Unique Structural Gems on China's Landscape

The new **Taiyuan Botanical Garden** complex in Taiyuan, China, features three paraboloid domes ranging from 140 to 290 feet in diameter and from 40 to 100 feet in height. The gridshells comprise light doubly curved glulam beams arranged in two or three crossing layers. The project pushes the boundaries of structural engineering and construction technique in a country with little experience using timber for long-span applications, creating three beautiful gems for this growing city.

Timber was chosen for this project due to its adaptability to the geometric demands, inherent fire resistance, structural flexibility, natural aesthetic, and environmental sustainability. Working with Austrian architect DMAA, StructureCraft engineers developed an optimized geometry while looking at constraints like daylighting, structural performance, shipping, and fabrication and pre-assembly, all meticulously described, not only with digital files for the fabrication but with kit-of-parts erection and sequencing drawings for site crews.

Domes are usually constructed for efficiency using triangulation in the dome surface. However, for architectural and sun-shading reasons, the architect and client wished to create a more tightly spaced grid on the southern side, more open on the northern side. This led to the development of a less efficient gridshell-like and irregular rectangular grid.

Further, domes are usually spherical, leading to more repetitive surface patterns. The client and architect were insistent on a unique paraboloid and challenged StructureCraft: how could all this be built economically? And how could structural efficiency be enhanced, given the less stable non-triangulated surface?

The solution for the first question lay in exploiting the full potential of and writing new scripts for the latest in computational geometry software, seeking to optimize the precise shape of the paraboloid to minimize waste in the doubly curved glulam pieces while seeking structural efficiency at the same time.

To solve the second, more global structural issue, inherent local buckling instability resulting from the non-triangulated surface: a diagrid of almost invisible cables was inserted below the gridshell surface, which stabilized and organized the buckling modes.

The complex structure also needed to be buildable. Building piece-by-piece up to nearly 90.5 feet (30m) in the air, expecting all to fit with structural forces properly transferred, would be impossible. The solution lay in prefabricating precisely the individual pieces and a pattern of roughly 33- x 40-foot (10m x 12m) modules that could be placed on shoring towers and stitched together using simple, custom-designed scarf joints.

Gridshells are not entirely new. Traditionally, a non- triangulated gridshell was constructed by fitting wooden laths together onsite – labor-intensive and not very precise. But it was the only practical way to deal with the geometrical complexity.

The highly complex geometry was solved in advance with this project, allowing each unique piece to be prefabricated with confidence that it would fit on site. In addition, the geometry software was pushed so that the amount of two-way curvature necessary in each piece was rationalized. Thus, the volume of waste and CNC cutting time was minimized.

Secondly, a non-triangulated gridshell dome is especially vulnerable to snap-through buckling in numerous complex modes. This vulnerability was efficiently dealt with using a novel, relatively light grid of cable diagonal bracing installed just below the gridshell surface, almost invisible, yet allowing the timber members to be much lighter and saving tremendously in material costs and erection labor.

A significant challenge lay in how to tension the cables, given that they had to connect numerous nodes in a two-way pattern. Single adjustable pieces between nodes would have been prohibitively expensive and labor-intensive. Long lengths of cable continuous through the nodes also created a challenge in that tensioning at the extreme ends would be impossible due to friction at each node. The problem was neatly solved by devising for each node a unique casting with separate pieces joined with an adjusting bolt which could essentially "pull" tension into the cable. It proved to be a highly effective, constructible method onsite.

The result of these efforts is a unique series of long-span timber structures created through the cooperation of team members on three different continents in their desire for a world-class attraction.▪

StructureCraft was an Outstanding Award Winner for the Taiyuan Botanical Garden Domes Project in the 2021 Annual NCSEA Excellence in Structural Engineering Awards Program in the Category – New Buildings $30M to $80M