Technical Assignment 3

[Arena Stage]

Washington, DC

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Executive Summary

This technical assignment begins to identify areas of Arena Stage that are potential options for research, alternative methods, value engineering, and schedule compression. A telephone interview was conducted with the Project Manager of Arena Stage, Matthew Galbraith, to discuss the topics listed above. Mr. Galbraith answered questions pertaining to constructability challenges, schedule acceleration scenarios, and value engineering. The report concludes with project problem identification and construction management activities for technical analysis methods.

The first constructability challenge mentioned by Mr. Galbraith was selective demolition which was exceptionally difficult due to a two inch discrepancy from the initial site survey of the existing buildings. Second is the extensive amount of architectural cast-in-place concrete being placed on the project. Color inconsistencies in the finished concrete and “fat-bottomed” walls are being rejected by Bing Thom Architects (BTA) if not up to standard. Third is the collaboration of wood, glass, and steel on the 45-foot-tall curtain wall. Certain tolerance issues have become a concern as to how the materials will react as a combined unit once temperature takes effect and loads are applied.

Overlapping the concrete and steel operations is the one major schedule acceleration scenario being practiced at Arena Stage. This will hopefully allow the project to achieve watertight status and provide enough time to complete the massive amount of interior work inside the complex.

Dozens of Value Engineering (VE) ideas have been implemented on Arena Stage including deleting apartments above the Cradle theatre, changing the finish of the Cradle from zinc-clad to finished PERI-formwork concrete, and removing all water features, like the moat and waterfall. Also adjusted were the initial cable-supported cantilever roof, main lobby skylight, and glass flooring around the Fichandler theatre. Very few ideas that were contrived were not implemented. All VE measures were taken to reduce the cost of the project and help to deliver it on budget. Careful measures were taken to move money around appropriately and maintain BTA’s vision for an impeccable and sleek design.

Next, problematic features of the project were identified and considered for further analysis in the final thesis proposal.

The entire document culminated with the development of four construction management analysis activities that address the challenges and problems identified throughout this assignment. Topics chosen for analysis include removing the vertical slope of the curtain wall, altering the air distribution of the Fichandler, studying the acoustics and seating arrangement of the Fichandler, and examining the application of photovoltaic panels to combat the large amount of energy consumed by the building. Extensive research and communication with professionals will be required to successfully understand the building systems and how to properly analyze each topic. Finally, design and construction implications were considered.

A. Constructability Challenges

Selective Demolition:

According to Mr. Galbraith, there are several constructability issues on the project. The first is the selective demolition. From the beginning, knowing that the Fichandler and the Kreeger were going to be preserved as historical structures, the project team knew that the demolition phase of the project was going to be a challenge. To make matters more interesting, the initial site survey performed by the architect proved to be incorrect. The recorded locations of the existing buildings were recorded two inches off of their actual position.

Although two inches may seem minor to the average person, in the world of construction, two inches is a major dimension error that can cause compounding problems. Specifically, many issues arose when it came to making cuts to separate the Fichandler and the Kreeger from the existing administration building that was demolished. Luckily, the discrepancy was recognized and the project team addressed it immediately. Since the drawings had already been released for construction, the only way to resolve the issue was to write RFI's to the architect. Matt Galbraith stated that Bing Thom Architects (BTA) has been working hard to keep their responses timely to avoid any hold up on the project. Although this process is somewhat of an inconvenience and requires much more coordination, it keeps the personnel on their toes and makes them aware of the consequences of even the smallest mistakes.

Figure 1: Arena Stage during selective demolition in February 2008
(Provided by Clark Construction WebCam)

Architectural Cast-in-Place Concrete:

The second greatest issue is the massive amount of cast-in-place concrete on the project, which is being performed by Clark Concrete. Concrete is driving the schedule at Arena Stage and, according to Mr. Galbraith, a lot of coordination has been occurring "on the fly." He stated that it would have been nice to have a few more personnel on the project to be responsible for handling the amount of concrete coordination issues.

As with most theatre complexes, a lot of the areas are large, open spaces with very few columns present to provide support. Due to their large size, the concrete walls require a lot of time and man power to form and pour. In addition, the majority of the concrete walls are required to have an architectural finish. Of course, the Cradle Theatre is the epitome of these challenges. With 8 different wall radiuses that tilt on a 4 degree slope, getting the construction joints to match perfectly around the ellipse has been a great challenge.

Even more difficult is the problem that Clark Concrete has been facing. Despite the fact that all of the concrete batches are made using the exact same formula with the same material, each batch has noticeable variations. Although slight variations are common, a few batches have resulted in extreme color differences which BTA has had to refuse on several occasions since they do not meet their specified standards. Clark Concrete has not been able to pinpoint the exact reason for this problem, but they believe it may be due to variable pigment in the aggregate. Similarly, some of the larger walls have caused issues. Because they require the use of large, continuous formwork, they cannot always support the pressure of the concrete. This results in walls that have settling at the base, or "fat-bottomed." Unfortunately, several walls have been ripped down and replaced because of their unfavorable appearances.

Figure 2: Architectural concrete finish at the Cradle Theatre.
Some pigment discrepancies not tolerated.

Curtain Wall Connections:

The third and final constructability challenge is the curtain wall. Since there are multiple subcontractors that are involved with the construction of the curtain wall, coordination is a big issue. The parallam timber columns and window details are being performed by StructureCraft Inc., the glazing is by Icon Exterior Building Solutions, and the structural steel that ties into the system is installed by Banker Steel Company, LLC.

Not only is installation going to be a challenge, but the fact that these three different materials are expected to work together brings about tolerance issues. Wood, glass, and steel all behave very differently under temperature changes and load applications. Although a great deal of engineering went into its design, Clark is still weary of the final installation of the entire system to see if will come together as it was designed. Everyone has paid careful attention to the design of the curtain wall components and constant communication exists between the associated contractors. Despite the project team's planning efforts, an actual solution to this problem has not been determined. It will be addressed if and when problems arise on site.

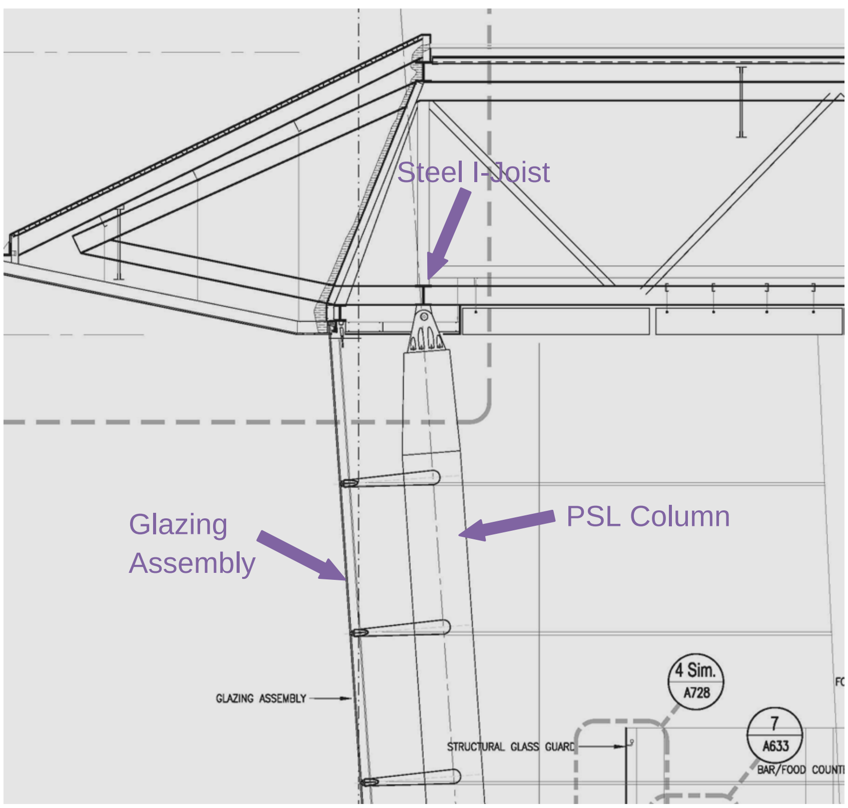


Figure 3: Wood, glass, and steel connection at the curtain wall

B. Schedule Acceleration Scenarios

The critical path of Arena Stage relies mainly on concrete which began in March 2008. Concrete work is being performed all over the site from small locations in the Kreeger and Fichandler to large work at the Cradle, parking garage, and lobby. Upon completion of the concrete operations in March 2009, the critical path moves to the steel of the high roof, to the parallam timber columns of the curtain wall, to the curtain wall glazing and windows, to the MEP within the theatres, and ends with interior fit out. See Figure 4 for the critical path sequence.

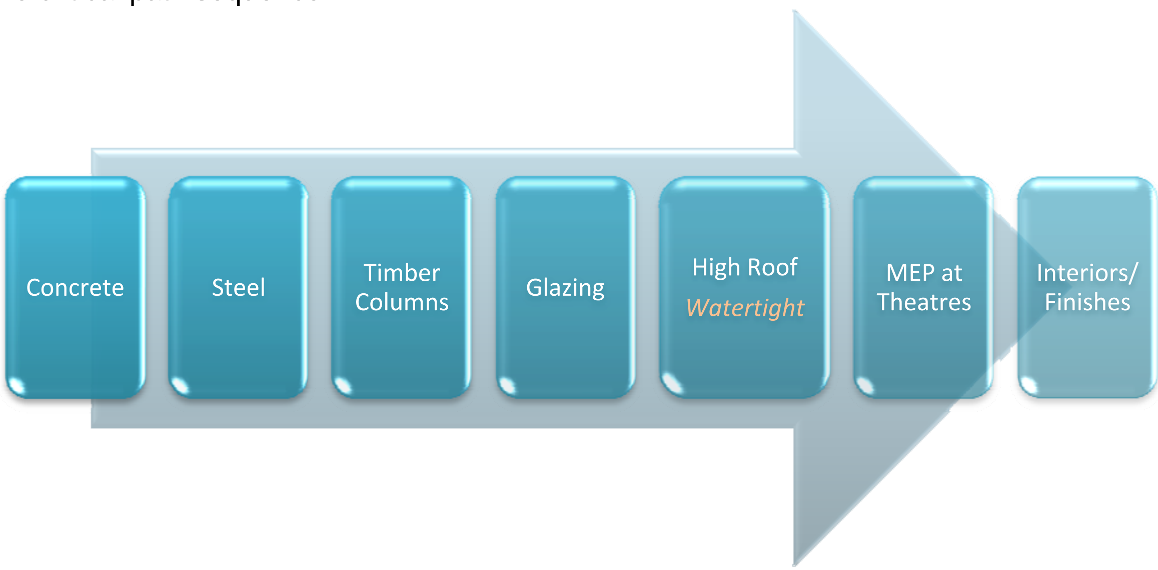


Figure 4: Critical Path of Arena Stage

According to Matt Galbraith, the highest risk to the project's completion date is achieving watertight status. While this is a major milestone for all construction projects, Arena Stage has a massive amount of high end interior work, which makes it even more crucial to this project. No work inside the three theatres or the lobby can begin until the steel of the high roof is erected and the glazing of the curtain wall and windows are installed and sealed off. As of November 2008, Clark Construction is only about three weeks behind the schedule's targeted date to become watertight in November 2009. This is mostly due to setbacks that occurred at the beginning of the project. The first was a two week delay due to bearing piles that did not come up to capacity, which resulted in driving them 15 feet deeper than initially required. The second was due to rain and problems with the erection of the first tower crane, which set the project back by a week.

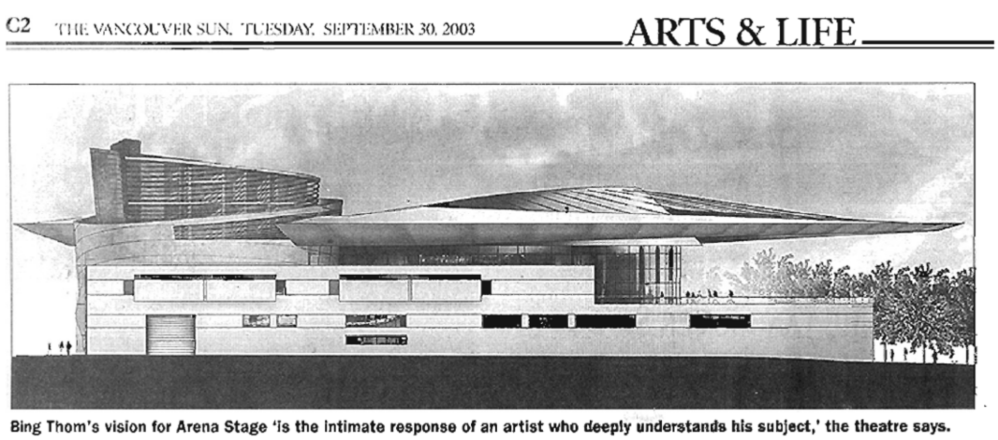
Matt identified one key area that is being used to accelerate the schedule and that is beginning the steel erection early. Originally, the concrete and the steel operations had a start-finish relationship. Now they are scheduled to overlap, ideally beginning around December 5, 2008. The reason that this acceleration option is being exercised is because of watertight status. As stated before, the finishes are expected to take a very long time to install and any time that can be gained is necessary. Once construction moves inside the building, there are going to be very few opportunities to accelerate the schedule by a considerable amount.

In order to ease issues with coordination between the concrete and steel, engineers have been producing as-builts to give to the steel erectors. For these two operations to occur simultaneously, major coordination and cooperation will be required. Since the steel manufacturer has agreed to fabricate and deliver the steel per the accelerated schedule, this scenario has caused little to no cost impact.

C. Value Engineering Topics

Arena Stage has been in the making for the last 8 years. Since the inception of the design in 2003, it has undergone major changes. After Clark Construction received the construction contract in May 2007, they immediately began to look for areas where they could implement Value Engineering (VE) to help the project save money so that it could be delivered on budget.

It is Clark's main objective to make sure that the entire project team remains happy with the project regardless of any adjustments. They worked closely with Arena Stage, KCM Inc., and BTA to make sure that they all stayed satisfied. Obviously, Arena Stage's top priority is the budget. Since the project is being funded by private donors, the budget must be closely monitored and money must be moved around very strategically. Likewise, BTA's main concern is the design. They have worked hard to make sure that no matter what is altered on the project, the integrity of their design is maintained. There are a few areas of the project that BTA specified as nonnegotiable from the beginning. These include the shape of the Cradle, the main ceiling, and the interim areas of the lobby. Clark has honored those requests and has avoided any major adjustments to their designs.


C2 THE VANCOUVER SUN, TUESDAY, SEPTEMBER 30, 2003 ARTS & LIFE

Bing Thom's vision for Arena Stage 'is the intimate response of an artist who deeply understands his subject,' the theatre says.

Figure 5: The original design of Arena Stage released in *The Vancouver Sun* in 2003

As stated before, Clark and the Owner's Representative sat down and discussed VE ideas very early on. Office Engineer, Anna Samaha, explained that the Owner's Rep. has a very keen eye for identifying and estimating potential VE options. Multiple Value Engineering ideas were implemented on this project long before breaking ground. Most of the ideas discussed in this document are large VE options that were exercised to deduct expensive, aesthetic components that served no functional purpose and, therefore, were not necessary for the complex to operate. These VE changes will be called "Primary VE's" from this point forward.

The Primary VE's are all very similar. They are architectural elements that were excessive and had the potential to be very expensive. The exact cost savings for deleting these items are unknown, but it is important to notice that they were eliminated in order meet the inflexible budget. For this reason, BTA was not opposed them being deleted since they did not affect the overall design.

The Cradle's Low Walls and Cladding:

Since the radial shape and slant of the walls is strictly an aesthetic trait, Clark offered to provide Arena Stage a deduct if they would allow them to make the bottom level walls perpendicular to the ground until they were publically visible. BTA and Arena Stage agreed to this VE idea, which saved Clark the headache of constructing all of the walls on a 4 degree slope.

Also, the Cradle was originally designed to be clad in zinc panels. This expensive feature was quickly VE'd and changed to board-formed finish concrete. This method, however, is also very expensive and would require an enormous amount of man power, so it was also VE'd. The Cradle finish that was agreed upon is the current PERI-RUNDFLEX finish which has circular voids from where the formwork ties together.

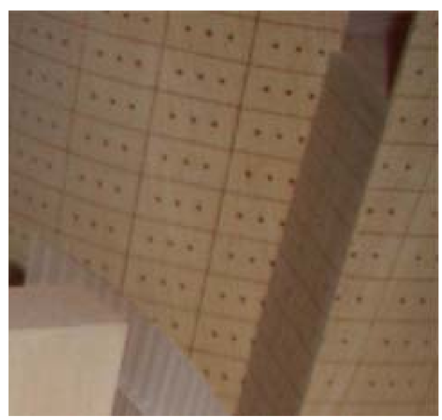



Figure 6: (Left) Original zinc-clad Cradle exterior finish (Original Rendering from BTA)
(Right) PERI-formwork finish being implemented (Most current model)

Cradle Apartments:

Since Arena Stage is the largest producing theatre in North America that focuses on American plays, BTA wanted to promote the continuation of the production and performance of new plays. They added the Cradle to the two existing theatres as an intimate, black box theatre that would house smaller, less expensive venues. Its purpose is to encourage experimental works and nurture the next generation of writers. When it was first designed, this was expressed quite literally. The theatre was originally designed to have 21 apartments atop the theatre to house visiting actors, designers, and directors.

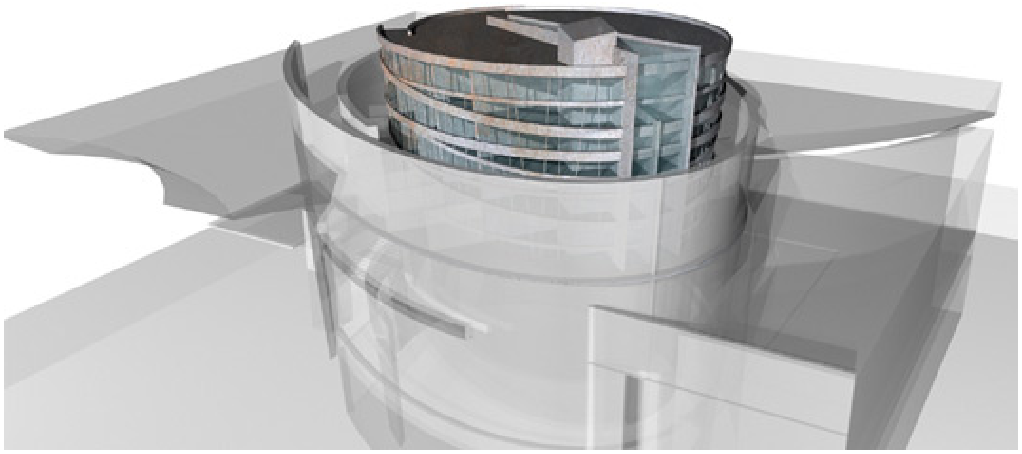


Figure 7: Rendering showing the Cradle apartments emerging from the roof (Original Rendering from BTA)

The team immediately made the suggestion that the apartments should not be executed since they were not needed for the theatre to operate. The high cost of the apartments was quickly recognized and they were deleted from the project as a Primary VE. Not only did this save Arena Stage a lot of money, but it kept the project from having to meet both commercial and residential code/zoning requirements. Arena Stage also recognized that if desired, the apartments could be added to the Cradle at a later point in time.

Water Features:

Another aspect of the original design was a reflecting pool that surrounded the complex like a moat and culminated with a waterfall at the 6th Street glass-encased entrance. This was also a Primary VE that was taken out to save money, save time, and avoid the complications that major water components often have.

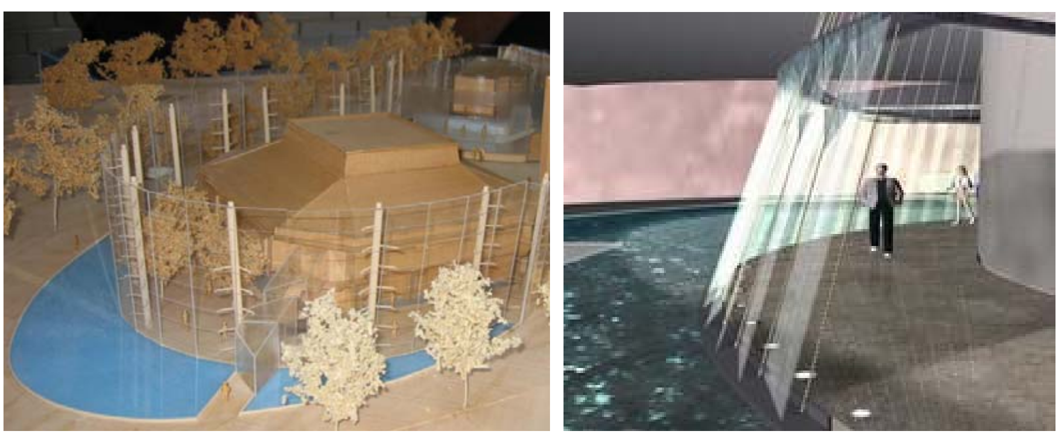


Figure 8: (Left) Reflecting pool and glass-encased entrance at the Fichandler (Old model) (Right) Reflecting pool surrounding the Kreeger (Original Rendering from BTA)

Architectural Roof Features:

Other architectural features that were Primary VE deducts were the main lobby skylight and the "harpsichord"-cable cantilever support. These rooftop characteristics were seen as excessive expenses. Also, an unrealistic amount of time would be needed to properly engineer the "harpsichord." Since it attracted so much technical concern from the project team, it was VE'd and replaced with a steel-framed truss system which is also used on the rest of the high roof.

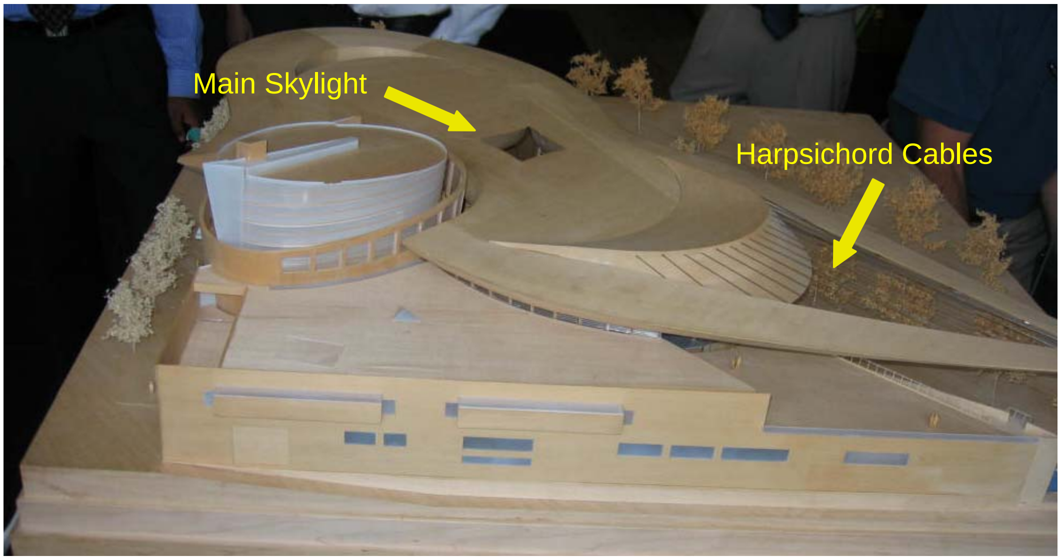


Figure 9: The old model showing the "harpsichord" cantilever support and the main lobby skylight

Glass Floor around the Fichandler

Originally, the Fichandler was designed to have glass floors surrounding the perimeter of the theatre in the lobby space. This floor was going to be used as a tribute to the people who donated money to Arena Stage to make its renovation and expansion possible; each donor's name was going to be etched into the flooring. Similar to this glass floor, a glass wall was designed to hang by the Kreeger theatre as a screen.

These glass elements were VE'd and combined in order to save money. While the glass wall at the Kreeger cost more money than the glass floors at the Fichandler, the decision was made to delete the glass floors and etch the names of the donors into the wall at the Kreeger. The money that was originally allotted to the floors was moved into the funds for the glass walls. This alternate VE idea did not necessarily save money, but it did "kill two birds with one stone."

Other VE ideas:

Several other Value Engineering ideas were implemented on Arena Stage. These included:

- Changing concrete components to CMU where possible

- Using a new, all-inclusive, glass railing system to utilize only one contractor instead of involving miscellaneous metals, glass, and concrete contractors
  - Limiting the number of embedded angles/channels needed for support
- Changing the main ceiling of the upper roof from acoustical baffles to a fine-lined, inlaid grid system
- Allowing electrician to run wire without conduit where not needed by code (exposed shielded cable)

Unfortunately for this assignment, there were no substantial VE ideas that were considered but not implemented. There were very few areas of Arena Stage that were untouched by Value Engineering. Everything has been looked at with a very critical eye as an effort of the entire project team to deliver this building within the budget. The easiest way to comprehend how VE has affected the project is to look at the old and new models of Arena Stage (See Figures 10 and 11). Both the exterior and interior of the building have been changed dramatically while still preserving the pristine architecture.

Figure 10: Original model of Arena Stage (2007) viewed from the North end of the building

Figure 11: Most recent model of Arena Stage (2008) viewed from 6th Street SW

D. Problem Identification

Along with the constructability challenges listed above, there are several complexities on Arena Stage that could be viewed as problems. They all vary in degree, but would require a decent amount of analysis in order to fully comprehend their effects and come up with an alternate solution or a way to resolve the problem. Topics or features of the building that were complex and caused/will cause issues:

- Excavation support
- Selective demolition
- Historical considerations
- Tree preservation
- Cradle shape and cast-in-place concrete
- Curtain wall slope and serpentine shape
- Cantilever roof truss system
- Energy consumption (theatres are energy hogs)
- Lack of LEED consideration
- Theatre lighting loads and fixture costs
- Air distribution in theatres
- Restoration of terne roof at the Fichandler
- Project designers/contractors in British Columbia (geographic separation from job and remainder of project team)
- Delivery of distant materials (transportation costs)
- Wood slat wall at the Cradle (installation and acoustical performance)
- Refurbishment of theatre décor as acoustical medium
- Availability of parking aside from the underground lot

Since the project is very large and has room for various areas of analysis, it is favorable that close attention be paid to certain areas of the project to maximize the effectiveness and feasibility of studies. From this point forward, the Fichandler and the envelope of Arena Stage will be the main sources of analysis and topics of technical research.

E. Technical Analysis Methods

Upon review of the problematic features of the project, four construction managmenet activities have been chosen for analysis:

<u>Analysis 1: Slant of the Curtain Wall</u>

One of the most problematic features of the project is the 45’ tall curtain wall. The glazing is on an inverted 4 degree slope and the wall is a serpentine comprised of multiple radii. It is sectioned off into 12’×1-1/8” insulated glass frames which weigh approximately 850 pounds per unit. Due to the slope and curve of the wall, there are several sections of glass that are trapezoidal instead of rectangular. The glass is hung from the ceiling by stainless steel cables which are supported by wide flange beams located in the ceiling above the lobby. Finally, the load is passed off to the parallam timber columns which have a cast ductile-iron caps and bases.

As one of the main design features of Arena Stage, the curtain wall is a very extravagant and expensive component. According to the detailed estimate performed in Technical Assignment 2, the curtain wall costs approximately $3,925,000, or $143.15 per square foot of glazing. By eliminating the slope of the glazing, and therefore removing the trapezoidal units, the cost and difficultly of construction could be reduced.

This analysis would consist of studying the current system and understanding exactly where the complexities lie. I have already built relationships with representatives from both StructureCraft Inc. and Icon Exterior Building Solutions, who are both very willing to assist with my academic endeavors. Once a full set of shop drawings are obtained from both companies, adjustment of the system and load paths could be fully analyzed. Also, the type and number of materials have the potential to change as well. This analysis would not only alter the design of the curtain wall, but would most likely effect its installation as well. A schedule analysis could also be conducted based on historical performance logs of both of the contractors and working with them to determine a realistic time deduction for a simpler system.

Analysis 2: Fichandler Air Distribution System

The air distribution system in the Fichandler is served by two separate constant volume air handling units (AHUs) located in its mechanical room, one for the stage and one for the seating area. The stage is supplied by AHU 1 from low velocity, high throw air jets located in the wood ceiling portions of the theatre. In order to direct air to the correct area of the stage, the jets have an adjustable discharge slot. These slots are fed from branch ducts above the refurbished wood ceilings, which connect to a ring duct around the top of the Fichandler exterior wall. The ring duct is served from two risers on either side of the main entry from below. Two low pressure variable volume, pressure independent dampers connect to each ring duct and discharge via flexible duct to diffusers located in the concrete ceiling. Return air from the Fichandler will be via ceiling diffusers to a riser located in the southeast corner of the theatre that runs to the mechanical room.

AHU 2 serves the seating area with is conditioned via swirl diffusers located under the rows of seats. The existing concrete floor is being core drilled with 9”-diameter holes in the horizontal tread. A plenum under the seats will be created by closing off the current storage and lining it with 2” thick acoustic liner. The four seating areas will each have an individual plenum chamber fed by various ducts. Supply air ducts will be routed via existing return air pathways and by new duct trenches in the slab.

The refurbishment of the Fichandler HVAC system consists mainly of the large ring plenum and the installation of the 4 plenum chambers with 220 under-seat diffusers, shown in Figure 13 below. The large ring plenum, shown in Figure 12, seems like a very complex and heavy run of ductwork. Also, while underseat diffusers are deemed the most comfortable form of air distribution in theatres, the 220 core drills that need to be made in order to install them seem like a very laborious process. It would be interesting to see what alternate technical considerations could have been made to ease the constructability of the mechanical system, such as running fabric duct (duct sox or euro air) throughout the theatre.

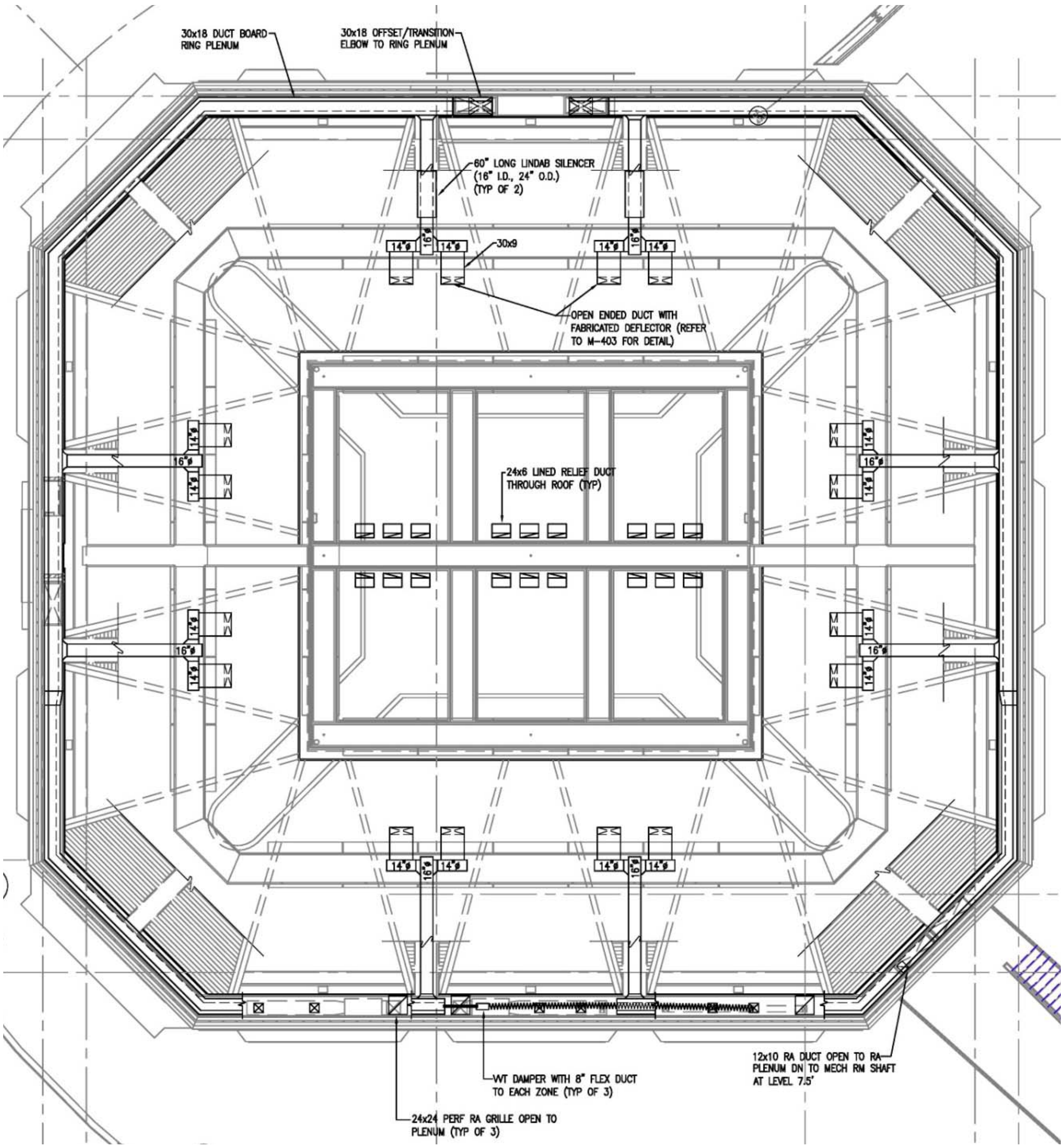


Figure 12: Mechanical Plan MH-142 (Level 43.0') – Ring Plenum

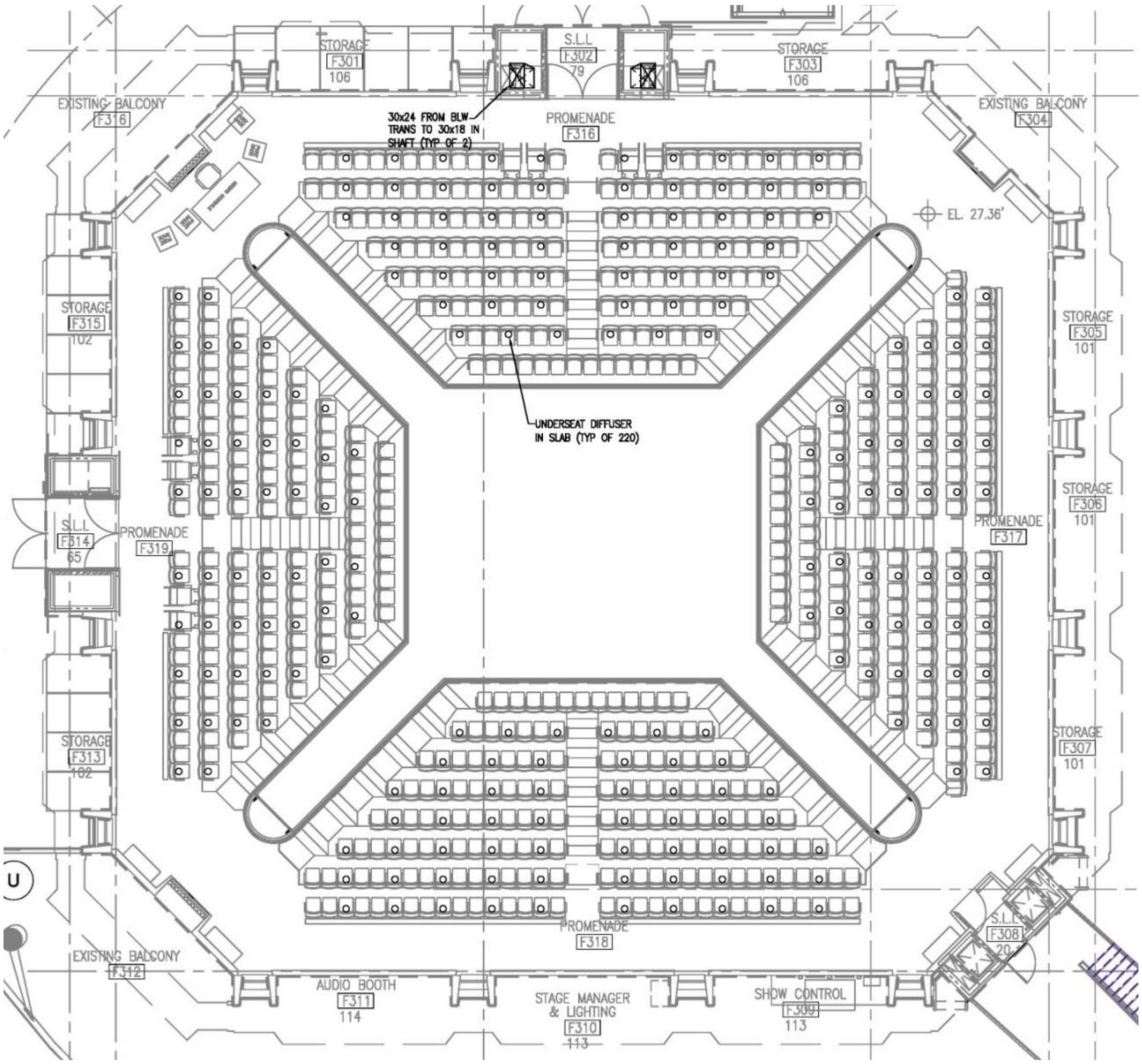


Figure 13: Mechanical Plan MH-132 (Level 27.5') – Underseat Diffusers

In order to perform this analysis, a full review of the mechanical system and the sizes of the duct (required cfm) need to be recorded. Extensive research needs to be performed on fabric duct and how it ties into standard sheet metal duct. Also, the availability of the fabric duct and an experienced installer needs to be located, hopefully within a reasonable radius of the site location. Finding case studies on the use of fabric duct in theatres would also be useful to see how it may have compared to alternate systems, such as the one currently designed for Arena Stage. Schedule impacts could also be analyzed to see if any time was saved by avoiding the underseat core drills.

Analysis 3: Fichandler Acoustics and Seating

Through the renovation of the Fichandler and the Kreeger, Arena Stage wanted to fully restore the theatres with elegant décor and state of the art systems. Included in this process was the removal and refurbishment of the theatre seats. Per the architectural plans, the seats in the Fichandler are going to be installed in the same fashion as they were in the original Arena theatre designed by famous American architect, Harry Weese.

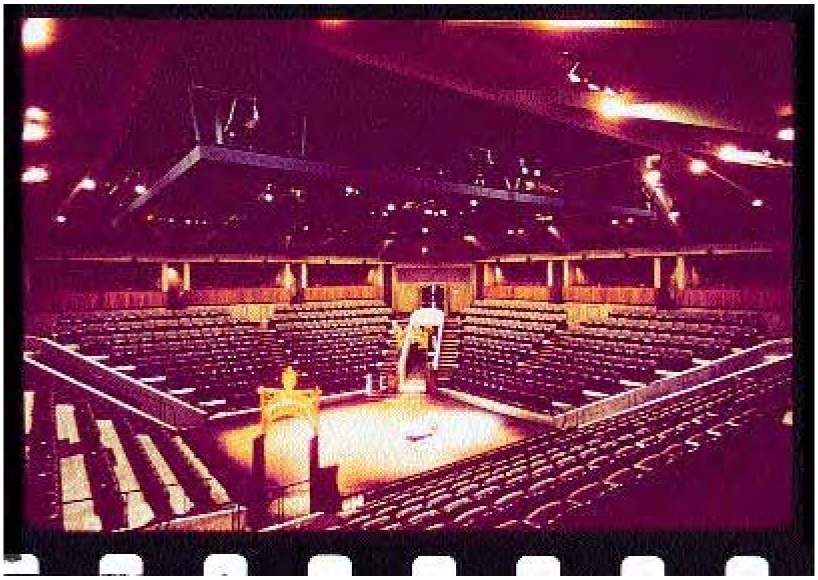


Figure 14: The original Fichandler Theatre circa 1960

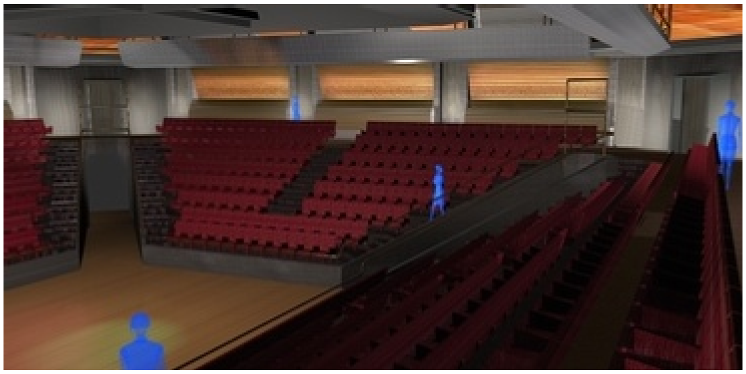


Figure 15: Restoration of the Fichandler seating (Rendering from BTA)

Currently, only the layout of the seats in the Fichandler is known. It would be valuable to know what is being done to refurbish the seats and what materials and upholstery are being applied to the seats, both for aesthetic and acoustical purposes. Also, after taking AE 309, *Architectural Acoustics*, I have an interest in acoustical analysis of spaces, and what better to analyze than a theatre. On each side of the theatre, there were viewing boxes which were reserved for special guests during performances. These boxes are not being maintained during the restoration and will become storage spaces instead. The openings in the boxes are being covered with fabric lined panels for acoustical reasons.

In order to examine the acoustical performance of the Fichandler, I would need to perform a spatial analysis of the theatre and understand the four-way projection of sound from the "theatre in the round." Research on the types of acoustical material being used on the seating, fabric panels, and in the ceiling are also important. This would then be followed up by suggesting more effective materials and/or layout of the seating, including what would be best for audience viewing. Also, the Fichandler roof is constructed out of terne which is a thin sheet of steel coated in lead and tin to inhibit corrosion. Possible reverberation from the metal roof would be an interesting study as well.

<u>Analysis 4: Energy Analysis, Photovoltaic Panels</u>

Since Arena Stage is not striving to achieve LEED certification, little was done in regard to the environment or energy considerations. Theatre complexes are usually large energy hogs due to their large open spaces and high ceilings which can result in excessive heating/cooling. Since *Energy and the Economy* is a critical industry issue that was discussed at the PACE Roundtable, it would be wise to apply the idea to Arena Stage. It may reveal opportunities where Arena Stage may have been able to be a little more energy conscious and increase the life-cycle cost of the building.

An applicable topic may be the use of solar tracking panels. I will be taking EDSGN 498A in the Spring which is a *Solar Electrical System Design and Construction* course. Hopefully this course will enhance my knowledge of the implementation of photovoltaic (PV) systems and how it may apply to Arena Stage. It will also be important to research the availability of sunlight on the site and where PV panels could be installed in order to optimize solar gain. Examining the sun path in Washington, DC and the effects of the shade from surrounding buildings will also be necessary. Once this is done, a calculation can be performed to see what types of energy savings could be expected. If possible, it would be nice to obtain projected energy costs of the building as it is being constructed, but that would rely on their availability. Finding a material provider and experienced PV installer from the area would be pivotal for this addition. Also, the cost and time associated with adding the system would be produced as well.