ARENA STAGE

Washington, DC

Fast + Epp

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CANADIAN CONSULTING ENGINEERING AWARDS 2011

Category A: Buildings

Project Owner: The Arena Stage Mead Centre for American Theatre

Project Client: Bing Thom Architects

Contractors: Project Manager – KCM
General Contractor – Clark Construction
Timber Façade Design Builder – StructureCraft Builders

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Upgrade and renovation of two heritage theatres with a large addition including a third new theatre, 500 foot roof, and heavy-timber-supported glazed façade enclosing extensive new spaces.

ARENA STAGE HIGHLIGHTS

Arena Stage transformed an existing building with the upgrade of two acoustically deficient heritage theatres and the addition of a new experimental theatre and extensive support spaces under a new high roof and timber façade - a catalyst for redevelopment of a derelict Washington, DC neighbourhood one mile south of the National Mall.

The engineers rose to the demand for an exuberant free-form expression with practical and elegant solutions to the resulting complex technical challenges.

Significant acoustical deficiencies and a meager artist's budget informed the many structural challenges. In addition to structural design for all the other numerous other intricacies of this $130 million renovation/addition, Fast + Epp provided structural solutions to the two major elements enclosing the existing theatres, which effectively isolate the theaters from the noise of the busy capitol while creating a beautiful lobby.

The high roof structure is 500 feet long, with tapered curvilinear edges, and spans over the theatres before dramatically cantilevering 85 feet toward the Washington Monument. Every truss in the roof is unique and supported by a 50-60 foot high wood column, elliptically-shaped in cross-section, which also carries the other acoustical barrier, a 650 foot long double-glazed façade.

The façade follows a compound curve in plan and slopes to optimize transparency through the glazing 4 degrees, as do the columns, leading to resolved permanent stresses in the roof diaphragm. All the lateral forces from the large roof and façade were focused into the concrete walls of the new "Cradle" theatre, eliminating the need for visually disturbing bracing along the length of the façade.

This was in every respect a complex structure to build. The design necessary to fulfill the dynamic aesthetic expression and significant functional demands was further complicated by a large drop in funding available to the Client and rising construction costs in the wake of the 9/11 attacks.

Creativity, a willingness to go above and beyond to refine design concepts to their purest form, and extreme care and attention to technical detail was necessary to make this project a success. Not only was the structural design demanding, but there were significant challenges when it came to executing the final designs in Washington. The general contractor realized this early and put his most meticulous people on the job. The entire team of consultants similarly engaged with the project, paying close attention to detail in planning, 3D-modeling, and shop drawings. To ensure smooth execution of the most important feature, the timber façade, StuctureCraft Builders, a company related to the Engineer, took on the contract for its design, testing, fabrication and installation. A high level of communication and collaboration within the entire team from design through construction allowed this complex project to be realized with the highest degree of quality.

NEW APPLICATION OF EXISTING TECHNIQUES: ORIGINALITY AND INNOVATION

Most modern theatres are designed as a "box within a box", essentially two structures, an inner and a massive outer, to effectively deal with the problem of outside noise. It would be very expensive in this case to add an entire new structure around each of the existing theatres, and heritage goals would not be achieved.

The Architect's idea was to "wrap" the heritage Kreeger and Fichhandler theaters with a glass screen and signature roof that would not only allow the existing buildings to remain exposed to view, but solve the noise issues. Further, by expanding the perimeter of the glass facade and having the roof clear span over both structures, he created a large lobby, protected from the elements, which connects the theatres, including the third new theatre. All of this needed to communicate a bold architectural statement, expressing Arena Stage's new presence, both locally and nationally.

Fast + Epp's role as structural engineer was to facilitate the demands of this aggressive program for an exuberant free-form expression with practical and elegant solutions to the complex technical challenges (and shrinking budget) of two major elements enclosing the existing theatres, isolating them from the noise of the busy capitol while radiating the warmth of well-detailed timber to the outside community.

High Roof – The initial scheme, already fully designed and peer reviewed, had the roof cantilevering 180 feet, supported by harped steel cables anchored into a custom steel space truss. However, post-9/11 funding shortfalls necessitated redesign. A steel truss structure was introduced, retaining drama by bringing a support wall only part way along the back side, leaving an 85 foot cantilever which appears similar to the original design (Fig. 1).

Figure 1: View of the high roof cantilever during construction.

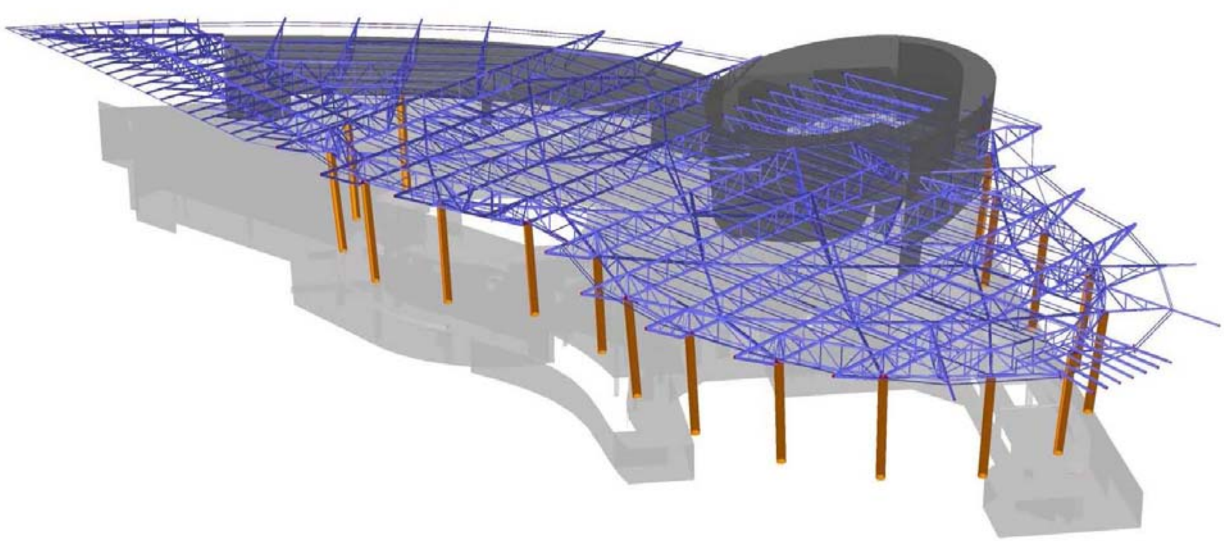


Figure 2: High roof steel truss system supported on timber façade and laterally restrained by the concrete 'Cradle' theater structure.

The large and complex roof required close collaboration between engineer and erector. Every 9 foot deep truss is unique (Fig. 2), has unique support conditions, and spans up to 170 feet. A sharp edge was efficiently achieved with light steel framing.

To accommodate the multiple orientations of the leaning support columns, a single 2.5” diameter bolt connection (Fig. 3) was devised, speeding erection of the large trusses. When complete, a simple “bounce test” (one engineer, all alone) was used to test the stiffness of the cantilever tip, resulting in an instruction for minor stiffening in the secondary trusses.

Figure 3: Steel trusses fastened to Timber Columns with a single universal bolt.

Timber Façade – The roof is supported by a series of large engineered timber columns, which also serve as backup to a sinuous 650 foot long, up to 58 foot tall suspended glass façade, the acoustical and environmental barrier (Fig. 4). The geometric complexity is exacerbated by a four degree tilt from vertical. For efficiency, two-thirds of the double-glazed facets were designed to be identical in size; the remaining bays unnoticeably take up the irregular geometry.

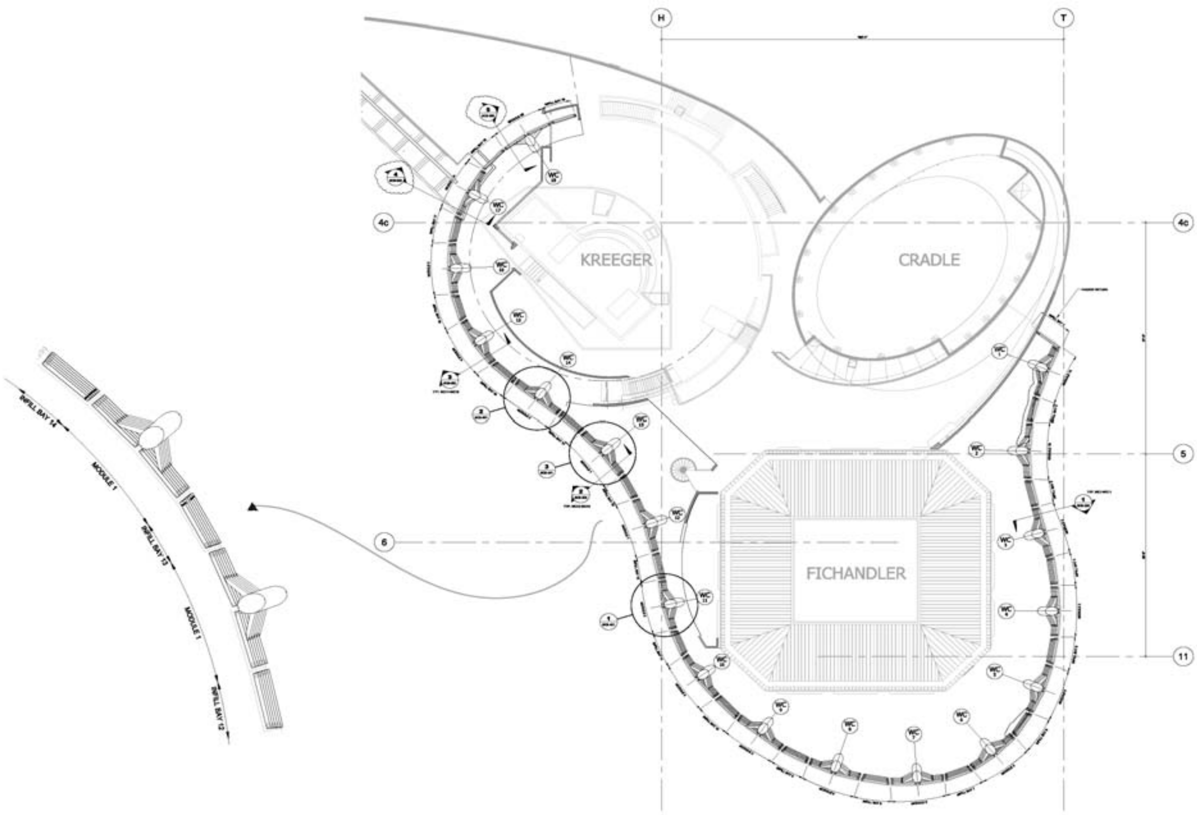


Figure 4: Timber PSL column-muntin façade layout (note close-up on left).

The timber columns are set back from glazing plane, receiving tapered timber arms that reach out to laterally support timber muntins, to which the glazing units are clipped (Fig. 5). All of the timber is of engineered wood – parallel strand lumber (PSL).

The 20x30" elliptical timber column is designed to carry axial forces (up to 1700 kN) and out of plane near hurricane wind-forces while minimizing the amount of PSL used.

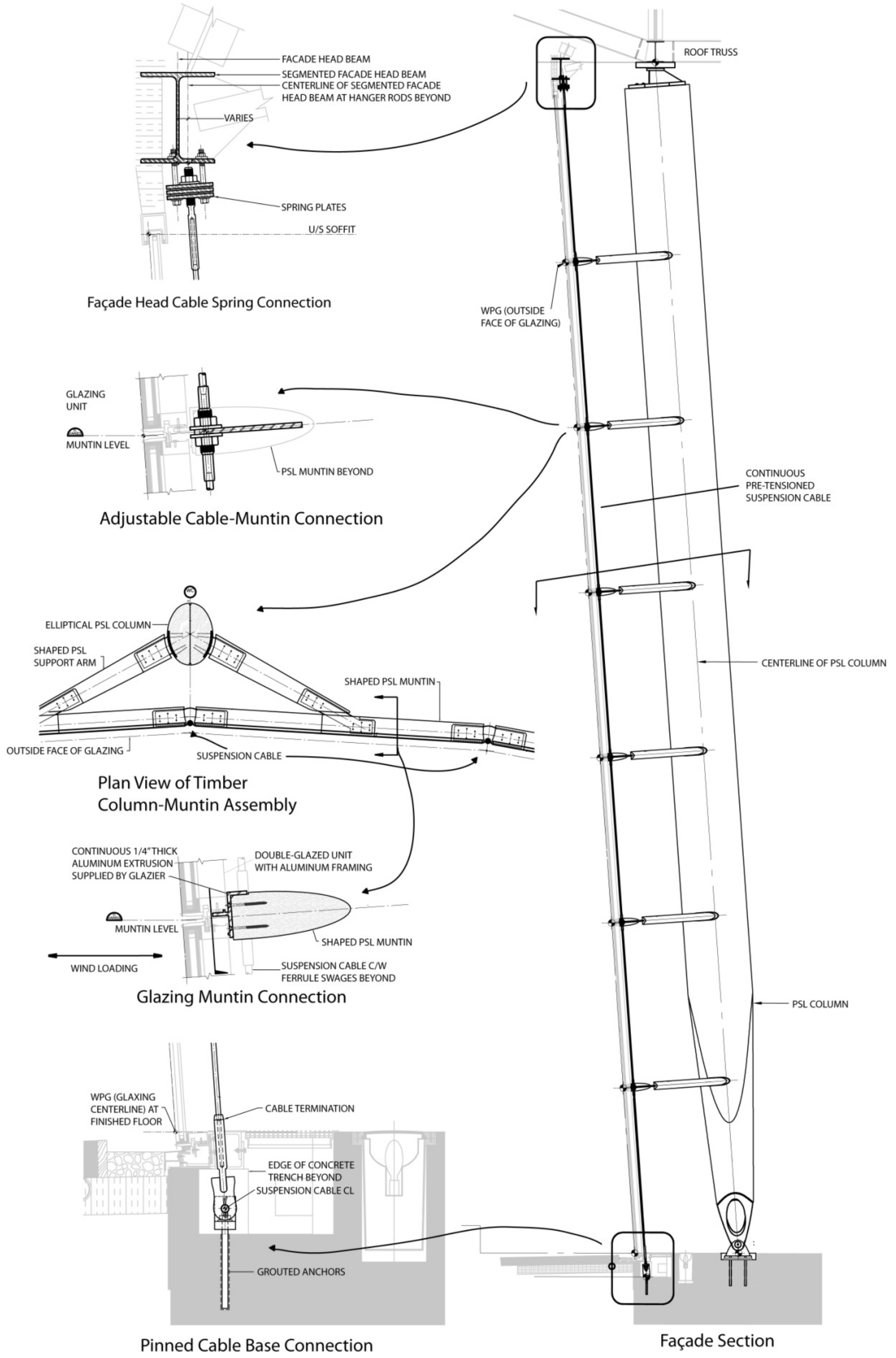


Figure 5: Façade Details

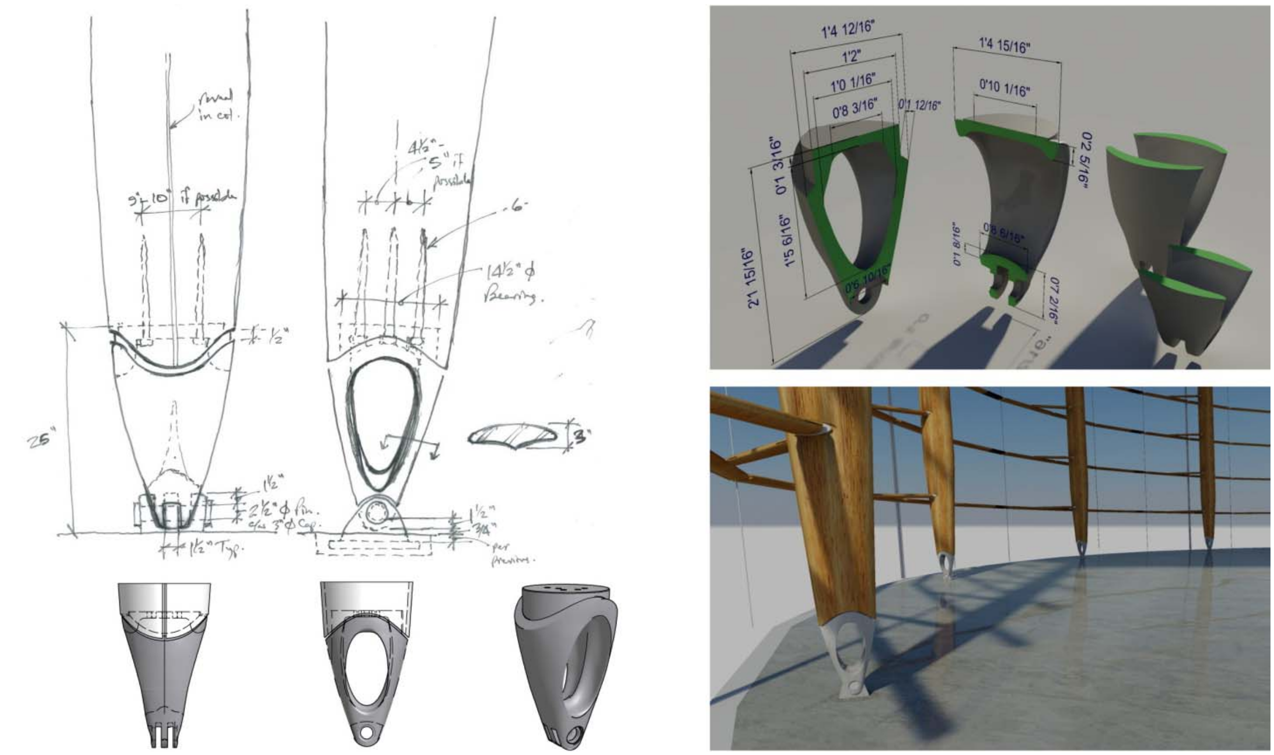


Figure 6: Development of column castings.

Deflection actually controlled the design. The column cross-section was designed with a partially restrained relief joint through the neutral axis to manage the strong potential for movement and checking in the timber. The base connector for the columns is a highly visual element meant to reference a lightly touching ballet slipper, heightened by "pencil-sharpened" tapering on the bottom 10 feet of the timber (Fig. 6). Non-linear 3D solids finite element analysis and full scale load testing was performed to create least weight of the ductile iron casting.

The roughly 6x12 foot glazing units and shaped PSL muntins are suspended from 9/16" diameter stainless steel cables (Fig. 7) via fully adjustable connectors. In order to accommodate erection tolerances and ensure tension during the life of the building, a carefully calculated assembly of 3 plates as "leaf springs" (Fig. 8) was installed at the top of each cable.

Figure 7: Timber and cable façade structure prior to glazing. **Photo Courtesy of Bing Thom Architects**

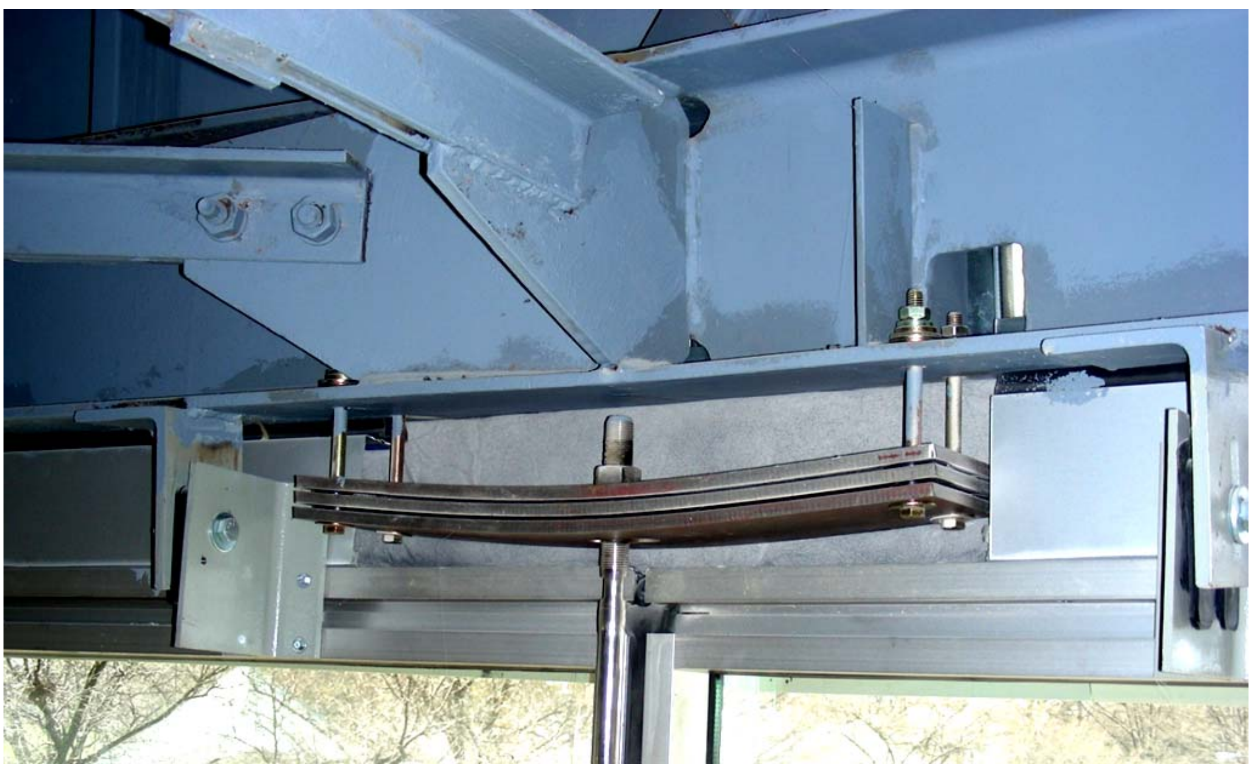


Figure 8: Cable spring plate connection at top of façade.

The entire façade is structurally complex; lateral deflections occur in both the span of the columns and in the slender spans of muntins between the columns, which gain their stiffness through a combination of bending and axial forces (catenary action). Analysis determined that stiffness in the system was quite dependent on bending moments being carried through every PSL muntin to muntin joint, making the connection an important part of the overall design.

Research and load testing was carried out on a tight-fitting multi-pin connector (Fig. 3) which would allow the connection to be virtually invisible, yet efficiently carry the high forces. It was further proved on a system basis when a full size 50x60 foot mock up was constructed and tested with full design wind forces at a test facility prior to erection on site.

This is believed to be the tallest timber-backed glass façade in the world.

Cradle Theater – A third significant structural element in the Arena Stage project was the Cradle Theater. Contrary to what its name implies, the structure for the Cradle Theater is not small. Its 80 foot high, 10" thick, elliptical, petal-like sloping concrete walls grow out to create fairly dominant features in the exterior of the facility. Architectural concrete was the only finish affordable, but there was great concern over the skill of concrete trades that were not accustomed to achieving this feature in the Washington market, especially with the curved and tilted surfaces, which splay out at 4° from vertical. The team turned to a formwork system called PERI to help achieve goals. Further, "box in a box" was the acoustical mandate for this new theatre, so the slender 10" walls became the backing for a variety of large steel embedded brackets for acoustical isolaters to rest the interior structures on, creating reinforcing challenges. (Fig. 9)

Figure 9: Tilted elliptical concrete walls of the Cradle Theater; note acoustical isolation brackets which support interior floors.

There was a strong desire to avoid any cross-bracing in the plane of the façade, and it was discovered that by strategic connection of the high roof to the Cradle walls, this shape could withstand the lateral forces, including torsion, on the entire roof. (Fig. 10 and 11)

It was the setting and achieving of such goals which made the project so successful in its final execution, as can be testified by visiting the facility. The project has garnered much local and international media attention. As one local critic commented, "It took Canadians to bring a change to Washington."

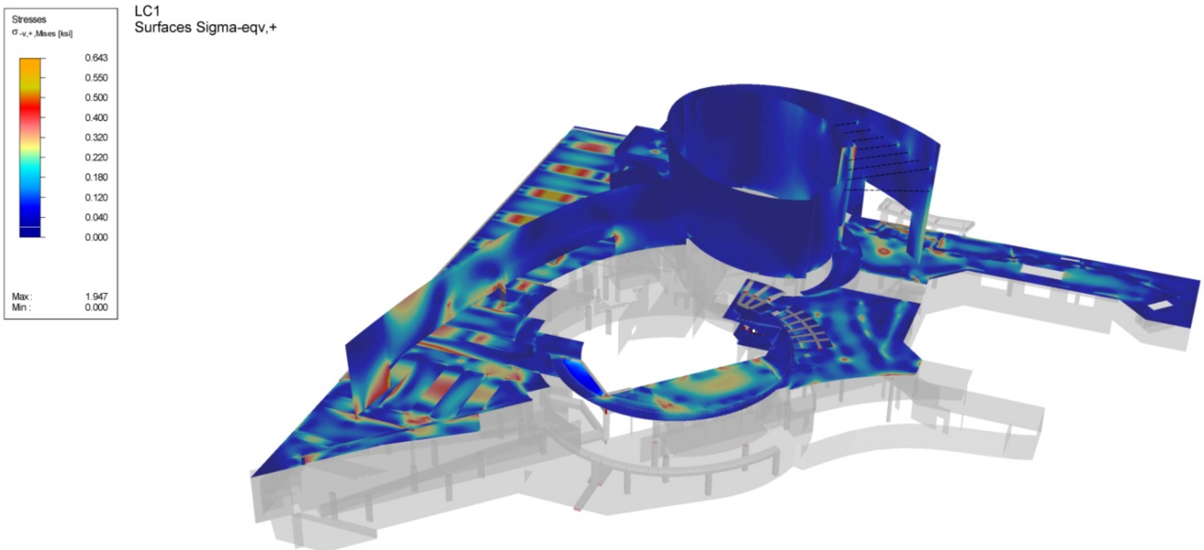


Figure 10: Finite Element Model of Concrete Structure.

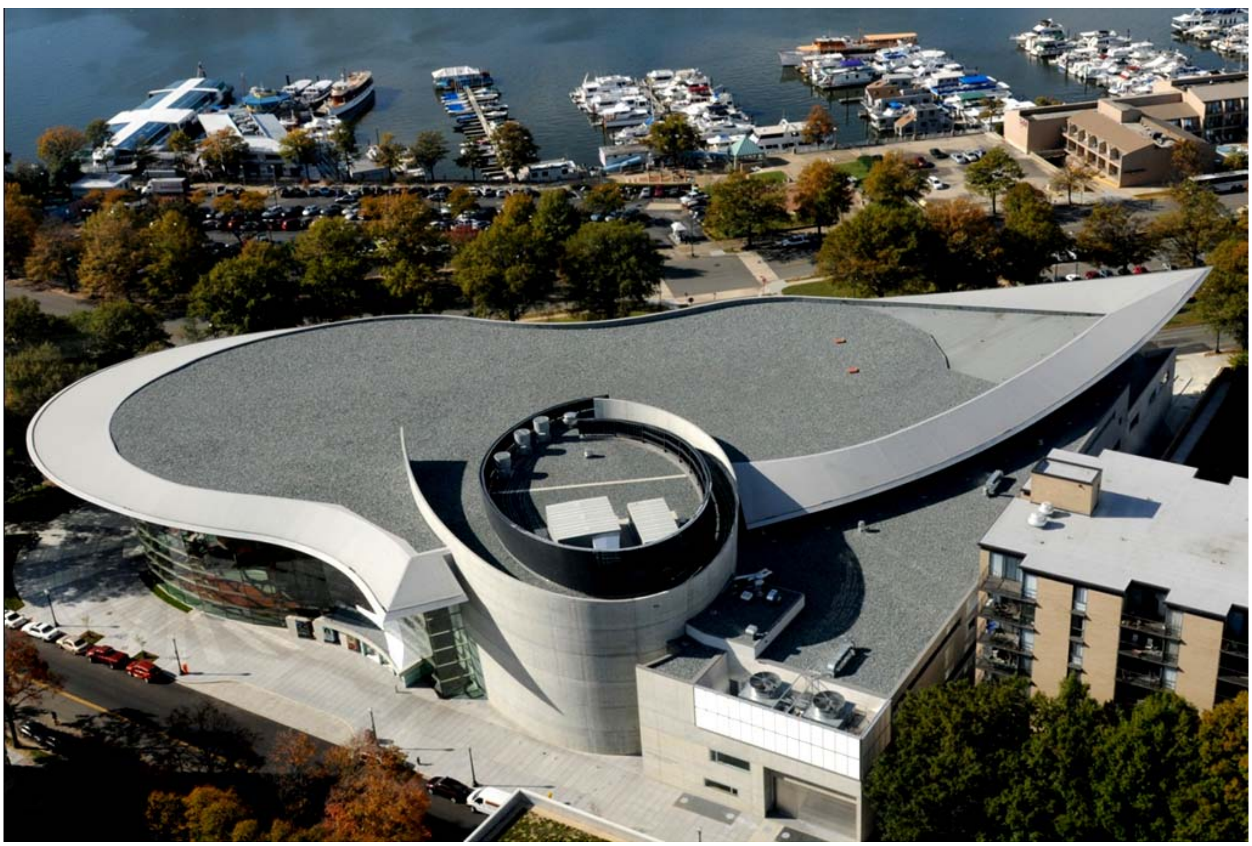


Figure 11: Aerial view; note elliptical concrete cradle structure.
Photo Courtesy of Washington Metropolitan Area Transit Authority

COMPLEXITY

- Convincing local authorities to approve exceptions to the Washington building code through detailed reports and testing to accommodate the structural heavy timber and other custom structural solutions. Proving the high fire resistance of heavy timber was a key achievement.
- Developing alternate schemes to make the difficult geometry cost-effective in response to Client budget shortfalls.
- Using a variety of materials, each appropriate to their use, particularly materials and finishes which are unusual in the local market and lack experienced trades.
- Developing foundation structure to span across existing sanitary sewer.
- Ensuring acoustic isolation between spaces; accomplished by free-standing façade; new Cradle theater structure interior entirely supported on neoprene pads; new floors supported directly on the roof of one of the original theatres.
- World class timber structure, showcasing new ideas in wood.
- Using wood to support large span steel roof.
- Development of large, unique, highly stressed casting as column base, including testing.
- Development and testing of tight-fitting pin timber connector for the project, resisting axial forces and bending moments.
- Believing in and proving a risky design and spring-loaded suspension system for a sensitive glass façade. Glazing units are sealed to provide an acoustic barrier; the backup system had to resist wind loads and forces sufficiently to prevent the seals from popping.
- Supervising erection for the difficult parts of the structure, including full-scale mockup of façade.
- Believed to be the tallest free-standing timber-backed façade worldwide.
- Truly innovative and precedent-setting Canadian engineering in the US Capitol.

ENVIRONMENTAL IMPACT AND ECONOMIC BENEFITS

This project involves the unprecedented use of architecturally exposed engineered wood. Such wood is far and away the most sustainable structural material.

Extensive use of efficient architecturally exposed structural materials starkly contrasts with the heavily clad structures of Washington. Persistent “value engineering” eliminated superfluous finishes and put pressure on the structural engineer to provide aesthetically satisfying structure.

For example, the custom timber façade is not only structurally unique, but also uniquely serves as acoustical barrier and roof support, yet costs less than commercially available alternatives.

SOCIAL AND ECONOMIC BENEFITS: MEETING & EXCEEDING CLIENT’S NEEDS

The original design intent for Arena Stage called for a creative and ‘dramatic’ design that would bring new vitality, not only to the aging theater, but to the surrounding neighbourhood. The client wanted to create a warm place that people were excited to visit, and so be a catalyst for change in the entire area, a forgotten district just south of the National Mall.

Additionally, there was a community desire to retain the two existing theatre structures, the Kreeger and the Fichhandler, as heritage buildings, while replacing and upgrading everything else between them, and adding a new experimental theatre.

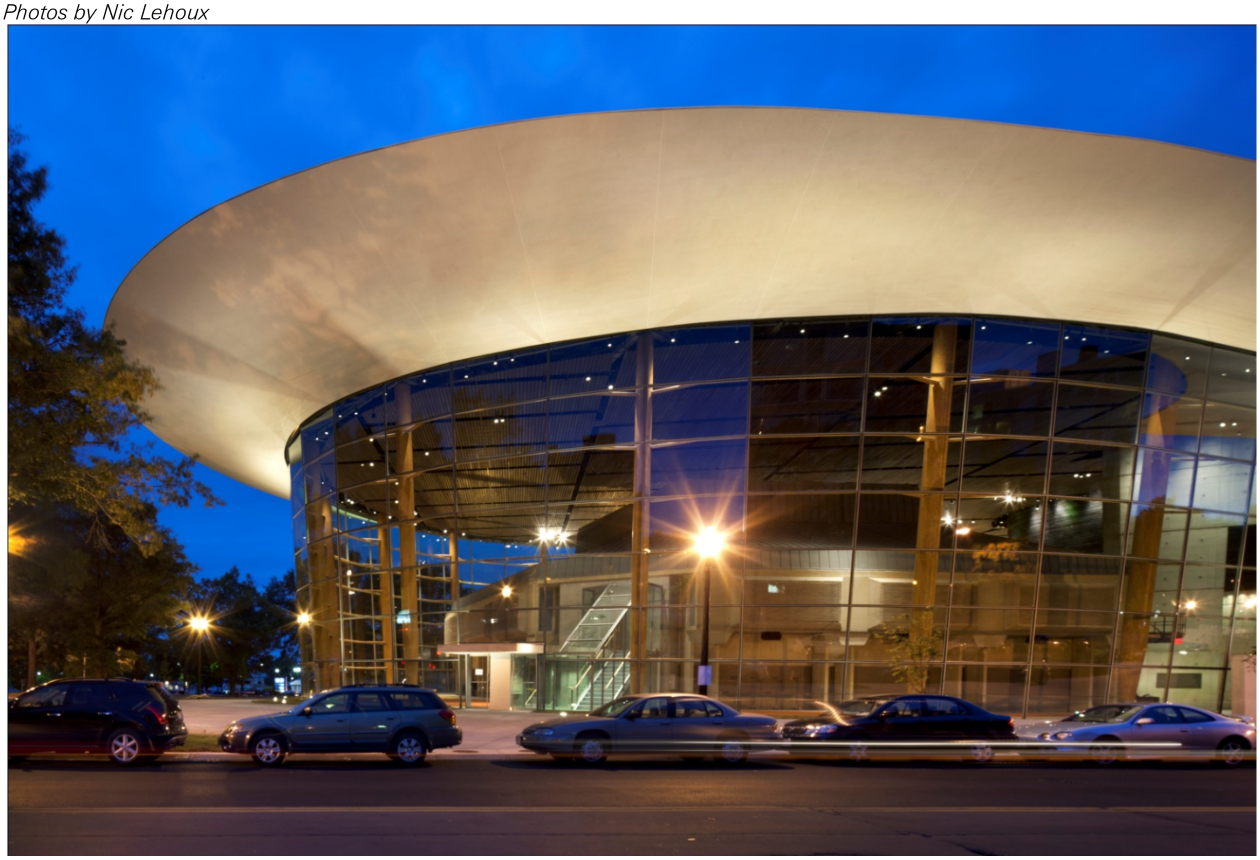
Another important objective was to improve the poor acoustics of the existing theatres – the site is located on the Potomac River, right across from Reagan National Airport, and being so close to the Capitol has numerous helicopters and other aircraft flying overhead.

All of the above goals were realized in the final structure, despite the severe aftereffects of 9/11 which included rising construction costs and lowered donor involvement. The initial design was put on hold just prior to the construction phase, and after a few years and a $30 million budget cut, extensive value engineering and redesign was necessary to accomplish the dramatic, aesthetically and functionally excellent structure that has since garnered significant attention in the capitol and beyond.

The engineer has since been invited to participate in other revitalization/ redevelopment projects in the area.

Complete Project Photos

Photos by Nic Lehoux



Top photo by Nic Lehoux, bottom photo by Stephan Pasche