The Hangzhou Tennis Center: A Case Study in Integrated Parametric Design

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This paper will provide a detailed overview of the parametric methodologies which were integral to the design and development of the Hangzhou Tennis Center. The tennis center is a 10,000 seat facility located in Hangzhou, China and is a part of a larger sports and entertainment master plan which features retail, public recreation, and an Olympic-size stadium to be completed in 2013.

The design of the stadium envelope is based on a modular system of sculptural steel trusses which provide shade and house the arena's technical systems. To design the exterior, an integrated parametric system was created to conceptualize, simulate, and document the complex geometric systems. For conceptualization, the parametric system was set up to explicitly define the control surface geometry and study formal variations. Physics simulation tools were used to test basic structural behavior. For detailed analysis and engineering, custom scripts were used to automate the communication of centerline information to the structural engineering team. For the documentation process, parametric workflow systems were invented to link together disparate design and documentation environments for a more seamless international collaboration.

Figure 1. The Hangzhou Olympic Sports Center featuring a 10,000 seat tennis stadium.

Introduction: Design Computation at NBBJ

Computation is playing an increasingly important role in the design process at NBBJ. The demand for formal innovation and performance-driven systems have necessitated that designers search for novel processes which extend their capabilities beyond 'out-of-the-box' 3D modeling and BIM packages. Additionally, the accelerated drive towards global practice have required design teams at NBBJ to negotiate the complexities associated with coordinating international design and delivery efforts.

The topic of design computation is ultimately a topic of *relevance* for the AEC professional practicing in the 21st century. What emerging technologies will help us extend our ability to navigate the complexities of a global economy? What tools will help the designer realize their visions and enable new constructions to perform better than their predecessors?

The Hangzhou Tennis Center design team had to negotiate a range of challenges whose solutions were enabled, in part, by the customization of parametric tools in addition to the implementation of new computational processes. This paper will provide a detailed overview of the computational methodologies that were used for the successful design and delivery of the Hanghou Tennis Center.

Project Context

The Hangzhou Tennis Center is a 10,000-seat tennis stadium located in Hangzhou, China. (Figure 1) NBBJ, in collaboration with CCDI, designed the Tennis Center as part of a larger sports and recreation master plan which includes an 80,000 seat Olympic-size stadium, an extensive retail development, and a public recreation park. The main stadium and the tennis finals court are the two main structures on the site. Both facilities share a common architectural language of repetitive sculptural truss geometries which compose the exterior envelopes.

Construction documents for the main stadium were completed by NBBJ and CCDI in December of 2009 and the facility has since entered into the construction phase. Rhinoceros 3D with the Grasshopper plug-in were instrumental tools for the design and documetation for both stadiums.

Process

For the tennis center finals court, a parametrically-driven process was implemented. An elaborate parametric algorithm was developed in Grasshopper and was used to study the stadium geometry and coordinate information with the team of collaborators. Exceeding the capabilities for the main stadium system, the tennis center algorithm was significantly expanded and included integrated capabilities for:

- **Geometry Design:** Parametrically defining and controlling the exterior geometry.
- **Form Variations:** Rapid refining of the building form and testing alternatives.
- **Structural Collaboration:** Systems for producing analysis-ready structural models.
- **Conceptual Simulation:** Integrating intuitive physics simulation for an intuitive understanding of complex structures.
- **Surface Analysis and Cladding:** Surface property visualization and detailed parametric paneling systems.
- **Coordination:** Organizing and exporting parametrically generated models for use in external documentation software.
- **Documentation:** 2D descriptive geometry systems for elements which cannot be represented using orthographic projection

Geometry Design

The exterior envelope is composed of a twenty-four truss modules arrayed around a circular arc. Referred to as 'petals', the trusses create a large-scale repetitive pattern which encloses the stadium seating bowl. In addition to giving the tennis stadium its visual image, the shell also functionally provides shade and rain protection for the seating bowl. The structure also houses the stadium technical equipment such as the sports lighting.

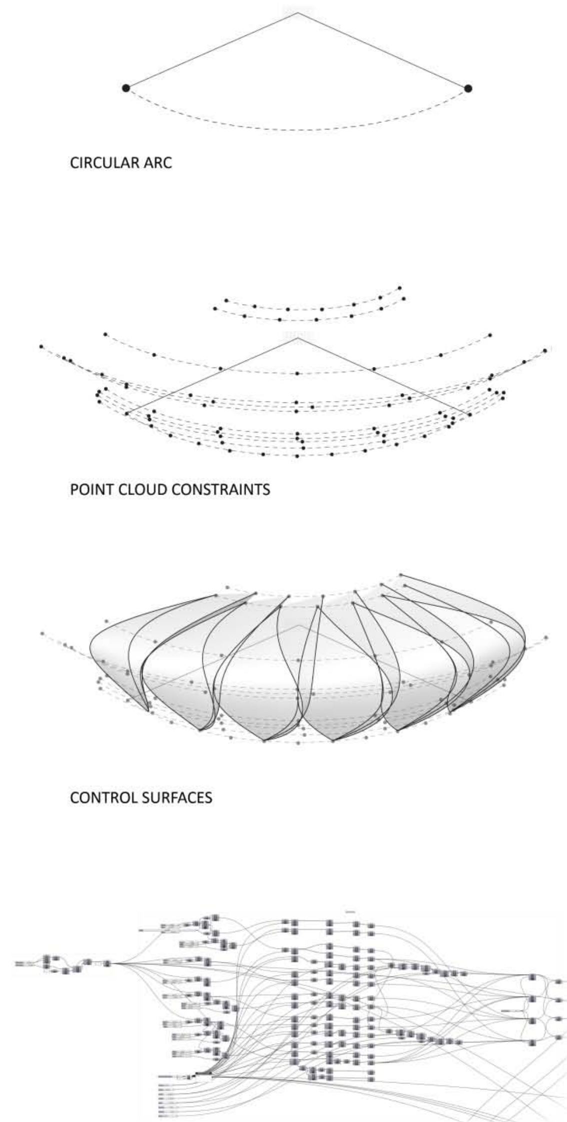


Figure 2. The algorithm for defining the geometry of the exterior shell. A point cloud driven by circular arcs creates the control system for NURB control surfaces.

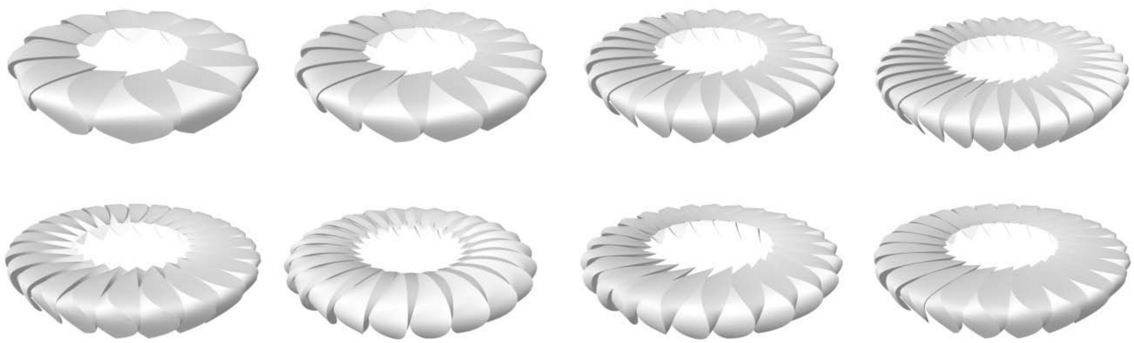


Figure 3. Variations on the exterior envelope. The point cloud constraints were manipulated to create different geometric effects. The number of petal modules could also be increased or decreased.

The initial surface geometry served as a constraint system for building additional complexity into the envelope at later stages. The modular system was defined parametrically by establishing a point cloud system which would serve as control points to define the edge curves of the surface. A ruled surface is then spans between the edge curves. (Figure 2)

Due to the stadium's symmetry, only one quadrant of the entire envelope was computed at this stage. This approach improved the computational performance of the system allowing for much quicker iterations while still enabling the designers to evaluate the overall appearance.

Form Variations

The parametric definition of the exterior geometry allowed the design team to efficiently explore design alternatives and variations within the conceptual constraints. Parametric control of the point cloud was the primary means of controlling the form. Parameters for manipulating the point cloud (sorting, transforming) enabled the design team to study different configurations of the exterior surfaces. (Figure 3)

While much of the evaluation was based on aesthetic judgment, parameters for shade, drainage, structural performance, and sports technical systems were also drivers for arriving at the final form.

Structural Collaboration

Given the integral relationship between the form and the structure, the design team engaged in a very close dialogue with the structural engineers. NBBJ worked with CCDI structural engineering team to coordinate the 3D steel model. A truss centerline model was parametrically driven from the ruled surface control geometry. Parameters were established to allow control over structural member spacing and truss depth.

The engineers required a structural centerline model which could be used for analysis. To facilitate this process, the Grasshopper algorithm would automate the generation of a wireframe structure which was compatible with the tolerances of the engineer's analysis software. (Figure 4) This allowed the teams to eliminate, with some minor exceptions, the design-analysis turnaround time associated with rebuilding an engineering-specific model. In addition, adjustments could quickly be made to the model based on the engineer's calculations.

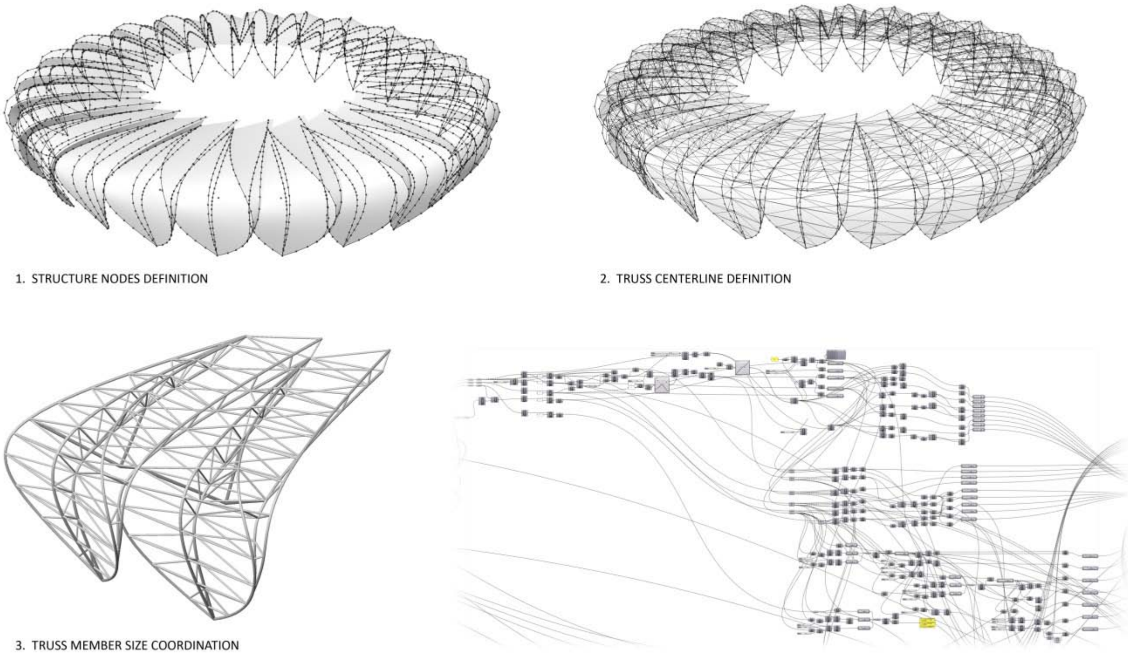


Figure 4. The parametric structural design model. Centerline information was exported for structural analysis. Member sizing was coordinated with NBBJ's parametric model.

Conceptual Simulation

While the structural team was able to perform a comprehensive analysis to engineer the structural systems, additional functionality for conceptual simulation was added into the Grasshopper algorithm.

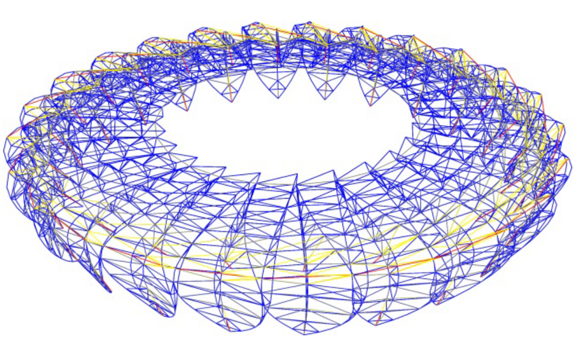


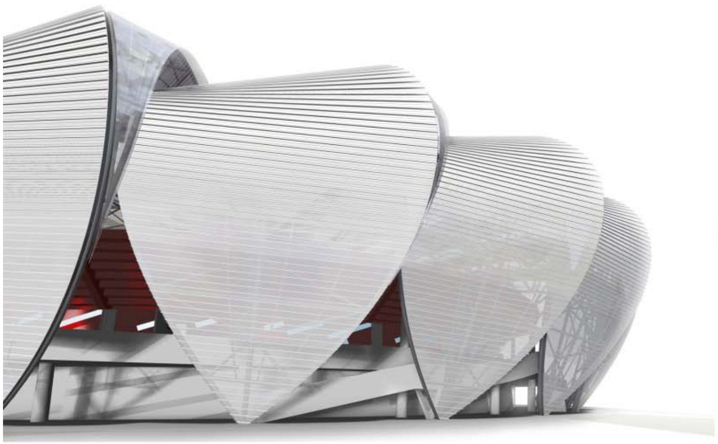
Figure 5. Using the Kangaroo physics engine to visualize gravity loading on the truss centerline model.

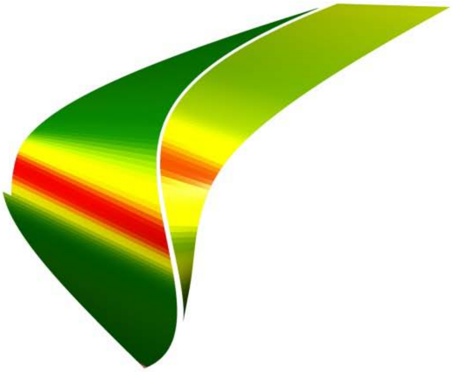
An experimental physics engine was tested with the structural centerline model to simulate gravity loading on the steel truss structure. (Figure 5)

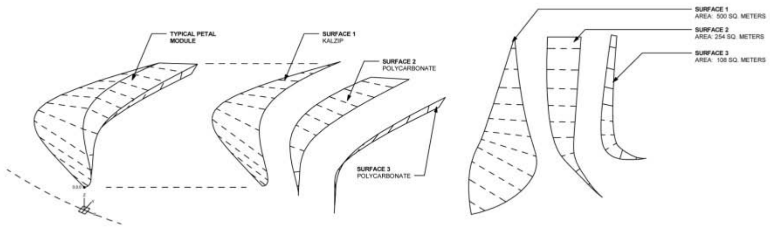
Kangaroo physics, in combination with a visualization script, was used to provide an intuitive display for how forces moved through the structure. Tensile and compressive forces could be visualized in addition to areas of maximum stress. Having this capability embedded into the design model at a conceptual level allowed the design team to make more informed decisions and engage in a more nuanced dialogue with the structural engineering team.

Surface Analysis and Cladding

Surface analysis was also integrated into the parametric algorithm in order to visualize and quantify areas of curvature in the geometry. The ruled surface of the petal







PETAL SURFACE AREAS

SURFACE	MATERIAL	NUMBER OF MODULES	TOTAL AREA (SQ METERS)
SURFACE 1	KALZIP	24	12000
SURFACE 2	POLYCARBONATE	24	6096
SURFACE 3	POLYCARBONATE	24	2592
		TOTAL SURFACE AREA	20688

Figure 6. Surface analysis and cladding of the petal truss form. Panel planarity was visualized and a detailed standing seam panel system was created to clad the structure. The parametric algorithm as unrolled the surfaces and estimated material quantities.

was paneled using the UV coordinates of the surface. Each panel was tested for planarity. The curvatures informed the selection of a standing-seam aluminum cladding system. (Figure 6) The cladding system was parametrically modeled in order to more accurately study the visual appearance of the panel seams, spacing, and perforation ratios.

The fabrication process of the aluminum panels allow for continuous spans from each edge of the surface with tapered configurations. This resulted in façade components which remained true to the ruled surface UV parameterization.

Coordination

For the design development phase of the tennis center, the tennis stadium geometry needed to be documented.

In addition to being an essential tool for geometric development and structural design, the Grasshopper algorithm also facilitated coordination with other external documentation tools. Custom scripts were created which automated the export process of key model elements to a file system of 3D DWGs. The script enabled automatic updating of converted files so external applications could make use of the most up to date information.

The design team used this method as the primary means of translating the 3D information into the Autodesk Revit model.

Documentation

Revit was used to generate documentation sheets

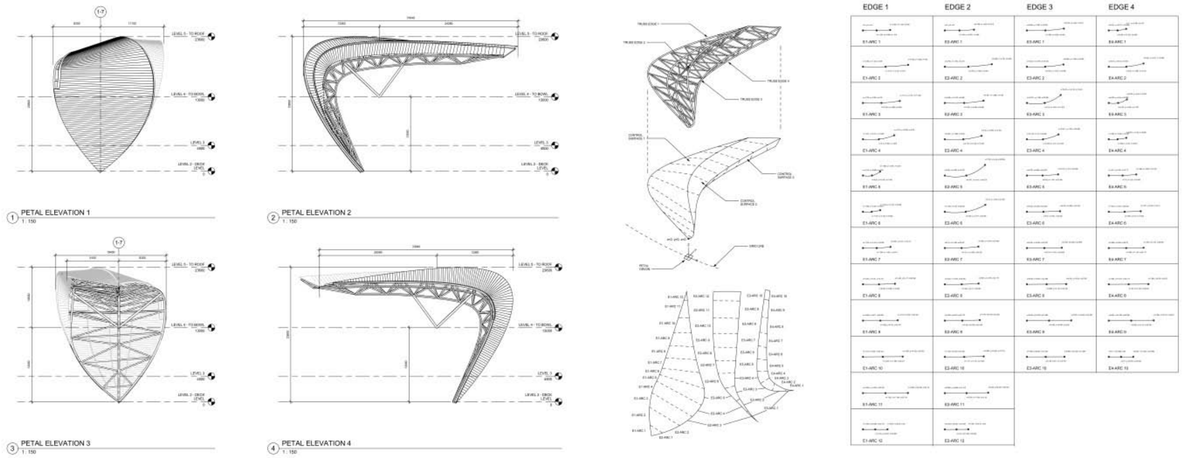


Figure 7. Examples of documentation created using a combination of Grasshopper-generated descriptive geometry and orthographic drawings created in Revit Architecture.

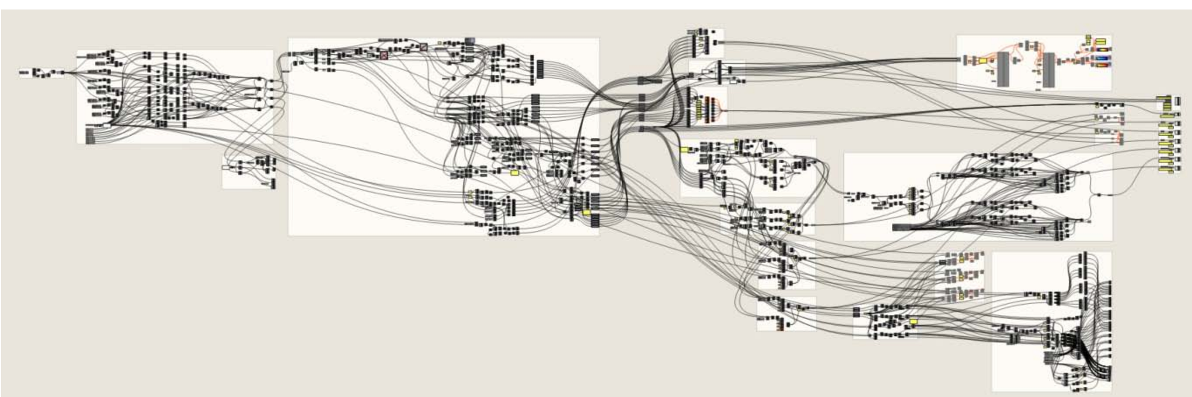


Figure 8. The complete Grasshopper 3D algorithm for the Hangzhou Tennis Stadium.

containing orthographic drawings of the exterior shell. The drawings of the exterior shell were exchanged

with the CCDI team for inclusion in the 2D documentation set. (Figure 7)

For geometry which could not be described using orthographic projection, the algorithm was also used to produce 2D descriptive geometry. In the case of the petal truss surfaces, a custom Grasshopper script automated the unrolling of the ruled-surfaces. These drawings were used in conjunction with a surface quantity spreadsheet. The algorithm also produced a live spreadsheet which contained information on surface curvatures.

Future Work: Design the Process

Historically, the AEC industry has been slow to adopt new technologies into the design process. Many of the tools popular in architecture offices today support design and production processes that have been in place for decades or longer.

However, the rapid acceleration towards global practice coupled with advancements in information-based economies necessitate that architects develop their systems and processes to be adaptive and flexible. The Hangzhou Sports center is an example of process a where new design tools were invented, developed, integrated, coordinated, modified and shared for the purposes of delivering a project of special civic value in China.

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