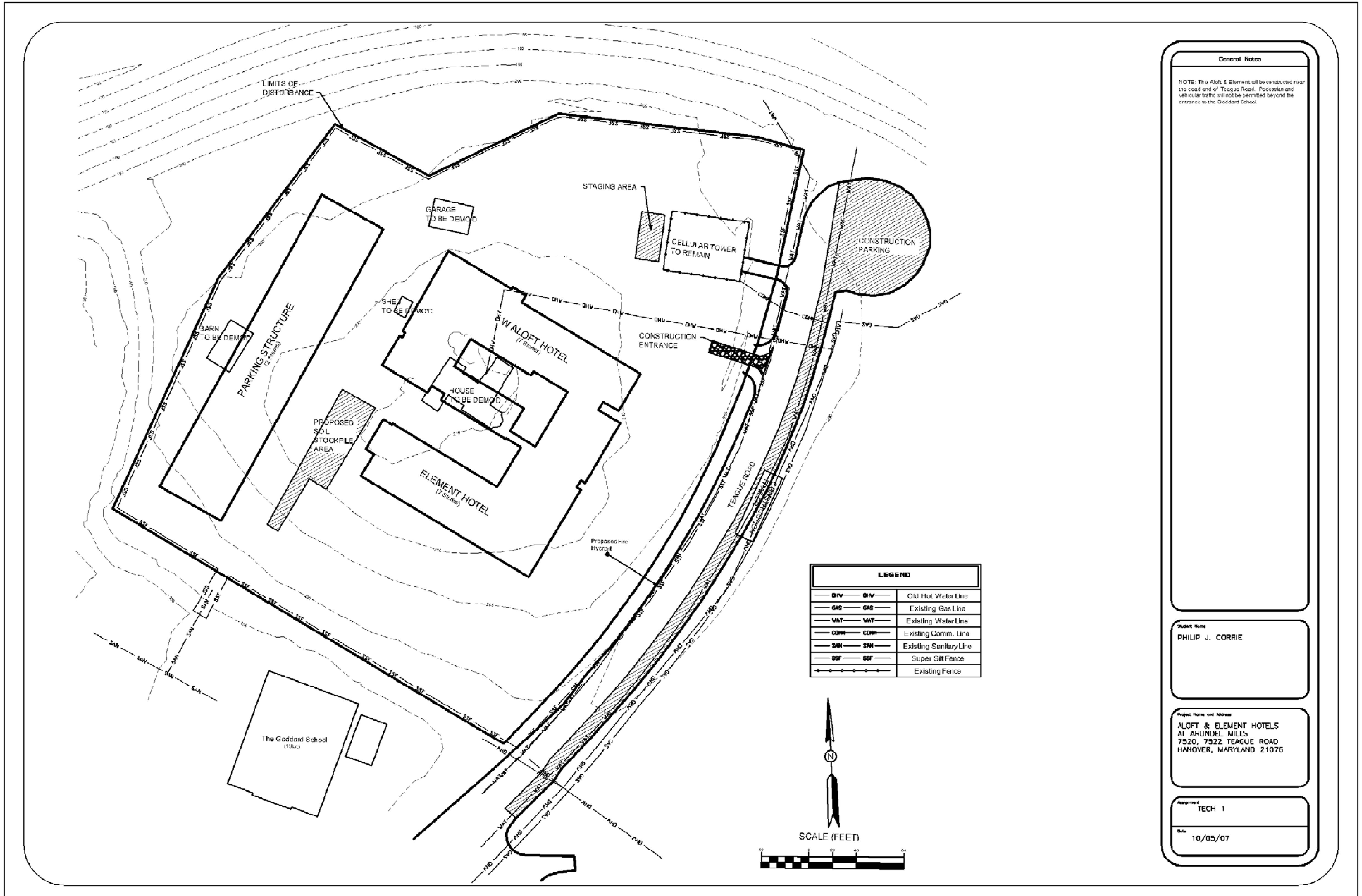


Figure III-8. Site Plan



G. Building Systems Summary

Architecture

As with most Westin Hotels, the architecture of the Aloft and Element Hotels take on minimalist ideals. The buildings consist of two L-shaped buildings adjoined at one corner, while the interiors take on a modern industrial feel. The Aloft Hotel consists of 142 guestrooms with several public spaces located on the lower floor including a lobby, a bar, restrooms, and a fitness center. The Element Hotel, an extended stay hotel, consists of 147 guestrooms with several public spaces located on the first floor including a lounge, business center, meeting room, breakfast area, restrooms, laundry rooms, and a fitness center. The space created in between these two L-shaped buildings contains an enclosed pool room as well as two courtyards, accessible by both hotels.

Building Envelope and Roofing System

The exterior of the Aloft Hotel consists of a combination of 3” drainable EIFS and Metal Composite Wall Panels, both being attached to 5/8” Densglass sheathing on 3-5/8” metal studs. The envelope of the Element hotel consists of insulate-core metal wall panels as well as a 3” drainable EIFS system, both again attached to 5/8” Densglass sheathing on 3-5/8” metal studs. The glass openings in both hotel buildings consist of aluminum windows, entrances, and storefront. The Aloft hotel specifically contains an aluminum curtain wall system spanning from floor 2-7 at the outside corner of its L-shaped floor plan. Both hotels take a step toward sustainability with the implementation of a white 60 mil adhered EPDM membrane for the roofing system.

Structural System

Cast in place concrete for this project is mainly reserved for spread footings and SOG’s and the parking structure. The concrete spread footings of the Aloft and Element are relatively shallow and vary in size. The SOG’s of the hotels are typically 5” in thickness and reinforced with 6” x 6” WWF. The parking structure is primarily a steel reinforced cast in place concrete structure consisting of concrete spread footings, columns, and slabs.

The Aloft & Element Hotels will uniquely reach their 7-story pinnacle by the implementation of a load bearing steel studs with pre-cast concrete planks used for decking. The lower level of the buildings is composed of a both load bearing studs and structural steel framing. The structural steel framing consists of mainly W-shapes of ASTM A992 steel. The columns and beams of the hotels are braced diagonally by structural steel tubing.

Mechanical System

Although the norm of a hotel is a Package Terminal Air Conditioner (PTAC) unit located in each guestroom, the mechanical systems of the Aloft and Element defy industry trends by utilizing a forced air system. Each guestroom of the hotels is fitted with a fan coil unit (FCU) which gives each guest the ability to control the temperature of their room separately. The air is forced through the spaces of the buildings by three air handling units (AHU’s) located on the roof of each hotel. The AHU’s of the Aloft range from 3300 to 10500 cfm in size, while the AHU's in the Element range from 3770 to 11775 cfm. A 3800 cfm ventilation unit located on the first floor of the Aloft hotel forces temperature controlled air through the swimming pool room.

Electrical System

The electric for the buildings are supplied by underground raceways stemming from a transformer. The Aloft and the Element each contain their own step down transformer supplying a 3-phase, 4-wire, 208/120V secondary service. One 480 kW generator located on the eastern corner of the site provides back up power for both the Aloft and Element buildings.

Curtain Wall

While both hotels contain a considerable amount of storefront, the Aloft hotel will uniquely display a curtain wall on the outside corner of its L-shaped floor plan spanning floors 2-7. This curtain wall supports itself with its 2 ¼" aluminum frame system and contains both spandrel panels and ¼" frosted glass.

Lighting

The interior lighting for the hotels is primarily comprised of fluorescent lighting. The guestrooms of the hotels typically consist of 120 V fixtures with fluorescent lamps.

Fire Protection

Both the hotels and the parking structure have standpipes designed into their fire suppression systems. The fire suppression systems of the Aloft and Element buildings also contained a water-based sprinkler system throughout.

Transportation

Employees and guests of the Aloft & Element Hotels will climb the floors of the hotels by entering into one of the four elevators of the project. Each hotel building contains 2 electric traction, machine roomless elevators with one having a rated load of 3500 lbs, while the other is just 2500 lbs. All elevators will have a rated speed of 200 feet per minute.

Telecommunications

Low voltage wiring will be run to each guestroom so that each guest has a telephone at their disposal. Each guestroom is also supplied with cable television, courtesy of the hotels. All floors will be equipped with a Tele/Data room to feed each floor.

H. Construction Considerations

Recently the designers in the Baltimore area have defied traditional steel and cast in place concrete design trends and moved towards a load bearing stud structures with precast concrete decking. This new structural trend not only cuts down on the schedule, but it is also extremely economical. There is, however, a bit of a learning curve for many building contractors. The general contractor, Whiting-Turner (WT), on this project is no exception. For all members of WT's Aloft and Element project team, the structural system is one that they have never taken part in constructing before.

The availability of construction parking provides a challenge for all parties involved. Early in the project, most vehicles will be required to park along Teague Road and across the street at Harmons Park. The construction trailer will also be placed along Teague Road during the early phases. Once the parking structure is complete, most vehicles will be required to utilize the two levels of parking provided by the structure. The job trailer will also later be moved to this location.

Typical to much of Anne Arundel County, the soils found on site range from red stiff clay to silty soil with gravel. Ground water should not be an issue on site, being that the construction site is elevated from much of the surrounding area.

Due to the tight 16 month schedule required by the owner of the Aloft & Element Hotel Project, the construction activities of the buildings have been developed so construction trades are able to complete all work for both the hotels and the parking structure at one time. Most building components, starting with the concrete foundations, will be constructed simultaneously for all three buildings. The steel and hollow core planks of the hotels will then be erected floor by floor upon completion of the foundation work. As the steel and precast planks are being erected for both hotels, the cast-in-place superstructure for the two-level parking garage will be constructed. Upon completion, the parking structure will serve as the primary site of construction parking, as well as, the location for the construction trailer.

While the crane swings the steel and hollow core planks in place, trade workers will follow closely behind their progress, constructing the slabs-on grade and the building enclosure. As the hotels top out, the EPDM roof membrane will be put into place in order to weatherproof the buildings. The MEP and finish trade workers with attempt to stay one step behind the building enclosure as they rough-in and finish the hotels floor by floor.

Prior to the commencement of on-site construction, a residential home, a barn, a shed, and a two-car garage require demolition. The home was demolished in December of 2006. Air-Conditioning units used to cool the pre-existing home required the abatement of Freon at the time of demolition.

I. Project Cost Evaluation

Actual costs reported are mere approximations and have been generalized per the request of the owner and general contractor. These values may not be an accurate representation of costs incurred throughout the project.

The actual building construction cost for the Aloft & Element Hotel Project at Arundel Mills is approximately $32.7 million and $156.12 per square foot, while the total project costs are approximately $36 million and $171.87 per square foot. Table I-1 below provides a breakdown of the site work and approximate costs of each building.

Table I-1. Approximate Actual Project Costs

CSI DIVISION		ALOFT		ELEMENT		PARKING STRUCTURE		SITE
		Amount	*Cost/SF*	*Amount*	*Cost/SF*	*Amount*	*Cost/SF*	*Amount*
00	Bidding Requirements	NA	NA	NA	NA	NA	NA	NA
01	General Requirements	$ 900,000	$ 11.71	$ 1,000,000	$ 10.21	$ 50,000	$ 1.44	$ 200,000
02	Site Work	NA	NA	NA	NA	NA	NA	$ 2,400,000
03	Concrete	$ 1,100,000	$ 14.31	$ 1,300,000	$ 13.28	$ 800,000	$ 23.05	NA
04	Masonry	NA	NA	NA	NA	NA	NA	$ 20,000
05	Metals	$ 600,000	$ 7.80	$ 600,000	$ 6.13	$ 30,000	$ 0.86	$ 30,000
06	Wood & Plastics	$ 400,000	$ 5.20	$ 1,200,000	$ 12.25	NA	NA	NA
07	Thermal & Moisture Protection	$ 1,000,000	$ 13.01	$ 1,200,000	$ 12.25	$ 20,000	$ 0.58	NA
08	Doors & Windows	$ 1,300,000	$ 16.91	$ 1,100,000	$ 11.23	NA	NA	NA
09	Finishes	$ 2,800,000	$ 36.42	$ 3,800,000	$ 38.81	$ 10,000	$ 0.29	NA
10	Specialties	$ 100,000	$ 1.30	$ 100,000	$ 1.02	$ 1,000	$ 0.03	$ 10,000
11	Equipment	NA	NA	NA	NA	NA	NA	NA
12	Furnishings	NA	NA	NA	NA	NA	NA	NA
13	Special Contruction	$ 100,000	$ 1.30	NA	NA	NA	NA	NA
14	Conveying Systems	$ 20,000	$ 0.26	$ 20,000	$ 0.20	NA	NA	NA
15	Mechanical/Plumbing	$ 4,000,000	$ 52.03	$ 3,700,000	$ 37.78	$ 50,000	$ 1.44	NA
16	Electrical	$ 2,200,000	$ 28.61	$ 1,800,000	$ 18.38	NA	NA	$ 300,000
TOTAL		$ 14,520,000	$ 188.86	$ 15,820,000	$ 161.56	$ 961,000	$ 27.69	$ 2,960,000

IV. Analysis 1 – Methodology to Evaluate the Effectiveness of BIM

A. Problem Statement

As the construction industry grows and buildings become more complex, architects, design engineers, and contractors are often assigned an increasing amount of responsibility. The result is often construction documents and shop drawings containing errors and omissions that frequently hinder the construction process and affect the quality of a finished building. It has been widely accepted across the industry that Building Information Modeling (BIM) will alleviate many of the problems associated with the construction process. Specifically, three-dimensional (3D) clash detection and mechanical, electrical and plumbing (MEP) coordination are being used more frequently by contractors and construction managers across the nation. What once was a process of overlaying two-dimensional shop drawings is now evolving into a process where work is modeled virtually in three dimensions before actual construction begins. Many owners, construction personnel, and architects are skeptical of any success that BIM lays claim to because they have not been presented with real life statistics that demonstrate its positive accomplishments. Currently there is no universal method that construction project participants can use to evaluate the success/failure of the implementation of BIM, which may continue to cause industry members to be reluctant to make an investment in “bimming” their building.

B. Goal

The goal of this research is to provide a method that may be used by parties such as, building owners, designers, and construction personal, which will provide a detailed resource that can be utilized to successfully evaluate the outcomes of BIM implementation. The methodology developed can be used to evaluate past projects, which in turn, may be used to justify the use of BIM to all parties involved. Throughout the research, lessons learned from past projects will be presented in addition to the evaluation method in order to further knowledge about BIM implementation.

C. Tools

1. Penn State Architectural Engineering faculty.
2. Industry professionals.
3. Experienced project managers familiar with both BIM projects and non-BIM projects.

D. Research Steps

1. Obtain contact information of construction personnel that have participated in completed projects that have used 3D MEP coordination and 3D clash detection.
2. Interview construction personnel to develop a list of criteria that will be used to evaluate BIM projects.
3. Obtain statistics specific to the evaluation criteria for the BIM project.
4. Obtain statistics specific to the evaluation criteria for a non-BIM project but of similar type and complexity.
5. Directly compare the statistics of the projects to one another.

E. Research

Because 3D MEP coordination and 3D clash detection is very new to the construction industry, it was somewhat difficult to find industry personnel that have actively participated in a BIM project that had completed construction. Employees of Holder Construction, one of the few construction companies that had taken the initiative to implement BIM early on in its development, were extremely helpful in developing a list of criteria that may be used to evaluate the outcomes of the implementation of 3D clash detection and 3D MEP coordination. Because of their initiative, Holder has a few BIM projects under their belt. One of Holder's BIM projects is the object of a case study that will be discussed later in this report.

Although Holder Construction continues to be a pioneer in the exploration of BIM, several other industry members contributed to the development of the evaluation criteria. Industry personnel from Penn State and Foreman Program and Construction Engineers also contributed in developing a methodology to evaluate the effectiveness of BIM. A complete list of industry personnel that have contributed to defining the methodology can be viewed below.

Tom Shumaker – Vice President, Holder Construction Company
Michael Arnold – Vice President of Operations, Foreman Program and Construction Managers
Jason Ellenberg – Project Manager, Holder Construction Company
David Epps – Senior Engineer of BIM, Holder Construction Company
Richard Gates – Project Engineer, Holder Construction Company
Robert Leicht – Graduate Student, The Pennsylvania State University
Craig Dubler – Graduate Student, The Pennsylvania State University

F. Outcome

Although the benefits of the use of 3D clash detection and 3D MEP coordination may be extremely evident to many contractors and construction managers, building owners continue to meet the push towards BIM with reluctance and opposition. Many owners continue to hesitate before investing in a process that does not immediately add to the value of a finished building. Therefore, a select number of contractors and construction managers are scrambling to develop a method to evaluate the success of BIM in order to justify its use on future projects.

One method developed by an organization puts a dollar figure on the savings incurred from virtual clash detection and MEP coordination. Deemed the "estimated cost of avoidance" this figure includes the estimated amount of money that has been saved from detecting clashes. By detecting these clashes, they are able to avoid the cost of potential change order work that would be incurred by the building owner. After a clash is detected, they can examine it and have the ability to estimate the material and labor costs that would have otherwise been necessary to correct the flaw.

Although the estimated cost of avoidance is brilliant and can be accurate in theory, the number of clashes found during the virtual coordination process is often in the hundreds. To be as accurate as possible, it would be necessary to estimate the material and labor costs for every one of the clashes. Many contractors are already spread thin with manpower as it is; therefore, taking the time to go back and examine every clash with such great detail would be extremely demanding and put a significant burden on the contractor. Understandably, the organization that has developed this evaluation method has avoided such an extreme burden by categorizing clashes into types. Each clash type is given a typical material cost per hour and labor cost per hour of work. As clashes are detected on a project, they are categorized, allotted an amount of time to solve the clash, which is then multiplied by the material and labor costs per hour for the category. To account for overestimating, this cost is then cut in half to achieve an estimated final cost for the clash. The final cost for all clashes are then totaled and reduced by seventy-five percent to account for clashes that may have possibly been caught during a shop drawing overlay coordination process and also during field coordination.

While the evaluation method previously explained provides an actual dollar value to those interested in the amount of potential savings that can occur from a specific aspect of BIM implementation, the evaluation method that I have developed has taken a different direction. This method named, "Comparison of Construction Metrics", examines specific aspects of the construction process that can be evaluated with hard statistics. The construction metrics method takes look at several aspects of the construction management process including the following:

- Number of RFI's per a square footage
- Number of RFI's per a dollar amount
- Number of change orders per a square footage
- Number of change orders per a dollar amount
- Ratio of total construction cost compared to total cost of change orders
- Ratio of the amount of contingency used relative to the total project cost compared to the total amount of contingency on the project relative to the total project cost

By examining several of the construction statics relative to a project's square footage and dollar amount, the user of the "Comparison of Construction Metrics" evaluation method can then compare the results of a BIM project directly to a non-BIM project or projects of similar type and complexity. To achieve the most telling and most accurate comparison, the metrics of the BIM project should be compared to non-BIM projects that have been completed by the same general contractor/construction manager under the supervision of the same project manager. Also, before any comparison has taken place it is important to adjust the total construction costs of the project with respect to date of completion, to account for inflation, and location, to account for varying construction costs across the United States.

Because each metric that is examined in the "Comparison of Construction Metrics" method is unique and may include many factors that influence the outcome, each metric of the evaluation criteria is explained in detail below.

Number of RFI's per a Square Footage

For this metric, it is absolutely vital to compare the BIM project to a project that has been completed by the same company under the supervision of the same project manager, because the RFI process varies greatly from company to company, particularly with regards to the frequency that RFI's are submitted. Some companies use RFI's as a last resort, while others look at writing an RFI as the first option. Also, depending on the degree of freedom that a project manager is given, the frequency that RFI's are written can even vary to a great extent between project managers of the same company. To enable a more direct comparison, the number of RFI's is divided by an amount of square footage that makes sense. A square footage that makes sense depends on the number of RFI's and the total square footage of the project. For example, if a BIM project has 268 RFI's and is 150,000 SF in size, and another project has 374 RFI's and is 175,000 SF in size, it makes sense to compare the number of RFI's per 1,000 SF. In this case it would be 1.79 RFI's / 1,000 SF compared to 2.14 RFI's / 1,000 SF, respectively.

The evaluation of the success/failure of the virtual clash detection and MEP coordination occurs when the two numbers are compared. Theoretically, the number of RFI's per a square footage for the

BIM project can be either higher or lower than the non-BIM project and still be deemed a success for BIM in both instances. Depending on the project management system that a company has implemented for a virtual clash detection and coordination process, the frequency of RFI's submitted can increase or decrease. Detected clashes can cause an RFI to be written or they can cause the construction team to resolve the conflicts during coordination meetings.

Number of RFI's per a Dollar Amount

This metric reflects the same ideas as the "Number of RFI's per a Square Footage" metric. The only real difference is that the number of RFI's is compared to a dollar amount that makes sense rather than a square footage that makes sense. For example, if a BIM project had 268 RFI's and totaled $60 million in total construction costs, while a non-BIM project had 374 RFI's and totaled $60 million in total construction costs, it would make sense to compare the number of RFI's per $1 million. For this example, it would be 4.46 RFI's / $1 million compared to 5.34 RFI's / $1 million, respectively.

Number of Change Orders per a Square Footage

This metric, along with the other metrics that involve change orders, should be of particular interest to building owners. Change orders often result in unexpected extra cost; therefore, if it can be proven by the "Comparison of Construction Metrics" that both the number and cost of change orders has been reduced, virtual MEP coordination and clash detection should tend to be more easily justified. For this metric, it is extremely important to make detailed distinctions between types of change orders. If a particular project has a large amount of change orders that were initiated by a change in the owners wants, it could skew the results of the comparison of construction metrics. Also, change orders that were issued to cover complete subcontract amounts to initiate construction as a project's subcontracts have been awarded, should be excluded from the collected data. Similar to the concept that was developed in the "Number of RFI's per a Square Footage" metric, it would be necessary to divide the number of change orders by an amount of square footage that makes sense.

Number of Change Orders per a Dollar Amount

This metric reflects the exact same ideas as the "Number of Change Orders per a Square Footage" metric. The only real difference is that the ratio is found by dividing the number of change orders by a dollar amount that makes sense rather than a square footage that makes sense.

Ratio of total construction cost compared to total cost of change orders

Because the previous two metrics to not take into account the scale of change orders, this construction metric examines the cost associated with those change orders. It is then compared to the total construction cost of the project to find a ratio that will explain that for every *n* dollars spent on a project, there is 1 dollar spent on a change order; therefore, it is important to understand that the greater the ratio, the better the outcome. For example, $345:$1 is better than $246:$1. Again, it is important to make distinctions between types of change orders and include only the proper ones in the collected data.

Ratio of the amount of contingency used, relative to the total project cost, compared to the total amount of contingency on the project, relative to the total project cost

While the title of this metric gives the impression that it is extremely complicated, in reality it is quite a simple concept. The best way to illustrate this is by a simple example. If a $20 million project had $2 million of contingency, then it had a total of 10% contingency. If $1 million of the $2 million worth of contingency was used up, than that would mean that 5% of the budgeted construction cost was used up in contingency ($1,000,000 / $20,000,000 x 100% = 5%). Thus the final ratio that will be used for the comparison of construction metrics would be 5%/10%. As is the case with metrics that involve change orders, it is important to make distinctions between activities that are included in the final total of contingency usage. Many owners choose to spend every dollar that they budgeted for, including contingency dollars; therefore, activities such as the purchasing of extra processing equipment should not be included in the total.

G. Case Study

Due to the generosity of Holder Construction, a case study that used the "Comparison of Construction Metrics" evaluation method was developed. It is important to note that some of the collected statistical data was a result of approximations on behalf of Holder Construction.

The following table shows the statistics gathered from a Holder Construction employee specific to two separate projects. The BIM project is a data center that was built in Delaware, Ohio and completed in July of 2007, while the non-BIM project was a data center built in Sioux Falls, South Dakota and completed in April 2006. Both projects were completed by Holder construction, under the supervision of the same project manager. The Ohio data center was a much larger project with respect to cost and square footage than the South Dakota data center. Also, judging by the cost per square foot, the Ohio data center was also a much more complex project.

Table IV-1. Collected Data

	Ohio Data Center (BIM Project)	South Dakota Data Center
Total Project Costs	$164.3 million	$73.2 million
Total Square Footage	304,000 SF	185,000 SF
Cost per Square Foot	$540.46	$395.68
Total Project Contingency	$4,947,753	$2,366,955
Number of RFI's	521	310
Number of CO's*	251	62
Total Cost of CO's*	$1,425,000	$65,993
Total Contingency Used**	$1,371,339	$79,192

Note: All costs have been adjusted using R.S. Means location and time factors.

* Owner change orders and change orders meant to encompass work that was found in the initial construction documents were not included.

** Contingency used at the owners request to improve the overall value of the building, was not included.

Table IV-2, below, uses the data collected to calculate values and compare the construction metrics for both projects.

Table IV-2. Comparison of Construction Metrics

	Data Center (Ohio)	Data Center (South Dakota)
# of RFI's / 1000 SF	1.71	1.68
# of RFI's / $1 million	3.17	4.23
# of CO's / 1000 SF	0.83	0.34
# of CO's / $1 million	1.53	0.85
Total costs : CO costs	$115 : $1	$1109 : $1
Conting. Used/ Tot. Conting.	0.8%/3.0%	0.1%/3.2%

H. Lessons Learned

The result of the case study yielded complex results. Some of the results were not what was expected from the "Comparison of Construction Metrics " method.

One of those lessons is with respect to RFI's. By comparing the RFI metrics, we can come to the conclusion that there were more RFI's on the South Dakota data center but not a large difference. The reason for this is because as the virtual coordination process was taking place, any questions that arose consequently caused an RFI to be written to the design team. By using this process, the project management team of a BIM project should notice an increase in the number of RFI's during the preconstruction phase and coordination process, and a decrease in the number of RFI's during the construction phase when compared to a non-BIM project. By catching clashes and writing RFI's during coordination, the number of RFI's that are written during construction should theoretically decrease.

The case study also yielded unexpected results with change orders and contingency usage. By looking at the construction metrics, we notice that both the number and costs of change orders of the BIM projects increased with respect to the number and costs of the change orders of the non-BIM project. The comparison between the metric involving contingency yielded a result that the non-BIM project actually used less contingency than the BIM project. Further investigation generated one simple but concrete answer as to why the comparison of the change order and contingency metrics produced an undesirable outcome. The owner of the South Dakota center had a desire to spend all the money that was within their budget, while the owner of the South Dakota data center was much more reluctant to spend any money that was in addition to the initial construction cost. Consequently, the amount of number and cost of change orders along with the amount of contingency used was higher than the Ohio Data Center.

Another small, but significant, lesson learned through the case study pertains to the BIM software itself. The Ohio data center project experienced one or two change orders that occurred directly from imperfections with the BIM software. In these instances, the clash detection software failed to detect the clash. Consequently, the clash went undetected until actual construction on the clashing components was underway, resulting in a change order. Understandably, many owners would be disturbed with the idea of spending money on change orders that were supposed to be prevented by the virtual coordination and clash detection. In other words, owners may question their initial investment in BIM if they are forced to pay for clashes anyway. Informing the owner up front that the virtual clash detection and coordination software is continuing to develop and may detect slightly less than 100% of the clashes, will make the consequences of an undetected clash more acceptable.

The lessons learned from the case study can simply be summarized through the following statements.

- Depending on the RFI process, the number of RFI's on a BIM project, relative to the number on a non-BIM project, may increase, decrease, or **even remain relatively the same**.

- An ideal comparison using the "Comparison of Construction Metrics method" would be a comparison of two projects (one BIM project and one non-BIM) completed by the same construction manager / general contractor, under the supervision of the same project manager, and **for the same owner**. An ideal comparison would also include the same designer for both.

- The construction manager / general contractor should convey to the owner that the **BIM software is not always 100% perfect** and that there may be a very small number of change orders that are a direct result of clashes that go undetected.

While the outcome of the case study did not provide exactly ideal results, it did produce some valuable lessons that can continue to improve the evolving process of 3D clash detection and 3D MEP coordination. Is it possible that the virtual clash detection and MEP coordination of the Ohio data center was not worth it? Possibly, but doubtful. Judging solely by the opinions of both the owner and the project management staff, the effort was well worth it. In an ideal situation, a comparison between projects constructed by the same owner and designed by the same design firm would yield more telling results.

V. Analysis 2 – PTAC Units in Lieu of a Forced Air System

A. Problem Statement

The cost of the Aloft & Element hotel project is currently over budget. Much of the project's cost lies in the HVAC system of the Aloft & Element buildings, which accounts for nearly 15% of the overall cost. For the mechanical systems for the Aloft and Element Buildings, each guestroom of the hotels has been designed to include a fan coil unit (FCU), which would give each guest the ability to control the temperature of their room separately. The air would be forced through the spaces of the buildings by three roof-top air handling units (RTU's) located on the roof of each hotel. Package Terminal Air Conditioner (PTAC) units may alleviate some of the strain on the budget of the project.

B. Goal

An in depth analysis will determine what components of the original HVAC can be eliminated if PTAC units were to be substituted. This analysis will also size a PTAC unit for a typical hotel guestroom and will also delve into changes in the cost, schedule, and constructability of using the PTAC units in lieu of the specified forced air system.

C. Tools

1. Penn State Architectural Engineering faculty.
2. Industry professionals.
3. Other Penn State AE, mechanical option, students.
4. R.S. Means 2008.
5. ASHRAE.

D. Research Steps

1. Research PTAC units and develop a list of positive and negative issues coinciding with PTAC units.
2. Analyze the heating and cooling load needed for a typical guestroom.
3. Size and choose a PTAC unit.
4. Analyze the necessity of originally designed HVAC equipment.
5. Analyze the effect to the budget.
6. Analyze the constructability issues of PTAC units specific to the project. Propose solutions to issues.
7. Analyze the implications to the schedule of the project.
8. Summarize results

E. Expected Outcome

This research should identify the positive impacts to the budget and schedule. It should also identify any issues with constructability and propose possible solutions to such issues. Research in this area should also identify and weigh the negative impacts to the quality of the hotel buildings.

F. Existing Design

The existing design of the HVAC system of the Aloft and Element hotel buildings implemented the use of three roof-top air-handling units (RTU's) for each building which comes to a total of six RTU's on the total project. The two smaller RTU's of each hotel building, ranging from 3,300 CFM to 7,375 CFM supply 45 CFM of slightly conditioned ventilation air to each guestroom. Twenty-four (twelve on each hotel) variable speed, air-cooled condensing units located on the roofs supply refrigerant to a FCU in each guestroom. The FCU's circulate the ventilation air throughout the room while conditioning the air with its electric heating coil and the refrigerant supplied cooling coil. 40 CFM of air is removed from each guest bathroom and is exhausted through the roof of the buildings. The two larger RTU's supply conditioned air to the common spaces of the first floors. The system originally designed for the Aloft and Element project is commonly known throughout the industry as a DX HVAC system.

G. Mechanical Breadth – Choosing and Sizing a PTAC Unit

First ,it was necessary to verify the required amount of ventilation air for a guestroom. The equation to determine the required CFM of ventilation air for a hotel room can be found below. To find the maximum amount of ventilation air that would be required for a guestroom, the calculations were run for the largest guestroom, the conference room.

> Note: The equation was determined from the ASHRAE 2005 Fundamentals Handbook. The people/room was determined from the amount allotted for each guestroom type on the construction drawings.

Ventilation Air Equation

$$(SF\ of\ Room\ \times 0.06) + \left({}^{People}/_{Room} \right) \times \left({}^{CFM}/_{Person} \right) = Ventilation\ CFM$$

Conference Room

$$(562\ SF\ \times 0.06) + \left({}^{3\ People}/_{Room} \right) \times \left({}^{5\ cfm}/_{Person} \right) = 48.72\ cfm$$

The result of the calculation revealed a required CFM that was greater than the 45 CFM of ventilation air that was designed for originally. Because the conference room is by far the largest room in the hotel buildings a calculation for a different guestroom type was performed. A ventilation air calculation for a 1-Bed yielded a CFM of less than the designed amount.

1-Bed

$$(457\ SF\ \times 0.06) + \left({}^{3\ People}/_{Room} \right) \times \left({}^{5\ cfm}/_{Person} \right) = 42.42\ cfm$$

Because the originally HVAC design called for 45 CFM of ventilation air to be supplied to each guestroom, and because the ventilation requirement of the conference room is the only guestroom type that exceeds designed amount, 45 CFM of ventilation air was used to size a PTAC unit.

Note: The four conference rooms are the largest rooms in the hotel buildings at 562 SF each. The next largest room type is a 1-Bed guestroom at 457 SF.

Because the FCU schedule in the construction drawings showed FCU's that circulated 280 CFM of air, this amount can also be used to size a PTAC unit for a guestroom. Several industry professionals suggested that Carrier® manufactured a quality PTAC unit that was both quiet and was known to avoid problems with moisture. Investigation into Carrier's different PTAC units showed the 52M Performance Series to be "quiet" and "efficient" to the where it "can save you money on utilities".

Figure V-1. – Carrier® 52M Performance Series PTAC unit

PTAC units, just like FCU's, re-circulate and recondition indoor air to save energy. To comply with the ventilation air requirement, PTAC units also suck in outdoor air which is mixed with the re-circulated air and conditioned to room temperature. Because the there is a required 280 CFM of air that must be circulated delivered to the room, we can determine the amount of indoor air that will be re-circulated by the PTAC unit. The amount of ventilation air has been increased to 65 CFM because the 52M Series PTAC unit supplies that amount of outside air.

$$280\ cfm_{Circulated\ Air} - 65\ cfm_{Outdoor\ Air} = 215\ cfm_{Indoor\ Air}$$

The lowest amount of indoor air that can be re-circulated by a Carrier® 52M Series is 265 CFM (See Table V-1 below), so 265 CFM of indoor air was used which will be combined with 65 CFM of outdoor air in order to determine the heating and cooling load for a guestroom.

Table V-1. Selection of PTAC

COOLING & ELECTRIC HEAT												
MODEL NUMBER	Cooling Capacity (BTUH)	EER	Electrical Heating Capacity (BTUH)	Reverse Cycle Heat (BTUH)	COP	Voltage Range	Indoor CFM			COOLING		Approx. Ship Weight lb.
							Low	Med	High	AMPS	WATTS	
52ME-U07---3	[illegible]	[illegible]	Determined by your power cord selection. See chart below.	[illegible]	[illegible]	187 – 253	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52ME-U09---3	8800 / 9000	11.4 / 11.4		–	–		265	290	330	3.9 / 3.7	770 / 790	125
52ME-U12---3	12,000 / 12,100	11.4 / 11.5		–	–		280	300	320	5 / 4.7	1060 / 1070	140
52ME-U15---3	–	–		–	–		–	–	–	–	–	–
52ME-U07---4	–	–		–	–	239–292	–	–	–	–	–	–
52ME-U09---4	9,100	11.7		–	–		265	300	320	3.3	790	125
52ME-U12---4	12,100	11.5		–	–		280	310	345	4.35	1050	140
52ME-U15---4	–	–		–	–		–	–	–	–	–	–

To confirm that the selected PTAC unit would be capable of condition the air of a typical guestroom, it was necessary to determine the heating and cooling load of the room.

First, the outdoor design temperatures were identified for the city of Baltimore from the ASHRAE 2005 Fundamentals Handbook.

Baltimore Outdoor Air (OA) Temperatures

Summer → 91°F

Winter → 13°F

The indoor design temperatures were then identified for a hotel building (these temperatures were verified by Professor Friehaut).

Hotel Indoor Air (IA) Temperatures

Summer → 75°F

Winter → 70°F

With the design temperatures in hand, the heating and cooling loads for a typical guestroom were determined through a series of equations.

$$CFM_{Total} = CFM_{Outdoor\ Air} + CFM_{Indoor\ Air}$$

$$CFM_{Total} = 65\ cfm + 265\ cfm$$

$$CFM_{Total} = 330\ cfm$$

Cooling Load Determined

$$T_{PTAC\ Unit} = \frac{(CFM_{Outdoor\ Air} \times T_{Outdoor\ Air}) + (CFM_{Indoor\ Air} \times T_{Indoor\ Air})}{CFM_{Total}}$$

$$T_{PTAC\ Unit} = \frac{(65\ cfm \times 91\text{°F}) + (265\ cfm \times 75\text{°F})}{330\ cfm}$$

$$T_{PTAC\ Unit} = 78.2\text{°F}$$

$$\dot{Q} = 1.08 \times CFM_{total} \times (T_{PTAC\ Unit} - T_{Indoor\ Air})$$

$$\dot{Q} = 1.08 \times 330\ cfm \times (78.2\text{°F} - 75\text{°F})$$

$$\dot{Q} = 1{,}140\ BTUh$$

Heating Load Determined

$$T_{PTAC\ Unit} = \frac{(CFM_{Outdoor\ Air} \times T_{Outdoor\ Air}) + (CFM_{Indoor\ Air} \times T_{Indoor\ Air})}{CFM_{Total}}$$

$$T_{PTAC\ Unit} = \frac{(65\ cfm \times 13\text{°F}) + (265\ cfm \times 70\text{°F})}{330\ cfm}$$

$$T_{PTAC\ Unit} = 58.8°\text{F}$$

$$\dot{Q} = 1.08 \times CFM_{total} \times (T_{Indoor\ Air} - T_{PTAC\ Unit})$$

$$\dot{Q} = 1.08 \times 330\ cfm \times (70°\text{F} - 58.77°\text{F})$$

$$\dot{Q} = 4{,}002\ BTUh$$

Based on the cooling load, the 52ME-U09---3 Carrier® PTAC unit was selected (see V-1.) The way in which Carrier's PTAC units are manufactured requires the selection of a power chord that will enable the PTAC unit to be manufactured to the correcting heating capacity. In this case the power chord PWRCORD-265V-15A was selected (See Table V-2).

Table V-2. Selection of Power Chord

Model No.	Voltage	Receptacle Type	Heating (BTUH)	Heater (Kw)	Input Power (Watts)	Current (Amps)	Branch Circuit Full Amps
PWRCORD-230V-15A	208/230V	15 amp /250V	7,800 / 6,400	2.5	2,393 / 1,985	10.4 / 9.5	15
PWRCORD-230V-20A		20 AMP / 250V	11,600 / 9,700	3.4	3,493 / 2,935	11.52 / 14.1	20
PWRCORD-230V-30A		30 AMP / 250V	17,000 / 13,600	5.0	5,170 / 4,147	22.5 / 20.0	30
PWRCORD-265V-15A	265V	15 AMP / 277V	7,800	2.5	2,396	9.2	15
PWRCORD-265V-20A		20 AMP / 277V	11,600	3.4	3,496	13.3	20
PWRCORD-265V-20A		30 AMP / 277V	17,000	5.0	5,170	19.6	30

NOTE: In compliance with UL, and the National Electrical Code, 265V units installed iwth a power cord require the use use of a 265V electrical subbase.

The Carrier® PTAC unit model 52ME-U09---3 with Power Cord PWRCORD-265V-15A has a cooling capacity of 8,800 BTUH and a heating capacity of 7,800 BTUH, which is more than enough to handle the heating and cooling loads of a typical guestroom.

H. Research

Prior to sizing and selecting a PTAC unit, it was necessary to investigate both the positive and negative consequences of implementing PTAC units in hotel rooms. The following industry members were interviewed to indentify these issues.

Mark Elder, P.E. – Senior Mechanical Engineer, Clark Nexsen Architecture and Engineering
Robert Holland – Associate Professor, The Pennsylvania State University
George Conley – Project Manager, WE Bauers & Associates

Several issues with PTAC units are described and discussed in relation to the Aloft and Element Hotel Project at Arundel Mills below.

Cost & Energy

PTAC units are very cheap and have a low initial cost compared to many of the other types of HVAC system, including the DX HVAC system type. Table V-3, which can be found later in this section, shows an estimate of the amount of money that could be potentially be saved in initial construction costs.

PTAC units are infamous for being very inefficient when it comes to energy consumption; however, they have come a long way since they were initially introduced. For the Aloft and Element project, which had been threatened to be realized since it was plagued with construction budget overruns, it makes sense to substitute PTAC units in lieu of the DX HVAC system.

It is possible to control two rooms with one PTAC unit with a simple length of duct between rooms. This means that one guest would control both rooms while the other guest lacked control of the temperature of his or her guestroom. For a hotel of the Aloft and Element caliber, it makes sense to put a PTAC in each room so that each guest will have a comfortable stay.

Noise

PTAC units are legendary for being a noisy HVAC system that can sometimes cause discomfort for a tenant. While many PTAC units have been known for excessive noise, the Carrier® 52M performance series unit is known for being relatively quiet in comparison. While PTAC units are louder than most, the noise of all HVAC systems will never be completely eliminated.

Condensate

While many PTAC units contain a "slinger", which is a device that utilizes condensate to cool the condenser of the PTAC, many industry members still consider it necessary to have condensate draining system. The condensate draining system for PTAC's would be very similar to the condensate draining system that was designed for the DX system.

Moisture and Humidity

PTAC units are notorious for poor air quality because they lack the ability to control humidity affectively. They are also known have numerous problems with leaking and causing mold. It is widely known that the combination of PTAC units, negative pressure caused by a continuous bathroom exhausting, and vinyl wall covering is an ideal situation for mold growth. The negative pressure of the room causes the infiltration of humid outside air that is trapped behind the vinyl wall covering, which in this case, acts as a vapor barrier. Eliminating all vinyl wall coverings in the hotel guestrooms could eliminate a potentially moldy situation.

Constructability

PTAC units are much easier to construct than a DX HVAC system. Compared to the DX system, PTAC units require little labor because ductwork is eliminated.

Maintenance

Just as the case with any other HVAC system, PTAC units require maintenance. The filters' of PTAC units require periodic cleaning to continue to be effective. Also, as is the case with many other HVAC systems, the compressors in PTAC's can fail which leads to an expensive repair.

Aesthetics

Many people view PTAC units as one of the least aesthetically pleasing HVAC systems. PTAC's are in plain view in the interior of a guestroom and are often viewed considered bulky. PTAC's can also be seen on the façade of a building because they must be installed on the exterior wall of the building. While PTAC's are in plain view of a hotel guest, many guests have become accustomed to PTAC's in hotel rooms because it is so typical. While PTAC's are visible from the outside, Carrier's PTAC's are available with a grille accessory that can be painted to match the façade and installed flush.

I. Implications

By implementing PTAC units in the hotel guestrooms, RTU-1, RTU-2, RTU-4, RTU-5, and all rooftop condensers can be eliminated (see Figure V-2). The FCU's in the guestrooms can also be eliminated. This HVAC equipment is used to condition all of the guestrooms of both the Aloft and Element buildings. RTU-3 and RTU-6 must remain because these units are used to condition the common spaces on the first floors of the buildings. Smaller condensing units are located on the ground outside of the building which allows some of the common spaces to be cooled. Not only is much of the HVAC equipment eliminated, but so is the extensive amount of ductwork that is used to supply the rooms with air. Not only is the ductwork expensive with respect to material cost, but the installation of the ductwork is extremely labor intensive and dramatically contributes to excessive cost. Table V-3 shows the difference in the HVAC contract amount between the DX system and PTAC units.

Figure V-2. Eliminated Rooftop HVAC Equipment

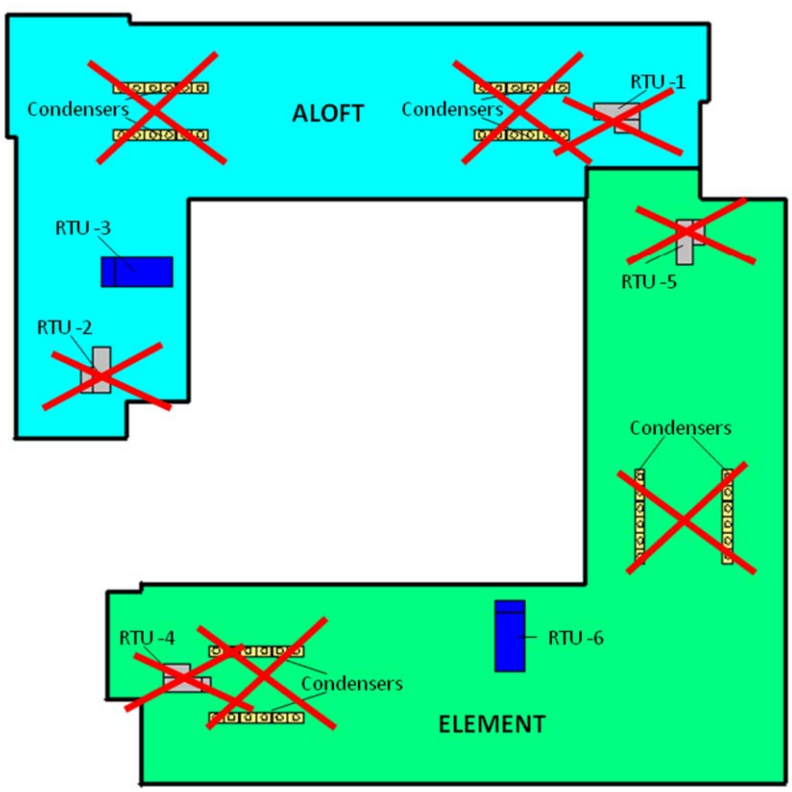


Table V-3. HVAC Construction Contract Amount Comparison

	ORIGINAL HVAC COSTS	ELIMINATED HVAC COSTS	PTAC COSTS	TOTAL SAVINGS	FINAL HVAC COST
ALOFT	$2,204,000	$991,324	$136,320	$855,004	$1,348,996
ELEMENT	$2,148,500	$1,168,584	$141,120	$839,796	$1,309,704

Table V-3 only includes work that will be completed by the HVAC contractor. It does not include any electrical or plumbing costs. The original HVAC costs have been taken from the original contracted amount. The other outlined costs and savings have been estimated using R.S. Means 2008.

Because implementing PTAC units in lieu of the DX system saves an astonishing amount labor, the schedule savings are very prevalent. Table V-4, shown below, breaks down the major HVAC activities of the original system and compares them to the system that would include PTAC units.

Table V-4. HVAC Schedule Breakdown

Activity	Aloft		Element	
	Orig. Duration	Final Duration	Orig. Duration	Final Duration
Set Rooftop Equip. & Hookup	26	* 12	22	* 9
Duct & FCU's	91	72	94	82
Refrigerant Piping	89	0	94	0
Devicing & Trim	43	* 8	48	* 18
PTAC Units	0	* 29	0	* 30

*These durations have been estimated using R.S. Means 2008

The reason that PTAC units save on both cost and precious schedule time is because they are so easy to construct. The basic steps of installing PTAC units are relatively simple. PTAC units require a wall sleeve to be inserted into the wall underneath the window during the construction of the building envelope. Electricians then run electricity to the walls sleeve and install a special receptacle into the sleeve. A small crew of HVAC contractors can later return to slide the PTAC unit in place. All basic components can be installed from inside the building. Consequently, no special lifts or scaffolding would be required.

While PTAC's weigh much less than the RTU's, the crane on site will still need to remain the same size. The two largest crane picks are the two largest RTU's that were in the original HVAC design. These two RTU's would continue to remain in a design that implements PTAC units.

J. Other considerations

Besides the consequences that were previously discussed, it is important to mention other implications of implementing PTAC units.

Electrical System and Consumption

While the HVAC contract would be reduced a considerable amount, the electrical costs should also be examined closely. Implementing PTAC units in lieu of the DX system would require changes to the design of the electrical system. Energy consumption would also be another area of concern. While the Carrier® 52M Performance Series PTAC unit claims to be more efficient than most PTAC units, logic would suggest that the energy consumption of the units would exceed the amount of energy that would be consumed with the DX system. This additional operating costs caused by more energy consumption, could eventually exceed and outweigh any savings in initial construction costs.

Smaller Plenum Space

Because bulky ductwork and FCU's can be eliminated on floors 2-7 of the hotel buildings, bulk heads intended to conceal the items can be reduced or even eliminated. This would result in higher ceilings in both the hallways and guestrooms, which would be more architecturally pleasing to many.

Roof-top Walkways

Walkways intended to provide access to HVAC equipment located on the hotel roofs, could significantly be reduced because several pieces of equipment would have been eliminated.

Fewer roofing penetrations

If rooftop HVAC equipment were to be eliminated, common sense would suggest that the roofing contract amount would be lessened, because the elimination of roof penetrations would reduce labor.

VI. Analysis 3 – Parking Structure

A. Problem Statement

The Aloft and Element Hotel Project at Arundel Mills was on the verge of dissolution due to extreme budgetary overruns. With every aspect of the project being examined as a target for value engineering, the onsite parking structure is no exception.

The onsite parking structure costs just under $1 million and accounts for nearly 3% of the total project's cost. Whiting-Turner's project team planned for the cast-in-place concrete of the concrete parking structure to commence on December 5, 2007 and finish on February 8, 2007, leaving 48 days for the concrete work to be completed. WT planned for the parking structure to be completed early on in the project so that the structure could be utilized for construction parking as soon as possible. With a recreational baseball park, Harmons Park, with plenty of parking spaces located approximately 500 ft away, the early completion of the parking structure may not be necessary. Harmons Park will be utilized for construction parking early on in the project anyway. Without the driving force of construction parking, the parking structure would not be on the critical path and would not need to be completed until the near end of the overall project. By utilizing float time, the total cost of the parking structure may be able to be reduced.

B. Goal

This analysis will explore different ways that schedule float time may be utilized to decrease the cost of the parking structure. Whether it be through a formwork design and sequencing that minimizes formwork costs, or a delayed schedule that could reduce winter protection costs, investigation into ways to utilize the float time should result in reduced costs.

C. Research Steps

1. Examine project schedule.
2. Speak with AE faculty.
3. Design formwork.
4. Develop elevated slab sequencing.
5. Speak with industry professionals.
6. Estimate winter protection costs.
7. Summarize results.

D. Expected Outcome

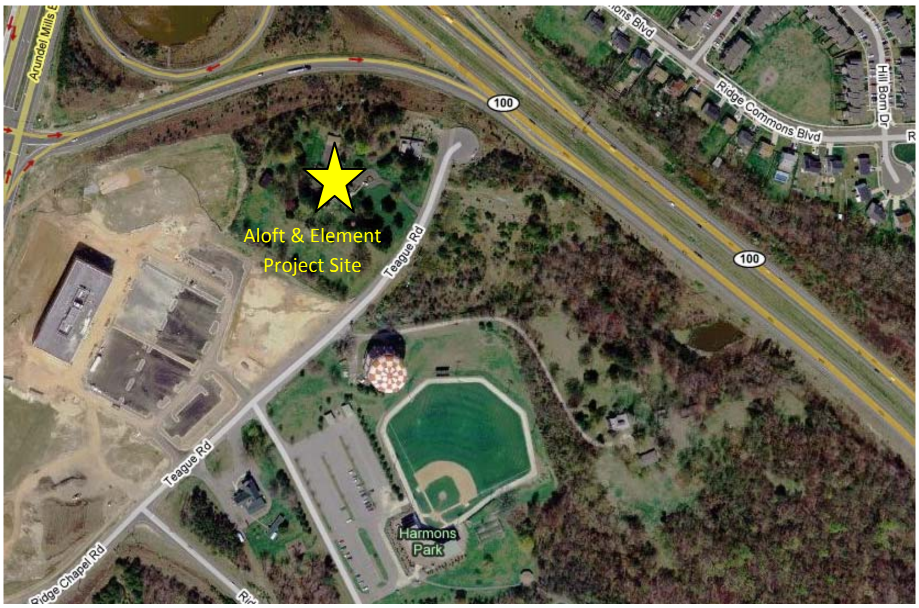
Research and analysis in this area should identify a formwork design and construction sequencing for the elevated slab of the parking structure that minimizes formwork costs. It should also identify extra costs associated with constructing the parking structure during the winter months.

E. Construction Parking

At the outset of the Aloft and Element project, Whiting-Turner's project team had thought out a plan that would allow workers to park at Harmons Park during the early phases of construction. The parking structure is scheduled to be completed during the early phases of construction so that it can be utilized for construction parking during the remainder of the project. Whiting-Turner has also suggested that Harmons Park will be utilized for any overflow construction parking throughout the remainder of the project.

Harmons Park is located approximately 500 feet away from future site of the Aloft and Element hotels. Figure VI-1 shows the location of Harmons Park in relation to the Aloft and Element site and shows the relative size of its parking lots.

Figure VI-1. Harmons Park



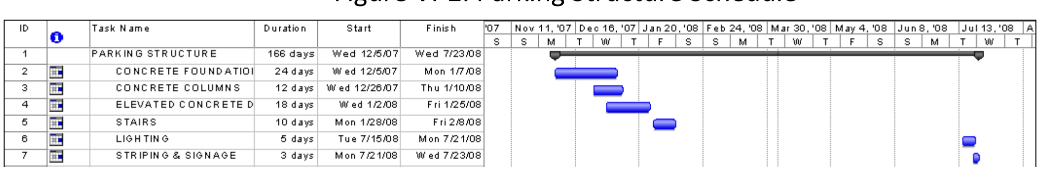
Courtesy of Google.com

If Whiting-Turner may be utilizing the Harmons Park to some extent throughout the project, with it being the sole location of parking early on, it makes sense that it could potentially serve as the main location for construction parking throughout the duration of the project.

F. Original Schedule

The original schedule of the Aloft and Element Hotel Project at Arundel Mills had the parking structure beginning on December 5, 2007. The concrete of the parking structure was to be completed on February 8, 2008. By this schedule, the concrete of the parking structure would take 48 working days to complete. The lighting and striping of the parking structure is scheduled to be installed in mid-July, leaving approximately 111 working days of float time in the parking structure schedule. Figure VI-2. provides a visual representation of the parking structure schedule.

Figure VI-2. Parking Structure Schedule



ID	Task Name	Duration	Start	Finish
1	PARKING STRUCTURE	166 days	Wed 12/5/07	Wed 7/23/08
2	CONCRETE FOUNDATIOI	24 days	Wed 12/5/07	Mon 1/7/08
3	CONCRETE COLUMNS	12 days	Wed 12/26/07	Thu 1/10/08
4	ELEVATED CONCRETE D	18 days	Wed 1/2/08	Fri 1/25/08
5	STAIRS	10 days	Mon 1/28/08	Fri 2/8/08
6	LIGHTING	5 days	Tue 7/15/08	Mon 7/21/08
7	STRIPING & SIGNAGE	3 days	Mon 7/21/08	Wed 7/23/08

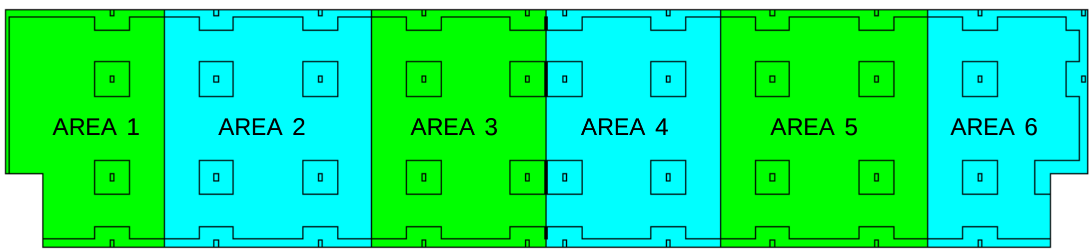
It should be noted that the concrete work for the parking structure is scheduled to begin directly upon completion of the Aloft and Element foundations. The lighting, striping, and signage of the parking structure are to be installed in mid-July because these installation crews will already be on-site for other aspects of the project. Refer to Appendix A to view a detailed project schedule to further understand the timeline of the parking structure relative to the rest of the project activities.

G. Formwork Design and Sequencing

Formwork can account for a very significant portion of concrete construction costs; therefore, the formwork design and sequencing was the first logical portion to examine for potential cost savings. What was most striking about the parking structure schedule was the amount of time allotted for the construction of the elevated slab. Totaling 18 days, the timeline for the elevated slab may seem somewhat accelerated to a person that is inexperienced in concrete construction. Further analysis into the construction of the slab yielded disappointing results.

First, to minimize the amount of formwork needed for the elevated slab, the slab was broken up into six areas that would require similar amounts of formwork with a typical formwork design. These six areas are shown below in Figure VI-3.

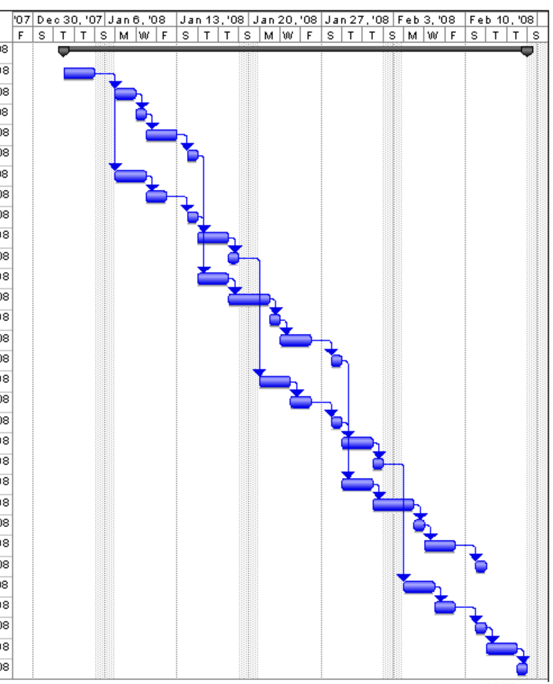
Figure VI-3. Elevated Slab Areas



Later, a sequence for the construction of the elevated slab was produced that implemented the six areas. This sequence can be seen below in Figure VI-4.

Figure VI-4. Revised Elevated Slab Schedule

ID	Task Name	Duration	Start	Finish
1	PARKING STRUCTURE ELEVATED DECK	33 days	Wed 1/2/08	Fri 2/15/08
2	Form Area 1	3 days	Wed 1/2/08	Fri 1/4/08
3	Reinforce Area 1	2 days	Mon 1/7/08	Tue 1/8/08
4	Pour Area 1	1 day	Wed 1/9/08	Wed 1/9/08
5	Cure Area 1	3 days	Thu 1/10/08	Sat 1/12/08
6	Strip Area 1	1 day	Mon 1/14/08	Mon 1/14/08
7	Form Area 2	3 days	Mon 1/7/08	Wed 1/9/08
8	Reinforce Area 2	2 days	Thu 1/10/08	Fri 1/11/08
9	Pour Area 2	1 day	Mon 1/14/08	Mon 1/14/08
10	Cure Area 2	3 days	Tue 1/15/08	Thu 1/17/08
11	Strip Area 2	1 day	Fri 1/18/08	Fri 1/18/08
12	Form Area 3	3 days	Tue 1/15/08	Thu 1/17/08
13	Reinforce Area 3	2 days	Fri 1/18/08	Mon 1/21/08
14	Pour Area 3	1 day	Tue 1/22/08	Tue 1/22/08
15	Cure Area 3	3 days	Wed 1/23/08	Fri 1/25/08
16	Strip Area 3	1 day	Mon 1/28/08	Mon 1/28/08
17	Form Area 4	3 days	Mon 1/21/08	Wed 1/23/08
18	Reinforce Area 4	2 days	Thu 1/24/08	Fri 1/25/08
19	Pour Area 4	1 day	Mon 1/28/08	Mon 1/28/08
20	Cure Area 4	3 days	Tue 1/29/08	Thu 1/31/08
21	Strip Area 4	1 day	Fri 2/1/08	Fri 2/1/08
22	Form Area 5	3 days	Tue 1/29/08	Thu 1/31/08
23	Reinforce Area 5	2 days	Fri 2/1/08	Mon 2/4/08
24	Pour Area 5	1 day	Tue 2/5/08	Tue 2/5/08
25	Cure Area 5	3 days	Wed 2/6/08	Fri 2/8/08
26	Strip Area 5	1 day	Mon 2/11/08	Mon 2/11/08
27	Form Area 6	3 days	Mon 2/4/08	Wed 2/6/08
28	Reinforce Area 6	2 days	Thu 2/7/08	Fri 2/8/08
29	Pour Area 6	1 day	Mon 2/11/08	Mon 2/11/08
30	Cure Area 6	3 days	Tue 2/12/08	Thu 2/14/08
31	Strip Area 6	1 day	Fri 2/15/08	Fri 2/15/08



If the revised schedule was utilized, the elevated slab would take 33 days to complete, rather than 18. Also, this schedule would allow for no more than two areas to before formed at any one time, which reduce the overall amount of forming material required. In addition, by following this schedule, the concrete contractor would need to purchase an early strip concrete mix that would allow the slab to be stripped after just three days of curing. The early strip mix typically costs \$6 - \$7 more per cubic yard of concrete. With approximately 50 CY of concrete in the elevated slab, the early strip mix would cost an additional \$300 - \$350 in all.

To further understand the elevated slab sequencing, the formwork for an elevated slab area was designed. For a project like the Aloft and Element parking structure, the type of formwork used for the elevated slab would most likely be a system that used plywood decking, wood or aluminum joists and stringers, and some sort of metal floor prop. Figure VI-5 provides a visual image of the type of system that would most likely be used.

Figure VI-5. Typical Formwork System

Image courtesy of Doka.com

H. Structural Breadth – Formwork Design

Designing a formwork system and layout is no easy task. Formwork designs are often required to be stamped by a professional engineer and require a thought process of a structural engineer. In retrospect, concrete forming and shoring is a mini-structural that is designed to temporarily support the permanent structure and additional construction loads.

The process of designing formwork for the elevated slab of parking structure followed a structural engineer's thought process. Each component of the design was selected using the design tables and data found in Appendix B.

Before any formwork system components were selected, it was necessary to determine the type of loads that the system would need to support. The majority of the elevated slab is to be 10" thick while the slab edge and column capitals are to be 16" thick. The calculations to determine the loading of the formwork system are shown below.

<u>10" Slab</u>

Dead Load of 10" Slab = 150 $pcf \times \left(\frac{10"}{12"/_{ft}}\right)$ = 125 *psf*

Construction Live Load = 50 *psf*

Estimated Formwork Dead Load = 5 *psf*

180 *psf*

16” Slab (Column Capitals & Slab Edge)

Dead Load of 16” Slab = $150\ pcf \times \left(\frac{16"}{12"/_{ft}}\right)$	= 200 psf
Construction Live Load	= 50 psf
Estimated Formwork Dead Load	= 5 psf
	255 psf

The first component of the system selected was the plywood decking. A plywood type was selecting that contained the properties specified in Table 7-2 of Appendix B. The plywood grade that was selected is shown below in Table VI-1.

Table VI-1. Plywood Grade

INTERIOR OR PROTECTED APPLICATIONS

Plywood Grade	Description and Use	Typical Trademarks	Veneer Grade			Common Thicknesses	Grade Stress Level (Table 3)	Species Group	Section Property Table
			Face	Back	Inner				
APA B-B PLYFORM CLASS I or II(2)	Concrete-form grade with high reuse factor. Sanded both sides, mill-oiled unless otherwise specified. Available in HDO. For refined design information on this special-use panel see *APA Design/Construction Guide: Concrete Forming*, Form No. V345. Design using values from this specification will result in a conservative design.(5)	APA THE ENGINEERED WOOD ASSOCIATION PLYFORM B-B CLASS 1 EXTERIOR 000 PS 1-95	B	B	C	19/32, 5/8, 23/32, 3/4	S-2	Class I use Group 1; Class II use Group 3	Table 1 (sanded)

Courtesy of the Engineered Wood Association

The species of plywood could be any of the plywood species in Group 1. See Table VI-2 below.

Table VI-2. Plywood Species

CLASSIFICATION OF SPECIES

Group 1	Group 2		Group 3	Group 4	Group 5(a)
Apitong(b)(c)	**Cedar, Port Orford**	**Maple, Black**	**Alder, Red**	**Aspen**	**Basswood**
Beech, American	**Cypress**	**Mengkulang**(b)	**Birch, Paper**	Bigtooth	**Poplar, Balsam**
Birch	**Douglas-Fir 2**(d)	**Meranti, Red**(b)(e)	**Cedar, Alaska**	Quaking	
Sweet	**Fir**	**Mersawa**(b)	**Fir, Subalpine**	**Cativo**	
Yellow	Balsam	**Pine**	**Hemlock, Eastern**	**Cedar**	
Douglas-Fir 1(d)	California Red	Pond	**Maple, Bigleaf**	Incense	
Kapur(b)	Grand	Red	**Pine**	Western Red	
Keruing(b)(c)	Noble	Virginia	Jack	**Cottonwood**	
Larch, Western	Pacific Silver	Western White	Lodgepole	Eastern	
Maple, Sugar	White	**Spruce**	Ponderosa	Black (Western Poplar)	
Pine	**Hemlock, Western**	Black	Spruce	**Pine**	
Caribbean	**Lauan**	Red	**Redwood**	Eastern White	
Ocote	Almon	Sitka	**Spruce**	Sugar	
Pine, Southern	Bagtikan	**Sweetgum**	Engelmann		
Loblolly	Mayapis	**Tamarack**	White		
Longleaf	Red Lauan	**Yellow-poplar**			
Shortleaf	Tangile				
Slash	White Lauan				
Tanoak					

(a) Design stresses for Group 5 not assigned.
(b) Each of these names represents a trade group of woods consisting of a number of closely related species.
(c) Species from the genus Dipterocarpus are marketed collectively: Apitong if originating in the Philippines; Keruing if originating in Malaysia or Indonesia.
(d) Douglas-fir from trees grown in the states of Washington, Oregon, California, Idaho, Montana, Wyoming, and the Canadian Provinces of Alberta and British Columbia shall be classed as Douglas-fir No. 1. Douglas-fir from trees grown in the states of Nevada, Utah, Colorado, Arizona and New Mexico shall be classed as Douglas-fir No. 2.
(e) Red Meranti shall be limited to species having a specific gravity of 0.41 or more based on green volume and oven dry weight.

Courtesy of the Engineered Wood Association

The plywood thickness chosen was ¾” because it less expensive and more common than 1” plywood and will reduce the number of joists required compared to the also common 5/8” thickness. To determine an appropriate joist spacing, Table 7-2 of Appendix B was revisited. For the 16” slab thickness, a 255 PSF load yields a joist spacing of approximately 18” (by interpolation). A 10” slab thickness yields a maximum joist spacing of 19.6”; however, an 18” joist spacing will be used to maintain consistency. To determine the maximum span of an aluminum joist, the manufacturer was first selected. In this case a 6 ½” aluminum joist manufactured by WACO® was chosen. The maximum span of an aluminum joist, and an aluminum joist used as a stinger, was determined through a few calculations. Please refer to Table B-1 in Appendix B to view the design data of the WACO® aluminum joists.

Maximum Joist Span

16" Slab (Column Capitals & Slab Edge)

$$Tributary\ width = 18\ in. = 1.5\ ft.$$
$$1.5' \times 255\ psf = 382.5\ {}^{lbs}/_{ft}\ on\ joist$$

Joists can span 8.5 ft.

10" Slab

$$Tributary\ width = 18\ in. = 1.5\ ft.$$
$$1.5' \times 180\ psf = 270\ {}^{lbs}/_{ft}\ on\ joist$$

Joists can span 9.5 ft.

Maximum Stringer Span

16" Slab (Column Capitals & Slab Edge)

$$P_{max} = (Tributary\ Length) \times (PLF\ of\ Joist)$$

$$P_{max} = 6ft\ \times 382.5\ plf\ = 2295\ lbs$$

Note: Maximum Joist length of 16" slab will be 12'; therefore the maximum tributary length is 6 ft. This results in a more conservative design.

$$w = \frac{2295\ lbs}{1.5\ ft/_{Joist}} = 1530\ plf$$

Stringers can span 5 ft.

10" Slab

$$P_{max} = (Tributary\ Length) \times (PLF\ of\ Joist)$$

$$P_{max} = 4.75\ ft\ \times 270\ plf\ = 1282.5\ lbs$$

$$w = \frac{1282.5}{1.5\ ft/_{Joist}} = 855\ plf$$

Stringers can span 6.5 ft.

Selection of Floor Props

Doka® floor props were selected by for this formwork design for no other reason than these props being widely used and recommended by many. The selection of the specific type of Doka® floor prop was based upon the calculations shown below and the data tables found in Tables B-2 and B-3 of Appendix B.

16" Slab (Column Capitals & Slab Edge)

$$Max\ Load\ on\ prop = 5ft\ spacing \times 1530\ plf = 7650\ lbs = 7.65\ kips$$

Must Use Eurex 30 props.

10" Slab

$$Max\ Load\ on\ prop = 6.5\ ft\ spacing \times 855\ plf = 5557.5\ lbs = 5.56\ kips$$

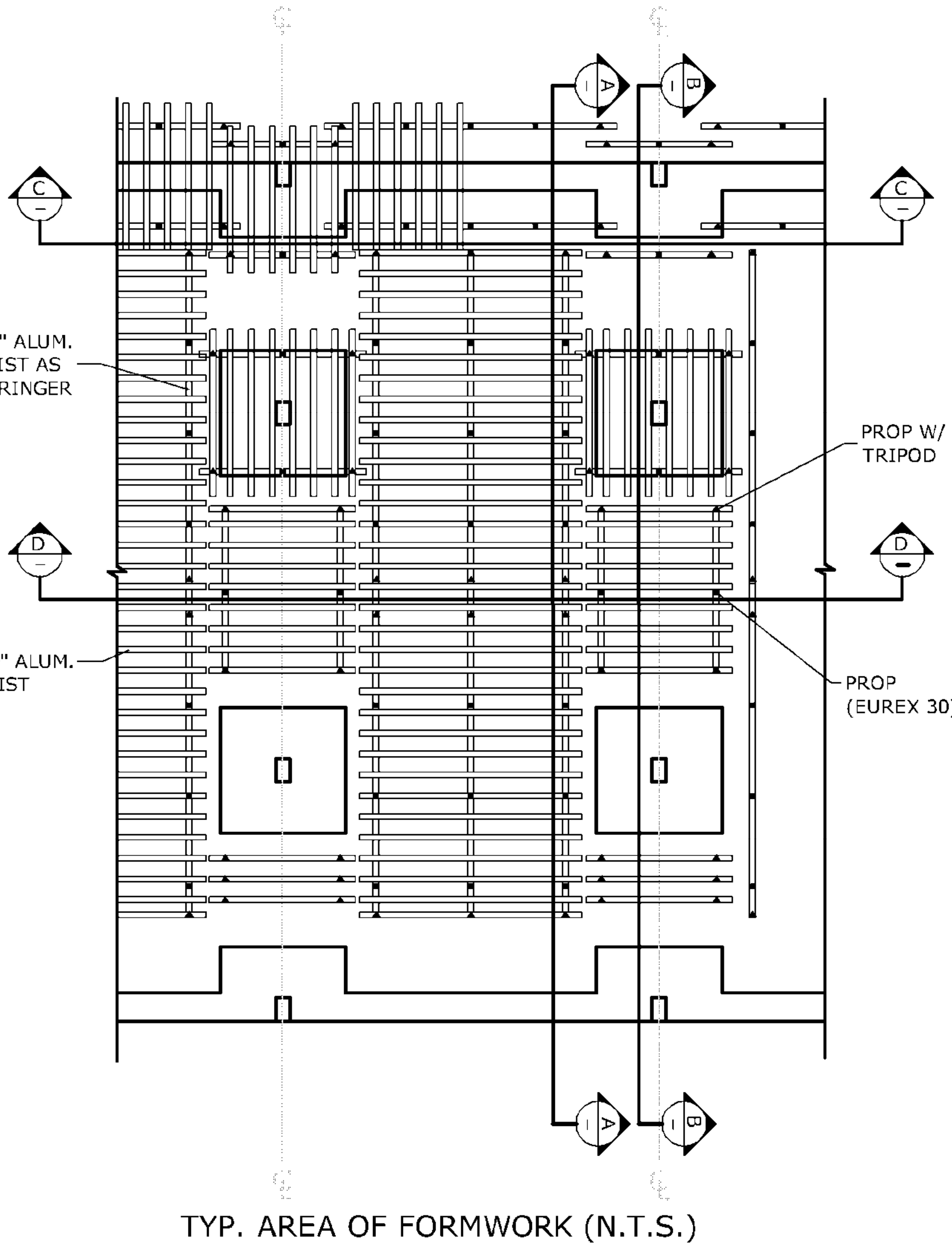
Can use Eurex 20 props, but use Eurex 30 props for consistency.

Once all of the components for design of the elevated slab formwork were selected, the formwork layout was designed for a typical area. This design can be viewed below in the following table and figures.

Table VI-3. Formwork component spacing.

SLAB DEPTH DL+ LL	"Z" JOIST SPACING (INCHES)	"X" (FT.) MAX	"Y" (FT.) MAX
10" (180 PSF)	18"	9.5'	6.5'
16" (255 PSF)	18"	8.5'	5'

Figure VI-6. Plan view of formwork layout.



Note: Tripods must be placed on props that are located at the end of a beam or joist.

Figure VI-7. Sections A and B of formwork design

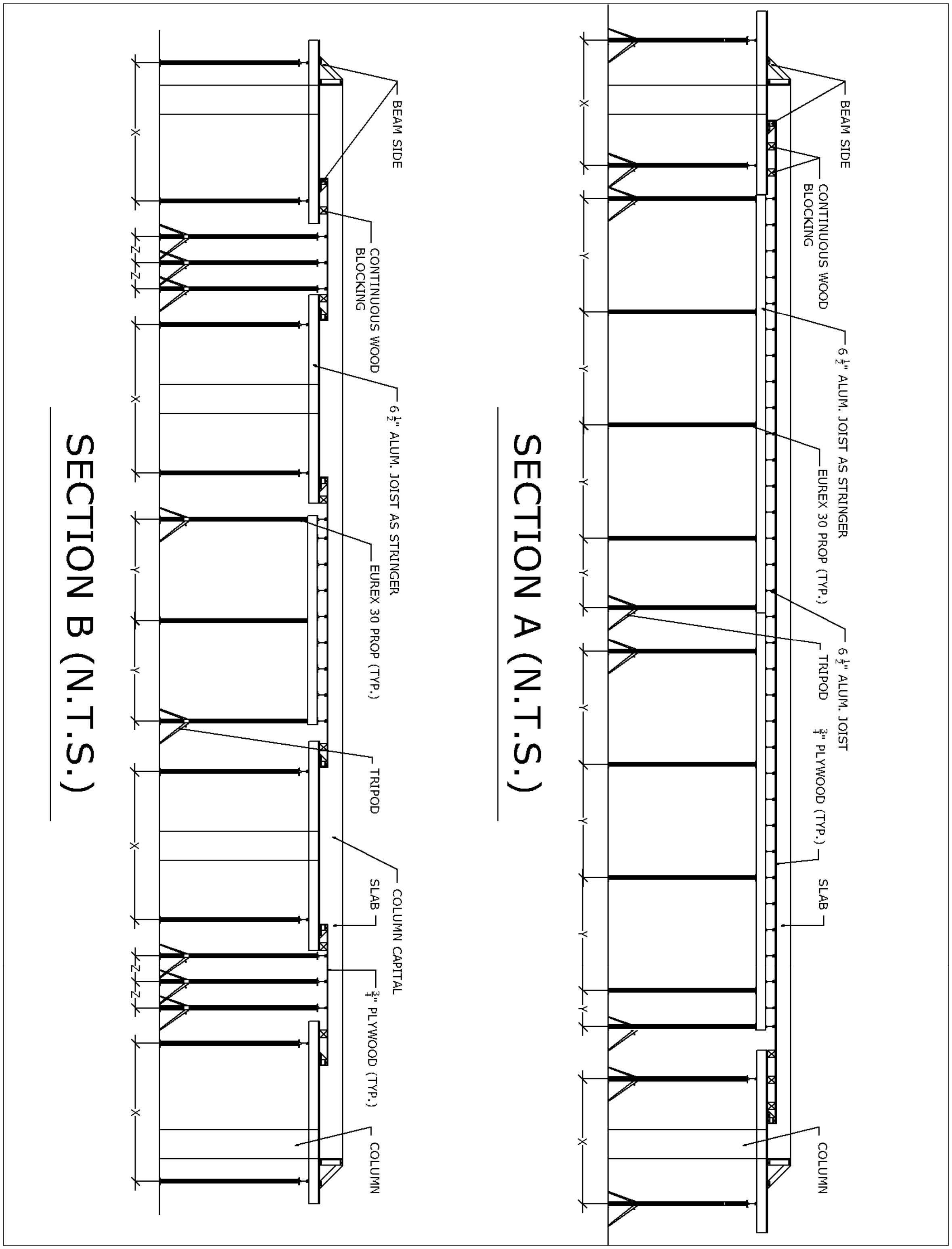
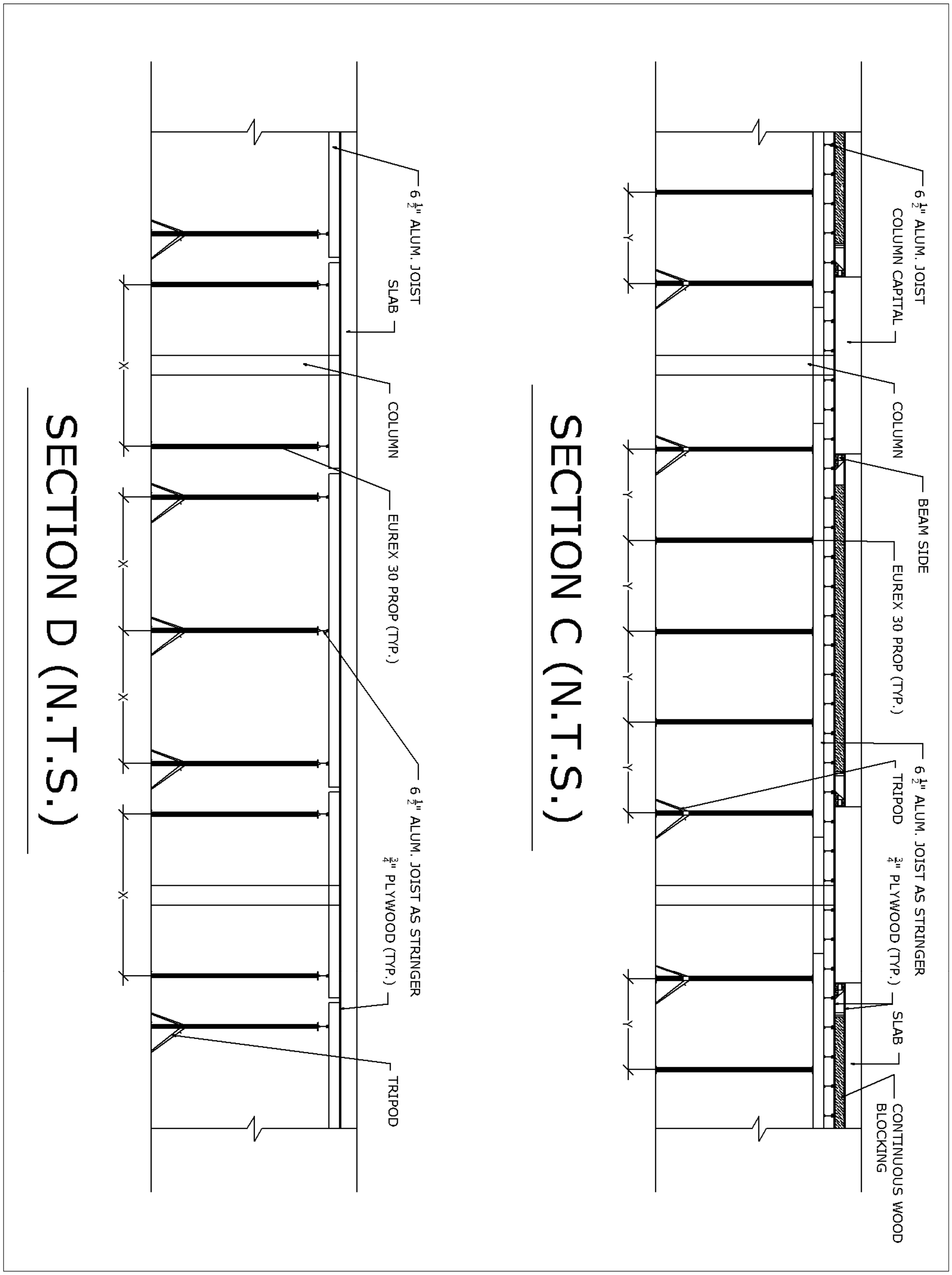


Figure VI-8. Sections C and D of formwork design



I. Problems with the Developed Formwork Design and Sequencing

The intention of the formwork design and sequencing was to reduce the material costs of the formwork; however, after speaking with Ray Sowers of Oncore Construction, LLC. and John Messner of The Pennsylvania State University, several flaws became evident. The original schedule of the parking structure is very feasible and may be more ideal for several reasons.

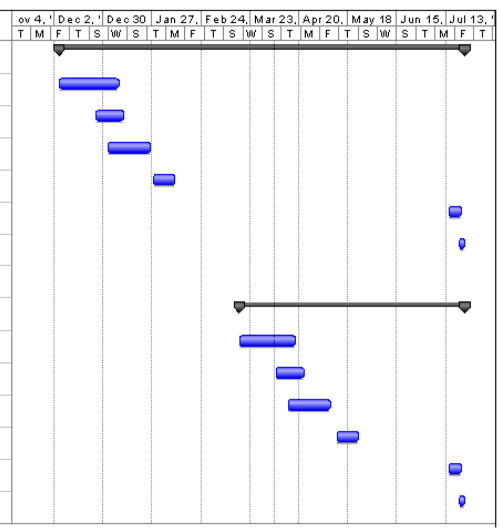
Minimizing the amount of material needed for the formwork may not reduce the cost. Many concrete contractors have enough manpower and own enough formwork to construct the entire elevated slab at once, with no extra costs. Also, the new sequencing plan for the elevated slab does not have a continuous flow of work for the workers. The carpenters, rebar workers, and concrete workers would finish an area quickly then be at a standstill until the next area was ready to be started. Forming and pouring the slab all at once would result a better flow of work. For a concrete contractor, it is more profitable to finish the work quickly rather than have workers and materials being held up for extended periods of time.

J. Cold Weather Concrete Construction

While the formwork design and sequencing that was previously developed would most likely not result in cost savings, there is may be another way to utilize the float time of the parking structure schedule to reduce construction costs. Under the original schedule of the parking structure, the concrete was set to begin on December 5, 2007 and finish on February 8, 2007. This would mean that the concrete would be placed during some of the coldest months of the year. Moving the start date of the parking structure up a few months to Mid-March could eliminate winter protection costs. Beginning the concrete no later than mid-March would also ideally eliminate any need for a retarding admixture. The following figure shows the revised parking structure schedule compared to the original schedule.

Figure VI-9. Original Parking Structure Schedule vs. Revised Schedule

ID		Task Name	Duration	Start	Finish	Predecessors
1		PARKING STRUCTURE	166 days	Wed 12/5/07	Wed 7/23/08	
2		CONCRETE FOUNDATIONS	24 days	Wed 12/5/07	Mon 1/7/08	
3		CONCRETE COLUMNS	12 days	Wed 12/26/07	Thu 1/10/08	
4		ELEVATED CONCRETE DECK	18 days	Wed 1/2/08	Fri 1/25/08	
5		STAIRS	10 days	Mon 1/28/08	Fri 2/8/08	
6		LIGHTING	5 days	Tue 7/15/08	Mon 7/21/08	
7		STRIPING & SIGNAGE	3 days	Mon 7/21/08	Wed 7/23/08	
8						
9		PARKING STRUCTURE (REVISED)	93 days	Mon 3/17/08	Wed 7/23/08	
10		CONCRETE FOUNDATIONS	24 days	Mon 3/17/08	Thu 4/17/08	
11		CONCRETE COLUMNS	12 days	Mon 4/7/08	Tue 4/22/08	
12		ELEVATED CONCRETE DECK	18 days	Mon 4/14/08	Wed 5/7/08	
13		STAIRS	10 days	Mon 5/12/08	Fri 5/23/08	
14		LIGHTING	5 days	Tue 7/15/08	Mon 7/21/08	
15		STRIPING & SIGNAGE	3 days	Mon 7/21/08	Wed 7/23/08	



By implementing the revised schedule winter protection costs from insulated formwork, temporary heat and temporary shelters, and heat blankets would be eliminated. Any costs from accelerating admixtures, such as calcium chloride would also be eliminated. Table VI-4 shows the winter protection costs that would be saved, and Table VI-5 shows the added cost of accelerator (calcium chloride).

Table VI-4. Winter Protection Costs.

ITEM	QUANTITY	2" POLYSTYRENE INSULATION FOR FORMS	TEMPORARY HEAT	TEMPORARY SHELTER	HEAT BLANKETS	SUBTOTAL
FOOTINGS	2,349 SF	$1.38 /SF			$0.39 /SF	$916.11
COLUMNS	2,725 SF	$1.38 /SF			$0.39 /SF	$1,062.75
WALLS	8,576 SF	$1.38 /SF			$0.39 /SF	$3,344.64
SOG	16,780 SF				$0.39 /SF	$6,544.20
ELEVATED SLAB	16,780 SF		$0.32 /SF	$0.68 /SF	$0.39 /SF	$23,324.20
					TOTAL	$35,191.90

Table VI-5. Accelerator Admixture Costs.

ITEM	QUANTITY OF CONCRETE	2% CALCIUM CHLORIDE	COST OF CALCIUM CHLORIDE	SUBTOTAL
FOOTINGS	1.3 CY = 5,294 LBS	106 LBS = 0.05 TONS	$460 /TON	$24.35
WALLS	63.0 CY = 255,150 LBS	5,103 LBS = 2.55 TONS	$460 /TON	$1,173.69
COLUMNS	20.3 CY = 82,127 LBS	1,643 LBS = 0.82 TONS	$460 /TON	$377.79
SOG	25.0 CY = 101,250 LBS	2,025 LBS = 1.01 TONS	$460 /TON	$465.75
ELEVATED SLAB	50.0 CY = 202,500 LBS	4,050 LBS = 2.03 TONS	$460 /TON	$931.50
			TOTAL	$2,973.08

The total cost that could be potentially eliminated by beginning the construction of the parking structure in mid-March totals approximately $38,200. This savings would be transferred to the owner only if several other criteria could be met. Those criteria are:

- Formwork is in possession of concrete contractor at time of bid
- Rebar can be purchased at time of bid
- Concrete costs are locked in at the time of bid

If the above criteria go unmet, accelerating material costs will most likely be accounted for in the bid, which could negate any potential savings from eliminating winter protection and eliminating an accelerating admixture.

VI. Summary & Conclusions

The research topic that was examined developed a method that may be able to measure the effectiveness of 3D MEP coordination and virtual clash detection. The "Comparison of Construction Metrics" method compares hard statistics of both a BIM and a non-BIM project. While the outcome of the case study did not yield exactly ideal results, it did produce some valuable lessons. Because no two projects are exactly the same, it is important to use the developed method on two projects that are as similar as possible. The "Comparison of Construction Metrics Method" should draw comparisons between two projects that have been completed by the same construction manager / general contractor, under the supervision of the same project manager, completed by the same owner, and if possible, designed by the same design firm.

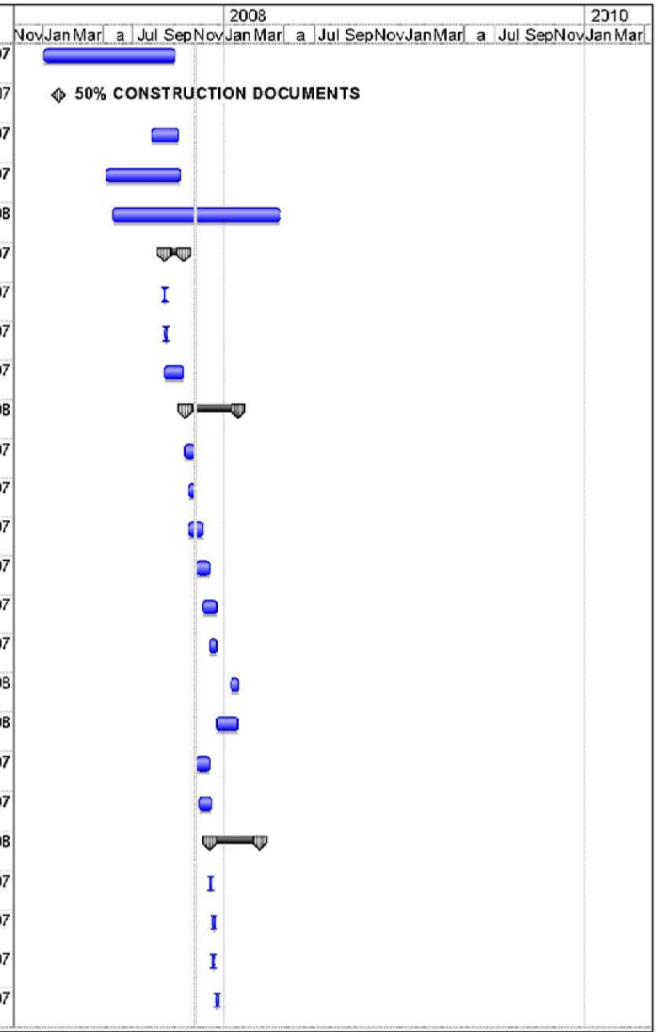
The first technical analysis examined the implications of using PTAC units for the HVAC system of the guestrooms rather than the originally specified DX system. After a PTAC unit was selected and designed based on input from industry professionals, implications to construction issues could then be examined. Because of their relative inexpensiveness and ease of installation, the potential construction costs savings are significant, totaling nearly $1.7 million. The schedule of the project would also be significantly impacted, because the individual activity durations for HVAC construction would be significantly reduced. Other implications such as a smaller plenum space, fewer roofing penetrations, and the elimination of rooftop walkways could be the direct result of a PTAC redesign.

The second and final technical analysis examined potential ways to cut costs of the parking structure. By utilizing the parking lots of a nearby baseball park, the parking structure could be eliminated from the critical path of the project schedule. As a result float time could be utilized to reduce the costs of the concrete structure. First instinct caused investigation into the formwork design and sequencing. While the formwork design may be acceptable for a typical bay or area, the sequencing plan that was developed for the construction of the elevated slab was flawed. With an alternative elevated sequencing plan being obsolete when it comes to cost cutting, other ways to utilize float time to reduce strain on the project's budget were evaluated. By moving the start of the parking structure from early December 2007 to mid-March 2008, additional costs associated with cold weather concrete could be eliminated. These costs totaled approximately $38,200.

Appendix A.

Detailed Project Schedule

ID		Task Name	Duration	Start	Finish
1		**DESIGN**	**190 days**	**Tue 1/2/07**	**Mon 9/24/07**
2		**50% CONSTRUCTION DOCUMENTS**	0 days	Thu 2/1/07	Thu 2/1/07
3		**PERMITS**	**38 days**	**Thu 8/9/07**	**Mon 10/1/07**
4		**BID/ AWARD**	**109 days**	**Tue 5/8/07**	**Fri 10/5/07**
5		**PROCUREMENT**	**242 days**	**Mon 5/21/07**	**Tue 4/22/08**
6		**SITE PHASE 1**	**29 days**	**Mon 9/3/07**	**Thu 10/11/07**
7		INSTALL CONSTRUCTION ENTRANCES	1 day	Mon 9/3/07	Mon 9/3/07
8		PREPARE PARKING / STAGING AREAS	4 days	Tue 9/4/07	Fri 9/7/07
9		CLEAR / DEMO SITE	29 days	Mon 9/3/07	Thu 10/11/07
10		**SITE PHASE 2**	**78 days**	**Mon 10/15/07**	**Wed 1/30/08**
11		ROUGH GRADE	15 days	Mon 10/15/07	Fri 11/2/07
12		SANITARY LINES	10 days	Mon 10/22/07	Fri 11/2/07
13		RETAINING WALLS	21 days	Mon 10/22/07	Mon 11/19/07
14		STORMWATER PIPING	20 days	Tue 11/6/07	Mon 12/3/07
15		WATER LINES	20 days	Tue 11/20/07	Mon 12/17/07
16		GAS SERVICE	10 days	Tue 12/4/07	Mon 12/17/07
17		FINE GRADE SITE & BASE COURSE PAVING	11 days	Wed 1/16/08	Wed 1/30/08
18		**SITE ELECTRIC**	**31 days**	**Tue 12/18/07**	**Tue 1/29/08**
19		**ALOFT FOUNDATIONS**	**20 days**	**Tue 11/6/07**	**Mon 12/3/07**
20		**ELEMENT FOUNDATIONS**	**20 days**	**Mon 11/12/07**	**Fri 12/7/07**
21		**ALOFT SUPERSTRUCTURE**	**73 days**	**Tue 12/4/07**	**Thu 3/13/08**
22		ERECT 1ST FLR COLS	4 days	Tue 12/4/07	Fri 12/7/07
23		ERECT WALLS 1ST FLR	5 days	Mon 12/10/07	Fri 12/14/07
24		ERECT/GROUT 2ND FLR PLANK	3 days	Mon 12/10/07	Wed 12/12/07
25		2ND FLR 2" CONC. TOPPING	4 days	Mon 12/17/07	Thu 12/20/07



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ID	Task Name	Duration	Start	Finish
26	ERECT 2ND FLR COLS 3RD FLR BMS	3 days	Wed 12/26/07	Fri 12/28/07
27	ERECT WALLS 2ND FLR	5 days	Wed 1/2/08	Tue 1/8/08
28	ERECT/GROUT 3RD FLR PLANK	4 days	Thu 1/3/08	Tue 1/8/08
29	ERECT 3RD FLR WALLS	4 days	Mon 1/7/08	Thu 1/10/08
30	ERECT/GROUT 4TH FLR PLANK	5 days	Wed 1/16/08	Tue 1/22/08
31	ERECT 4TH FLR WALLS	4 days	Wed 1/23/08	Mon 1/28/08
32	ERECT/GROUT 5TH FLR PLANK	5 days	Tue 1/29/08	Mon 2/4/08
33	ERECT 5TH FLR WALLS	4 days	Tue 2/5/08	Fri 2/8/08
34	ERECT/GROUT 6TH FLR PLANK	5 days	Mon 2/11/08	Fri 2/15/08
35	ERECT 6TH FLR WALLS	4 days	Mon 2/18/08	Thu 2/21/08
36	ERECT/GROUT 7TH FLR PLANK	6 days	Thu 2/21/08	Thu 2/28/08
37	ERECT 7TH FLR WALLS	4 days	Mon 3/3/08	Thu 3/6/08
38	ERECT/GROUT ROOF PLANK	5 days	Fri 3/7/08	Thu 3/13/08
39	ERECT STL FRAMING FOR ROOF SWOOF	3 days	Tue 3/11/08	Thu 3/13/08
40	**ELEMENT SUPERSTRUCTURE**	**66 days**	**Mon 12/17/07**	**Mon 3/17/08**
41	ERECT 1ST FLR COLS	5 days	Mon 12/17/07	Fri 12/21/07
42	ERECT WALLS 1ST FLR	2 days	Mon 12/17/07	Tue 12/18/07
43	ERECT/GROUT 2ND FLR PLANK	4 days	Wed 12/19/07	Mon 12/24/07
44	2ND FLR 2" CONC. TOPPING	4 days	Wed 12/26/07	Mon 12/31/07
45	ERECT 2ND FLR COLS 3RD FLR BMS	5 days	Mon 1/7/08	Fri 1/11/08
46	ERECT WALLS 2ND FLR	5 days	Mon 1/7/08	Fri 1/11/08
47	ERECT/GROUT 3RD FLR PLANK	4 days	Mon 1/14/08	Thu 1/17/08
48	ERECT 3RD FLR WALLS	4 days	Wed 1/16/08	Mon 1/21/08
49	ERECT/GROUT 4TH FLR PLANK	5 days	Wed 1/23/08	Tue 1/29/08
50	ERECT 4TH FLR WALLS	4 days	Tue 1/29/08	Fri 2/1/08

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ID	Task Name	Duration	Start	Finish
51	ERECT/GROUT 5TH FLR PLANK	5 days	Tue 2/5/08	Mon 2/11/08
52	ERECT 5TH FLR WALLS	4 days	Mon 2/11/08	Thu 2/14/08
53	ERECT/GROUT 6TH FLR PLANK	5 days	Mon 2/18/08	Fri 2/22/08
54	ERECT 6TH FLR WALLS	5 days	Thu 2/21/08	Wed 2/27/08
55	ERECT/GROUT 7TH FLR PLANK	5 days	Thu 2/28/08	Wed 3/5/08
56	ERECT 7TH FLR WALLS	4 days	Tue 3/4/08	Fri 3/7/08
57	ERECT/GROUT ROOF PLANK	5 days	Tue 3/11/08	Mon 3/17/08
58	**PARKING STRUCTURE**	**166 days**	**Wed 12/5/07**	**Wed 7/23/08**
59	CONCRETE FOUNDATIONS	24 days	Wed 12/5/07	Mon 1/7/08
60	CONCRETE COLUMNS	12 days	Wed 12/26/07	Thu 1/10/08
61	ELEVATED CONCRETE DECK	18 days	Wed 1/2/08	Fri 1/25/08
62	STAIRS	10 days	Mon 1/28/08	Fri 2/8/08
63	LIGHTING	5 days	Tue 7/15/08	Mon 7/21/08
64	STRIPING & SIGNAGE	3 days	Mon 7/21/08	Wed 7/23/08
65	**ALOFT STAIRS 1F-ROOF**	**61 days**	**Mon 1/7/08**	**Mon 3/31/08**
66	**ELEMENT STAIRS 1F-ROOF**	**56 days**	**Wed 1/16/08**	**Wed 4/2/08**
67	**ALOFT SOG (FRP)**	14 days	Fri 12/21/07	Wed 1/9/08
68	**ELEMENT SOG (FRP)**	22 days	Fri 12/21/07	Mon 1/21/08
69	**ALOFT ENCLOSURE**	**68 days**	**Mon 1/7/08**	**Wed 4/9/08**
70	PERIMETER STUDS	58 days	Mon 1/7/08	Wed 3/26/08
71	SHEATHING / MEMBRANE	58 days	Mon 1/14/08	Wed 4/2/08
72	STOREFRONTS & WINDOWS	43 days	Mon 2/11/08	Wed 4/9/08
73	**ELEMENT ENCLOSURE**	**60 days**	**Wed 1/16/08**	**Tue 4/8/08**
74	PERIMITER STUDS	49 days	Wed 1/16/08	Mon 3/24/08
75	SHEATHING / MEMBRANE	48 days	Mon 1/28/08	Wed 4/2/08

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ID		Task Name	Duration	Start	Finish
76		STOREFRONTS & WINDOWS	40 days	Wed 2/13/08	Tue 4/8/08
77		**ALOFT ROOFING**	**101 days**	**Tue 3/11/08**	**Tue 7/29/08**
78		ROOF DRAINS	5 days	Tue 3/11/08	Mon 3/17/08
79		BLOCKING & CURBS	5 days	Mon 3/17/08	Fri 3/21/08
80		ROOFING	10 days	Mon 3/24/08	Fri 4/4/08
81		SET ROOF TOP EQUIP & HOOK UP	68 days	Mon 4/7/08	Wed 7/9/08
82		FLASHING COPING	11 days	Tue 7/15/08	Tue 7/29/08
83		**ELEMENT ROOFING**	**97 days**	**Mon 3/17/08**	**Tue 7/29/08**
84		ROOF DRAINS	5 days	Mon 3/17/08	Fri 3/21/08
85		BLOCKING & CURBS	5 days	Mon 3/17/08	Fri 3/21/08
86		ROOFING	10 days	Fri 3/21/08	Thu 4/3/08
87		SET ROOF TOP EQUIP & HOOK UP	66 days	Mon 4/7/08	Mon 7/7/08
88		FLASHING COPING	11 days	Tue 7/15/08	Tue 7/29/08
89		**ALOFT PORT COCHERE**	**108 days**	**Tue 3/11/08**	**Thu 8/7/08**
90		ERECT STL & MTL DECKING	8 days	Tue 3/11/08	Thu 3/20/08
91		ROOFING	5 days	Tue 7/15/08	Mon 7/21/08
92		ELECTRICAL	14 days	Mon 7/21/08	Thu 8/7/08
93		**ALOFT POOL ROOM**	**75 days**	**Tue 5/13/08**	**Mon 8/25/08**
94		CONSTRUCT POOL SHELL	5 days	Tue 5/13/08	Mon 5/19/08
95		UNDERGROUND PIPING	3 days	Tue 5/20/08	Thu 5/22/08
96		FOUNDATIONS	5 days	Mon 5/26/08	Fri 5/30/08
97		STRUCTURAL STEEL	2 days	Tue 6/3/08	Wed 6/4/08
98		ROOF DECK	4 days	Mon 6/9/08	Thu 6/12/08
99		EIFS	5 days	Mon 6/23/08	Fri 6/27/08
100		MTL PANELS	3 days	Mon 6/30/08	Wed 7/2/08

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ID	Task Name	Duration	Start	Finish
101	STOREFRONT AND ENTRANCES	4 days	Mon 7/7/08	Thu 7/10/08
102	HVAC ROUGH-IN	5 days	Wed 7/9/08	Tue 7/15/08
103	ELECTRICAL ROUG-IN	5 days	Wed 7/9/08	Tue 7/15/08
104	PLUMBING ROUGH-IN	5 days	Wed 7/9/08	Tue 7/15/08
105	HANG FINISH & PAINT DRYWALL	5 days	Wed 7/16/08	Tue 7/22/08
106	FINISHES & EQUIP	20 days	Tue 7/29/08	Mon 8/25/08
107	FLOOR FINISHES	11 days	Tue 7/29/08	Tue 8/12/08
108	**ALOFT FLOORS 1-7 ROUGH-IN & FINISH**	**188 days**	**Mon 1/7/08**	**Wed 9/24/08**
109	LAYOUT & TRACK	52 days	Mon 1/7/08	Tue 3/18/08
110	SPRAY ON FIREPROOFING	3 days	Tue 1/29/08	Thu 1/31/08
111	ELECTRICAL POWER MAINS/DISTRIBUTION	5 days	Mon 2/4/08	Fri 2/8/08
112	ELECTRICAL RISERS	54 days	Tue 1/8/08	Fri 3/21/08
113	HVAC DUCT & PIPE MAINS	5 days	Mon 2/4/08	Fri 2/8/08
114	HVAC DUCT & PIPE RISERS	54 days	Tue 1/8/08	Fri 3/21/08
115	HM FRAMES/STUD FRAME WALLS	52 days	Mon 1/14/08	Tue 3/25/08
116	SPRINKLER MAINS AND BRANCHES	57 days	Tue 1/8/08	Wed 3/26/08
117	PRE-ROCK DENSARMOUR	43 days	Mon 2/4/08	Wed 4/2/08
118	FIREPLACE	3 days	Mon 2/11/08	Wed 2/13/08
119	ELECTRICAL BRANCH/LV ROUGH	54 days	Tue 1/15/08	Fri 3/28/08
120	HVAC DUCT/PIPE BRANCHES	5 days	Mon 2/11/08	Fri 2/15/08
121	FIT-OUT ELEC. SERVICE RMS	22 days	Thu 2/14/08	Fri 3/14/08
122	PLUMBING RISERS/SHOWER BASES	22 days	Thu 2/7/08	Fri 3/7/08
123	PLUMBING ROUGH/TEST & INSULATE	45 days	Thu 2/14/08	Wed 4/16/08
124	PERMANENT POWER AVAILABLE	0 days	Fri 3/14/08	Fri 3/14/08
125	WALL GYPBOARD	38 days	Mon 4/7/08	Wed 5/28/08

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PERMANENT POWER AVAILABLE

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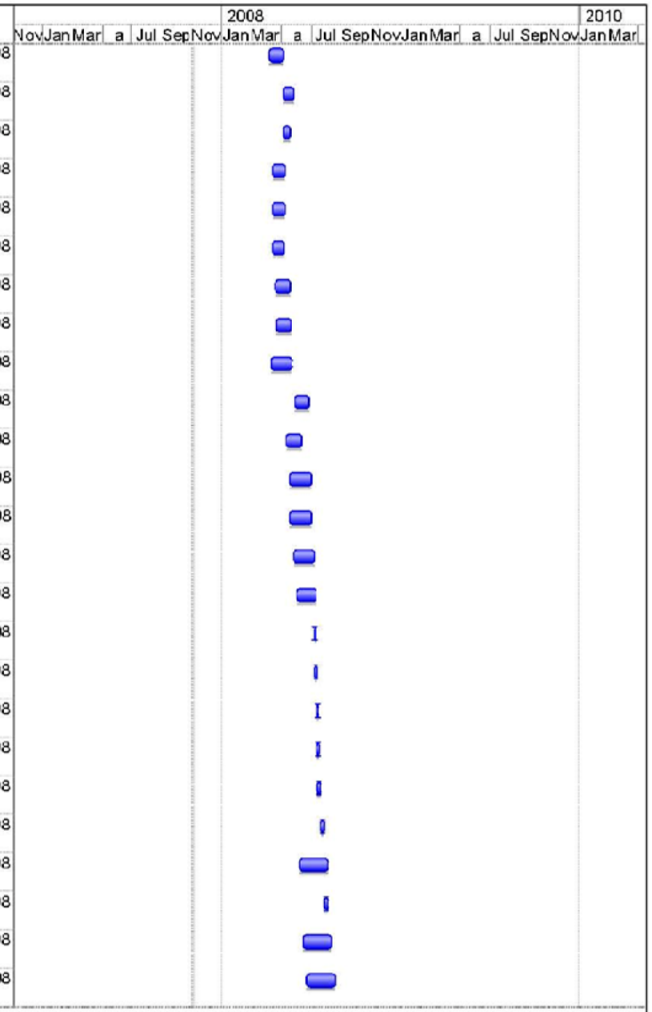
ID		Task Name	Duration	Start	Finish
126		FRAME HARD CEILINGS	21 days	Mon 4/7/08	Mon 5/5/08
127		FIT OUT WATER HTR RM	15 days	Tue 5/6/08	Mon 5/26/08
128		FIT-OUT FIRE PUMP RM	10 days	Tue 5/6/08	Mon 5/19/08
129		OVERHEAD LV/ELEC ROUGH	20 days	Mon 4/14/08	Fri 5/9/08
130		OVERHEAD HVAC ROUGH-IN CLGS	20 days	Mon 4/14/08	Fri 5/9/08
131		SPRINKLER HEADS	18 days	Mon 4/14/08	Wed 5/7/08
132		CEILING GYPBOARD	21 days	Mon 4/21/08	Mon 5/19/08
133		GYPCRETE FLOOR LEVELING	22 days	Tue 4/22/08	Wed 5/21/08
134		INSULATION	30 days	Fri 4/11/08	Thu 5/22/08
135		FIT-OUT IT/DATA ROOM EQUIP	20 days	Fri 5/30/08	Thu 6/26/08
136		TAPE & SPACKLE	24 days	Mon 5/12/08	Thu 6/12/08
137		TILE	32 days	Mon 5/19/08	Tue 7/1/08
138		PRIME PAINT WALLS	32 days	Mon 5/19/08	Tue 7/1/08
139		BATHROOM VANITIES & TOPS	30 days	Tue 5/27/08	Mon 7/7/08
140		BATHROOM PLBG FIXTURES & TRIM	29 days	Tue 6/3/08	Fri 7/11/08
141		CEILING GRID	3 days	Tue 7/8/08	Thu 7/10/08
142		KITCHENETTE CABINETS	5 days	Tue 7/8/08	Mon 7/14/08
143		GRILLES & DIFFUSERS	3 days	Mon 7/14/08	Wed 7/16/08
144		CASEWORK	5 days	Mon 7/14/08	Fri 7/18/08
145		KITCHENETTE STONE TOPS & BLACKSPLASHE	5 days	Tue 7/15/08	Mon 7/21/08
146		KITCHENETTE APPLIANCES	5 days	Tue 7/22/08	Mon 7/28/08
147		CARPET/FLOORING & BASE	41 days	Mon 6/9/08	Mon 8/4/08
148		VCT FLOORING & BASE	5 days	Tue 7/29/08	Mon 8/4/08
149		DOORS & RUNNING TRIM	41 days	Mon 6/16/08	Mon 8/11/08
150		FINISH PAINT	42 days	Mon 6/23/08	Tue 8/19/08



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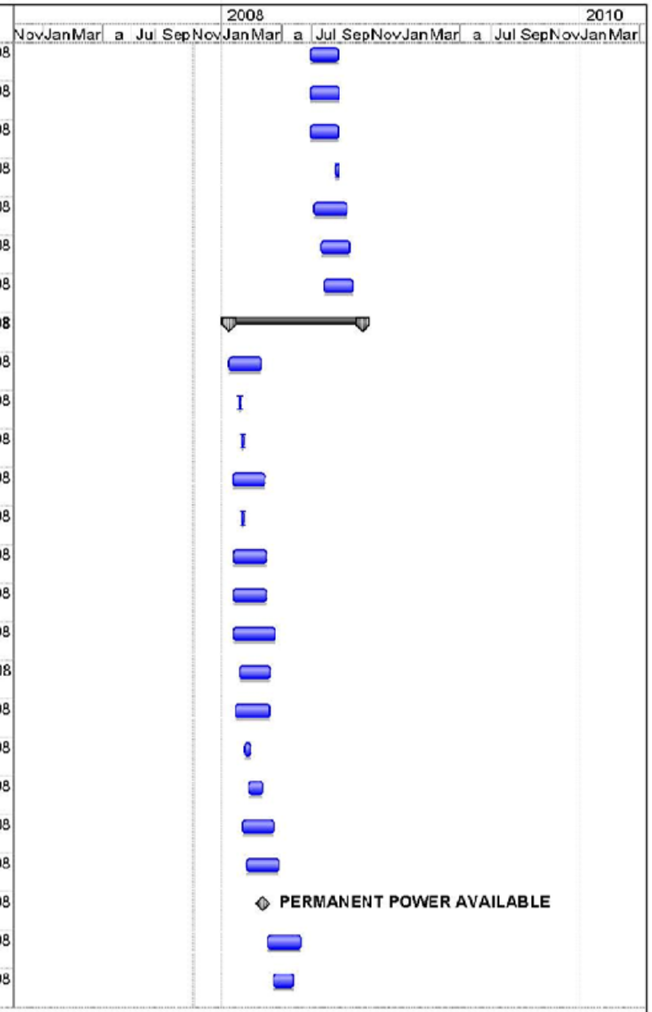
ID	Task Name	Duration	Start	Finish
151	FINISH HARDWARE	41 days	Mon 6/30/08	Mon 8/25/08
152	M/E/P DEVICING & TRIM	43 days	Mon 6/30/08	Wed 8/27/08
153	MISC ACCESSORIES	41 days	Mon 6/30/08	Mon 8/25/08
154	LAUNDRY EQUIP	5 days	Wed 8/20/08	Tue 8/26/08
155	CLEAN-UP & CONTRACTOR PUNCHLIST	49 days	Mon 7/7/08	Thu 9/11/08
156	A/E PUNCHLIST	44 days	Mon 7/21/08	Thu 9/18/08
157	COMPLETE PUNCHLIST & LOCK	43 days	Mon 7/28/08	Wed 9/24/08
158	**ELEMENT FLOORS 1-7 ROUGH-IN & FINISH**	**195 days**	**Wed 1/16/08**	**Tue 10/14/08**
159	LAYOUT & TRACK	48 days	Wed 1/16/08	Fri 3/21/08
160	SPRAY ON FIREPROOFING	4 days	Tue 2/5/08	Fri 2/8/08
161	ELECTRICAL POWER MAINS/DISTRIBUTION	5 days	Mon 2/11/08	Fri 2/15/08
162	ELECTRICAL RISERS	48 days	Wed 1/23/08	Fri 3/28/08
163	HVAC DUCT & PIPE MAINS	5 days	Mon 2/11/08	Fri 2/15/08
164	HVAC DUCT & PIPE RISERS	48 days	Thu 1/24/08	Mon 3/31/08
165	HM FRAMES/STUD FRAME WALLS	48 days	Thu 1/24/08	Mon 3/31/08
166	SPRINKLER MAINS AND BRANCHES	62 days	Thu 1/24/08	Fri 4/18/08
167	PRE-ROCK DENSARMOUR	45 days	Wed 2/6/08	Tue 4/8/08
168	ELECTRICAL BRANCH/LV ROUGH	50 days	Tue 1/29/08	Mon 4/7/08
169	HVAC DUCT/PIPE BRANCHES	8 days	Mon 2/18/08	Wed 2/27/08
170	FIT-OUT ELEC. SERVICE RMS	21 days	Mon 2/25/08	Mon 3/24/08
171	PLUMBING RISERS/SHOWER BASES	45 days	Wed 2/13/08	Tue 4/15/08
172	PLUMBING ROUGH/TEST & INSULATE	47 days	Thu 2/21/08	Fri 4/25/08
173	PERMANENT POWER AVAILABLE	0 days	Mon 3/24/08	Mon 3/24/08
174	WALL GYPBOARD	47 days	Fri 4/4/08	Mon 6/9/08
175	FRAME HARD CEILINGS	30 days	Tue 4/15/08	Mon 5/26/08



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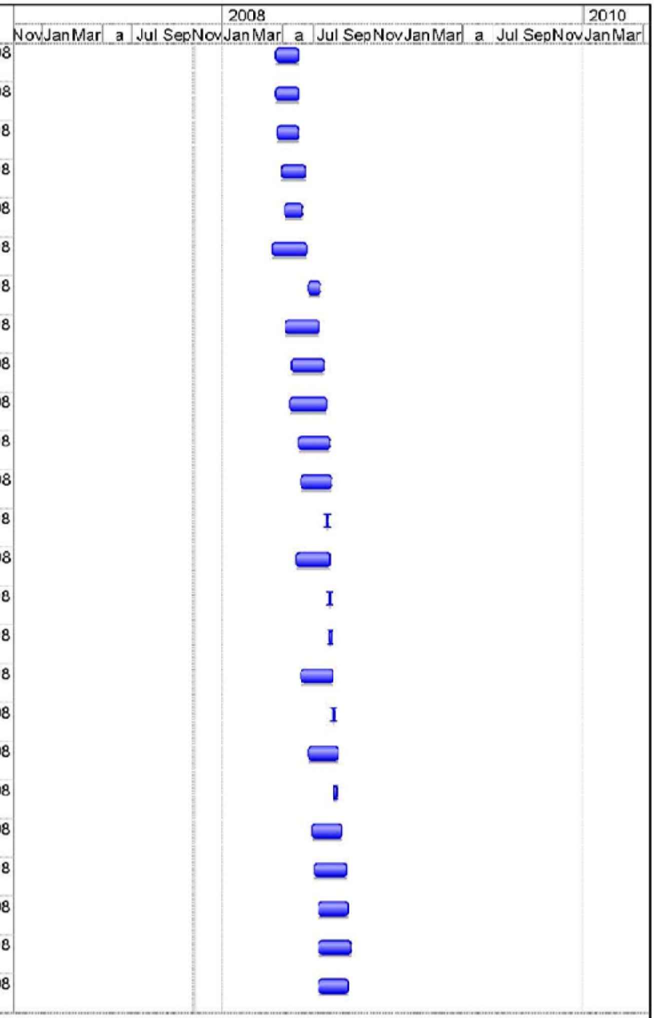
ID		Task Name	Duration	Start	Finish
176		OVERHEAD LV/ELEC ROUGH	33 days	Fri 4/18/08	Tue 6/3/08
177		OVERHEAD HVAC ROUGH-IN CLGS	33 days	Fri 4/18/08	Tue 6/3/08
178		SPRINKLER HEADS	31 days	Mon 4/21/08	Mon 6/2/08
179		CEILING GYPBOARD	35 days	Tue 4/29/08	Mon 6/16/08
180		GYPCRETE FLOOR LEVELING	26 days	Tue 5/6/08	Tue 6/10/08
181		INSULATION	49 days	Fri 4/11/08	Wed 6/18/08
182		FIT-OUT IT/DATA ROOM EQUIP	18 days	Mon 6/23/08	Wed 7/16/08
183		TAPE & SPACKLE	49 days	Wed 5/7/08	Mon 7/14/08
184		TILE	49 days	Mon 5/19/08	Thu 7/24/08
185		PRIME PAINT WALLS	53 days	Fri 5/16/08	Tue 7/29/08
186		BATHROOM VANITIES & TOPS	45 days	Tue 6/3/08	Mon 8/4/08
187		BATHROOM PLBG FIXTURES & TRIM	44 days	Mon 6/9/08	Thu 8/7/08
188		CEILING GRID	3 days	Wed 7/30/08	Fri 8/1/08
189		KITCHENETTE CABINETS	48 days	Fri 5/30/08	Tue 8/5/08
190		GRILLES & DIFFUSERS	3 days	Mon 8/4/08	Wed 8/6/08
191		CASEWORK	5 days	Mon 8/4/08	Fri 8/8/08
192		KITCHENETTE STONE TOPS & BLACKSPLASHE	46 days	Mon 6/9/08	Mon 8/11/08
193		KITCHENETTE APPLIANCES	4 days	Mon 8/11/08	Thu 8/14/08
194		CARPET/FLOORING & BASE	44 days	Mon 6/23/08	Thu 8/21/08
195		VCT FLOORING & BASE	5 days	Wed 8/13/08	Tue 8/19/08
196		DOORS & RUNNING TRIM	44 days	Mon 6/30/08	Thu 8/28/08
197		FINISH PAINT	47 days	Fri 7/4/08	Mon 9/8/08
198		FINISH HARDWARE	44 days	Mon 7/14/08	Thu 9/11/08
199		M/E/F DEVICING & TRIM	48 days	Mon 7/14/08	Wed 9/17/08
200		MISC ACCESSORIES	44 days	Mon 7/14/08	Thu 9/11/08



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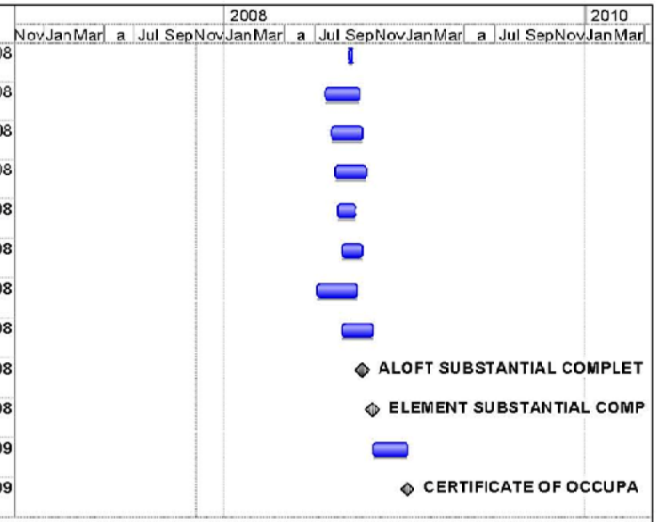
201		LAUNDRY EQUIP	5 days	Tue 9/9/08	Mon 9/15/08
202		CLEAN-UP & CONTRACTOR PUNCHLIST	51 days	Wed 7/23/08	Wed 10/1/08
203		A/E PUNCHLIST	45 days	Wed 8/6/08	Tue 10/7/08
204		COMPLETE PUNCHLIST & LOCK	45 days	Wed 8/13/08	Tue 10/14/08
205		**ALOFT FF&E**	**26 days**	**Mon 8/18/08**	**Mon 9/22/08**
206		**ELEMENT FF&E**	**31 days**	**Tue 8/26/08**	**Tue 10/7/08**
207		**FINISH SITEWORK**	**60 days**	**Mon 7/7/08**	**Fri 9/26/08**
208		**FINAL INSPECTIONS**	**45 days**	**Tue 8/26/08**	**Mon 10/27/08**
209		**ALOFT SUBSTANTIAL COMPLETEION/TCO**	**0 days**	**Tue 10/7/08**	**Tue 10/7/08**
210		**ELEMENT SUBSTANTIAL COMPLETION/TCO**	**0 days**	**Mon 10/27/08**	**Mon 10/27/08**
211		**PROJECT CLOSEOUT**	**51 days**	**Tue 10/28/08**	**Tue 1/6/09**
212		**CERTIFICATE OF OCCUPANCY**	**0 days**	**Tue 1/6/09**	**Tue 1/6/09**



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Appendix B.

Formwork Data Sheets

Table 7-2. Plywood

TABLE 7-2: SAFE SPACING IN INCHES OF SUPPORTS FOR PLYWOOD SHEATHING, CONTINUOUS OVER FOUR OR MORE SUPPORTS

Maximum deflection 1/360 of span, but not more than 1/16 in.

Pressure or load of concrete, pounds per square foot	Stresses and spans for short duration loads, for all sanded grades of Group 1 plywood. E modified for deflection calculations.								Stresses and spans for long term loading, for all sanded grades of Group 1 plywood. E modified for deflection calculations.							
	$F_b' = 1930$ psi; rolling shear = 72 psi; $E' = 1{,}500{,}000$ psi								$F_b' = 1545$ psi; rolling shear = 57 psi; $E' = 1{,}500{,}000$ psi							
	sanded thickness, face grain parallel to span				sanded thickness, face grain perpendicular to span				sanded thickness, face grain parallel to span				sanded thickness, face grain perpendicular to span			
	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.
75	20	23	26	31	10	14	18	25	20	23	26	31	10	14	18	25
100	18	21	24	29	9	13	17	23	18	21	24	29	9	13	17	23
125	16	20	23	27	8	12	15	22	16	20	23	27	8	12	15	22
150	15	18	21	26	8	11	14	21	15	18	21	26	8	11	14	21
175	15	17	20	25	7	10	14	20	15	17	20	25	7	10	14	20
200	14	17	19	24	7	10	13	19	14	17	19	24	7	10	13	19
300	12	15	17	22	6	9	11	16	12	14	16	20	6	9	11	16
400	11	13	15	20	5	8	10	15	10	12	14	18	5	8	10	15
500	10	12	14	18	5	7	10	14	9	11	12	16	5	7	10	14
600	10	11	13	16	5	7	9	13	9	10	11	14	5	7	9	13
700	9	11	12	15	5	7	9	12	8	9	10	13	5	7	8	12
800	8	10	11	14	4	6	8	12	7	9	10	12	4	6	7	12
900	8	9	10	13	4	6	8	11	7	8	9	12	4	5	7	10
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1100	7	8	9	12	4	6	7	11	6	8	8	11	4	5	6	9
1200	7	8	9	11	4	5	6	10	6	7	8	10	4	4	5	8
1300	6	8	9	11	4	5	6	9	5	7	8	9	4	4	5	8
1400	6	7	8	10	4	5	6	9	5	6	7	9	—	4	5	7
1500	6	7	8	10	4	4	5	8	5	6	7	8	—	4	5	7
1600	6	7	8	9	—	4	5	8	5	6	7	8	—	4	4	7
1700	5	6	7	9	—	4	5	7	4	5	6	7	—	4	4	6
1800	5	6	7	9	—	4	5	7	4	5	6	7	—	—	4	6
1900	5	6	7	8	—	4	5	7	4	5	6	7	—	—	4	6
2000	5	6	7	8	—	4	4	7	4	5	6	7	—	—	4	6
2200	4	5	6	7	—	4	4	6	4	5	5	6	—	—	4	5
2400	4	5	6	7	—	—	4	6	4	4	5	6	—	—	—	5
2600	4	5	5	6	—	—	4	5	—	4	5	5	—	—	—	5
2800	4	4	5	6	—	—	4	5	—	4	4	5	—	—	—	4
3000	4	4	5	6	—	—	—	5	—	4	4	5	—	—	—	4

NOTE: Above solid line, deflection controls span. Below dashed line, rolling shear governs. Between the lines, bending controls. Spans are given center to center of supports, assuming 1½ in. support width for shear spans. If supports of a different width are used, detailed calculations should be made to check spans in the range now shown as controlled by shear.

Calculations for these tables are based on section properties given in Table 4-3. If B-B Class I concrete forming grade of plywood is used, calculations may be based on data given in Reference 4-9 to obtain somewhat longer spans.

D-1

Table B-1. Aluminum Joists

WACO Scaffolding & Equipment

ALUMINUM HORIZONTAL SHORES

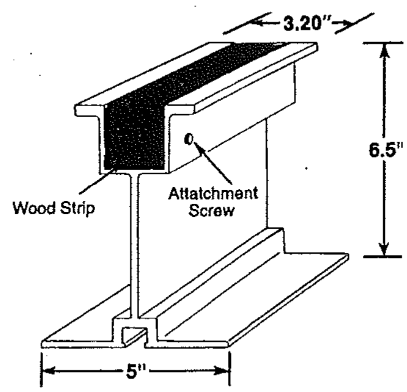
ALUMINUM BEAMS (6 1/2") (JOIST)

Part Number	Description	Weight	Std. Pkg.
	Per lineal foot	4.0	E
106AB	10'6" Length	42.0	E
12AB	12' Length	48.0	E
14AB	14' Length	56.0	E
16AB	16' Length	64.0	E
18AB	18' Length	72.0	E
21AB	21' Length	84.0	E
24AB	24' Length	96.0	E
A	A-Clamps	1	E

SPAN	ALLOWABLE DEFLECTION (inches)	SIMPLE SPAN (lbs./ft.)
4'0"	0.13	3080R
4'6"	0.15	2740R
5'0"	0.17	2020*
5'6"	0.18	1510*
6'0"	0.20	1160*
6'6"	0.22	920*
7'0"	0.23	730*
7'6"	0.25	595*
8'0"	0.27	490*
8'6"	0.28	405*
9'0"	0.30	345*
9'6"	0.82	295*
10'0"	0.33	250*
	Δ=1/360	

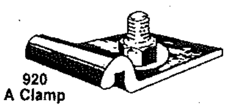
Beam Load Span Table
R = Reaction Governs
* = Deflection Governs

F.O.S. = 2.2:1



Aluminum Joist

Note: Place form plywood with its grain running at 90° to the joists, and stagger plywood sheets.

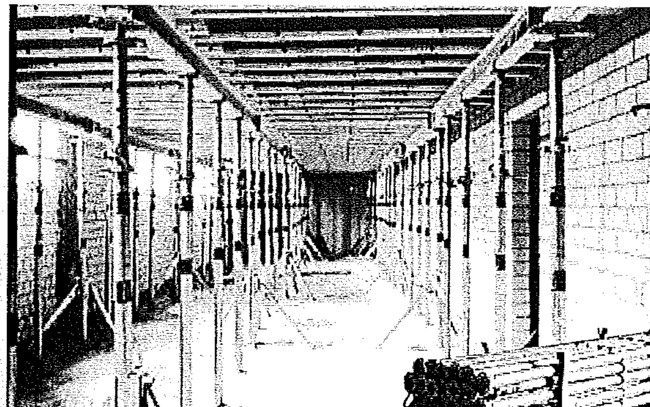


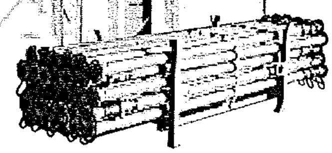
920
A Clamp

D.12

Table B-2. Eurex 20 Prop

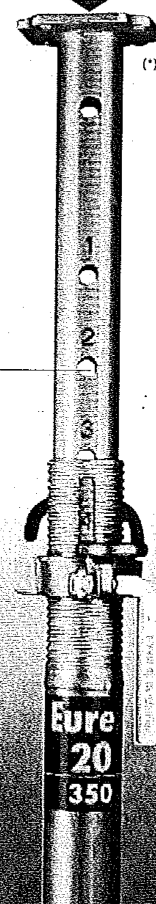
The best possible "support" on your site – Doka floor props





Eurex 20

6.0 kips (*)



(*) over entire extension range

- Doka floor props always have the same loadability – no matter how far you extend them (to ACI-Standards)
- Doka floor props are light weight
- Doka floor props are galvanized – no rust
- Doka floor props come with accessories for both H20 and Alu beams

The numbered holes are a convenient feature that makes for quicker and easier height adjustments.

Eurex 20 floor props

Type	Article Number	closed	extended	weight	Safe working load	safetey factor
Eurex 20 250	586086000	5' - 0"	8' - 2"	30 lbs	6,0 kips (26,7 kN) (**)	3 : 1
Eurex 20 300	586087000	5' - 8"	9' - 10"	34 lbs		3 : 1
Eurex 20 350	586088000	6' - 6"	11' - 5"	40 lbs		3 : 1
Eurex 20 400	586089000	7' - 6"	13' - 1"	51 lbs		3 : 1
Eurex 20 550	586090000	9' - 9"	18' - 0"	76 lbs		3 : 1

(**) according to TU Wien TEST REPORT on compressions test for Doka-post-shores EUREX 20 and Eurex 30, Nr. V86138, Date: 26.01.2000 and US-Standards

doka
The Formwork Experts

Österreichische Doka Schalungstechnik GmbH
Reichsstraße 23
A 3300 Amstetten / Austria
Tel. +43 7472 605-0
Fax +43 7472 605 64430
E-Mail: Oest.Doka@doka.com
Internet: http:// www.doka.com

Northeast Office
Corporate Headquarters:
Conesco Industries, Ltd.
214 Gates Road
Little Ferry, NJ 07643
Tel. 201-641-6500
Fax 201-641-6254

Puerto Rico Office:
Conesco Industries, Ltd.
638 Aldebaran St.
Banco De Desaro
LLO Economico Bldg.
Suite HQ-18
San Juan, PR 00920
Tel. 787-277-8560
Fax 787-783-9011

Texas Office :
Conesco Industries, Ltd.
1440 Halsey Way
Suites 204 & 206
Carollton, TX 75007
Tel 972-446-1662/1663
Fax 972-446-1772

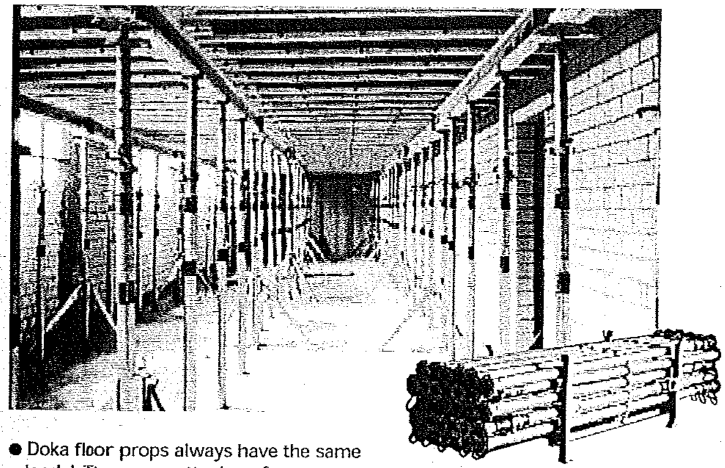
Mid-Atlantic Office :
Conesco Industries, Ltd.
6537 Mid Cities Avenue
Beltsville, MD 20705
Tel 301-595-1808
Fax 301-595-7395

Southeast Office :
Conesco Industries, Ltd.
105A Boulderbrook Circle
Lawrenceville, GA 30045
Tel 770-962-7914
Tel 888-618-4700
Fax 770-962-5238

Midwest Office :
Conesco Industries, Ltd.
1032 Moen Avenue
Rockdale, IL 60436
Tel 815-730-6700
Fax 815-730-8178

Table B-3. Eurex 30 Prop

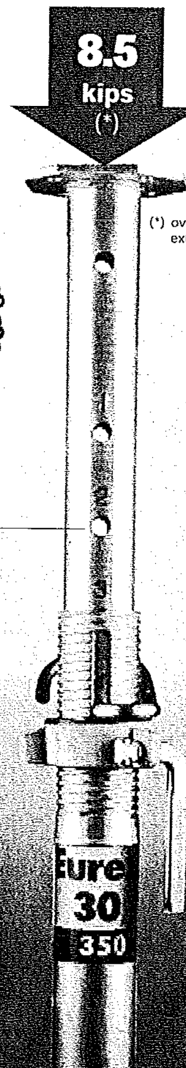
The best possible "support" on your site – Doka floor props



- Doka floor props always have the same loadability – no matter how far you extend them (to ACI-Standards)
- Doka floor props are light weight
- Doka floor props are galvanized – no rust
- Doka floor props come with accessories for both H20 and Alu beams

The numbered holes are a convenient feature that makes for quicker and easier height adjustments.

Eurex 30



(*) over entire extension range

Eurex 30 floor props						
Type	Article Number	closed	extended	weight	Safe working load	safetey factor
Eurex 30 250	586092000	5' - 0"	8' - 2"	33 lbs	8,5 kips (37,8 kN) (**)	3 : 1
Eurex 30-300	586093000	5' - 8"	9' - 10"	37 lbs		3 : 1
Eurex 30 350	586094000	6' - 6"	11' - 5"	45 lbs		3 : 1
Eurex 30 400	586095000	7' - 6"	13' - 1"	55 lbs		3 : 1

(**) according to DOKA TEST REPORT on compressions test for Doka-post-shores EUREX 30 8.5 kips, Nr. 861/01, Date: 27.09.2001 and US-Standards

doka
The Formwork Experts

Österreichische Doka Schalungstechnik GmbH
Reichsstraße 23
A 3300 Amstetten / Austria
Tel. +43 7472 6050
Fax +43 7472 605 4430
E-Mail: Oest.Doka@doka.com

Internet: http://www.doka.com

Northeast Office
Corporate Headquarters:
Conesco Industries, Ltd.
214 Gates Road
Little Ferry, NJ 07643
Tel. 201-641-6500
Fax 201-641-6254

Puerto Rico Office:
Conesco Industries, Ltd.
638 Aldebaran St.
Banco De Desaro
LLO Economico Bldg.
Suite HQ-18
San Juan, PR 00920
Tel 787-277-9560
Fax 787-783-9011

Texas Office:
Conesco Industries, Ltd.
1440 Halsey Way
Suites 204 & 206
Carollton, TX 75007
Tel 972-446-1662/1663
Fax 972-446-1772

Mid-Atlantic Office:
Conesco Industries, Ltd.
6537 Mid Cities Avenue
Beltsville, MD 20705
Tel 301-595-1808
Fax 301-595-7395

Southeast Office:
Conesco Industries, Ltd.
105A Boulderbrook Circle
Lawrenceville, GA 30045
Tel 770-962-7914
Tel 888-618-4700
Fax 770-962-5238

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Conesco Industries, Ltd.
1032 Moen Avenue
Rockdale, IL 60436
Tel 815-730-6700
Fax 815-730-8178