In Search of the (w)hole: Shadow Pavilion

Project Facts

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Faculty Lead Design / Research Project

**LOCATION:**
University of Michigan Matthaei Botanical Gardens

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The Shadow Pavilion explores the paradox of a perforated structure where the removal of material makes a structure lighter and weaker. The Shadow Pavilion, designed for a site at the University of Michigan Matthaei Botanical Gardens, is both a structure and a space made entirely of holes.

The pavilion surface is made with over 100 aluminum laser cut cones that vary in size. Beyond testing the limits of sheet aluminum, the cones will act to funnel light and sound to the interior space, offering visitors a space to take in the views and sounds of the surrounding landscape.

Organizational schemes for the cones are explored, including the logic behind the concept of phyllotaxis. In botany, phyllotaxis describes a plant’s spiral packing arrangement of its elements. The organization of the cones may limit the form, but can strengthen the structure.

The laser cutting process uses the digital design information to precision cut and finish the aluminum cones. The pavilion’s surface will maintain the natural aluminum finish and smooth edges resulting from the laser cutter.
In botany, phyllotaxis describes a plant’s spiral packing arrangement of its elements. The method of packing in plants is used to investigate formal and organizational options.

The grid of cones can take on several configurations: the two displayed here are the hexagonal grid (top) and the square grid (middle). The advantage of the hexagonal grid over the square grid are six points of connections versus four points of connections between cones/rings. When the cones take on a spherical shape (bottom), all of the cones point toward the center of the sphere.
Preliminary studies exploring the use of varied cones to create an undulating surface with varied thickness. As the cone height increases, the unrolled cone approaches the shape of a full circle.

The depth of the cones were varied to address different loading / spanning conditions. The depth would increase where the moment would also be greatest. Such a strategy allows for a reduction in weight were the material does not add to the load carrying ability.
The studies above look at the unit, which can be made of two cones or one cone and one ring, with varying ring size. Ring depths are a compromise between material and strength of the whole, but the location of the ring also determines its strength. Rings closer to the center are less likely to deform than rings at the edge.

Ring organization can depend on several factors. In the top scheme, cones, rather than rings, are used. In the middle scheme, thinner rings are found toward the center. In the bottom scheme, ring depth varies away from a point.
The shape of the unit of two (either cone + cone or cone + ring) affects the shadow pattern on the previous page. The top scheme is a cone and a ring. The middle scheme is cones of different sizes paired up and the bottom scheme is a 60 deg cone and another identical 60 deg cone.

The shadow was studied as it was a result of cone angle, depth, and arrangement. As the research moved from a prototypical condition to that of a site at the botanical garden, the importance of the shadow became apparent.
Each prototypical scheme looked at the shadow produced from the arrangement of the cones (top). Snapshots of the shadow pattern on the ground throughout a summer day are recorded (right). The shadows show a second set of openings apart from the openings of cone canopy; these 'openings' grow larger and smaller depending on the location of the sun relative to the pavilion.
An early scheme that explored curvature in one direction. Varying the width of the surface circle dimensions creates curvature while using identical cones on the bottom layer. In this proposal half of the cones would be identical, while the others vary to change the curvature.

By cutting individual cones, the openings in the cones can grow smaller or larger, but the tradeoff for a larger opening using this method is a loss of connection between cones. The resulting form is both more porous and more flexible. Each cone in these series is different from its neighbor.
RhinoScripting cones onto a pre-determined surface. A single-curved surface is first divided into a hexagonal grid, where each hexagon is tangent to its neighbor at the midpoints of each line segment. These tangent points are crucial because they are the six connection points that give the structure its strength. Guide geometry is then drawn that will determine the height of each cone on the bottom layer. Each cone in the top layer also responds to the guide geometry to connect to its six neighbors and to the three cones on the bottom layer that are closest to it.
(Left): The angle of the cone affects the amount of material cut out. In the far left series, a sixty degree cone will use the material in the most efficient way. The next series searches for an appropriate depth. (Right): Two cones comprise one unit. (Bottom Right): One cone and one ring comprises a unit, resulting in the use of one sheet of aluminum rather than two.
A single layer of cones are connected in a square grid (top). This approach results in a surface able to be reconfigured.

The organization of the units limits the forms, but variety can be obtained through a repetition of cones. To achieve this repetition, parts are revolved around a point or axis. Several of these types of revolutions are shown here. In the two forms on the left, a curve is revolved around an axis. In the rightmost form, each horizontal row of cone is slightly rotated along this ‘horizontal axis’ to produce a twisting form. In all cases, there are sets of duplicated cones.
The logic of the torus helps determine which cone units are repeatable and the number of cone variations. One row of cones can sit on a ground plane whereas the rest of the cones are lifted by a single column. The strength of the cones and the position of the rings helps determine which cone-ring configuration is the most suitable structurally. A flat canopy system of cones is explored. The position of the rings is meant to offset either compressive or tensile forces.

A continuous surface is applied to a single layer of cones to maintain the curvature in the bottom layer of cones. Because the cones may be easily compressed, rings are placed inside the cones to strengthen the structure. The disadvantage is increased material waste when rings are cut from a flat plane. Curvature is introduced into the canopy to offset any sagging that may occur from the weight of the cones.
In order to get a repeatable number of units, the logic of the torus was used. The model above has 10 cone variations: in the plan, all the cones within each horizontal row is the same sized cone. The ellipsoid produces repeatable units not only across each horizontal row, but also produces duplicates between the top and bottom half. The combination of a curved surface and a hexagonal grid reveals a spiral unit organization based on the botanical model of spiral circle packing.
RhinoScripting individual cone variation. The amount of curvature determines the size of the cones. Above are three methods of cone variations. In the top scheme, all the cones have the same height and the smaller openings are a factor of the larger openings. In the middle scheme, all the cones have the same height with different sized openings but are 60 degrees. In the bottom scheme, all of the cones are 60 degrees and have the same size smaller opening, but vary in height. The third option was developed because it allowed for the most efficient use of sheet material.
Located in the botanical gardens, the pavilion can be seen from the main road entrance. The pavilion is meant to act as a shaded shelter for groups walking along the nearby trails. Once inside, the pavilion orients a visitor to a long view across the prairie.
Plans and sections give the relative size compared to a visitor. The maximum cone size is based on the aluminum sheet size. As a result, the size of the pavilion is increased through addition of more units to increase the span or volume.
The built form for the botanical gardens is rotated around a single axis and tilted upwards from the ground plane to produce an oculus toward the front of the pavilion. Each ring and cone is held to its neighbor by six connections points, strengthening the overall structure.
Once the aluminum was laser cut all the parts were formed, and assembled into sub-assemblies that would be transported to the final site. As the cones were assembled, the sub-assemblies began to take the overall curvature of the pavilion. Based on an initial survey of the topography, the first row of cones was located on the site. The base cones were built to be closed and filled with gravel to prevent uplift of the pavilion. Once the first row was set, the assembly process took four days on site.
The reflective quality of the aluminum creates a reversal in the reflection of sky and ground (left). The oculus frames a view of the Sam Graham Trail and the clearing in the distance. The foliage of the trees framed by the view is expected to fall during the winter months, thus changing the view alongside the change in seasons.
The aluminum of the pavilion picks up the color of its surroundings. On a sunny day, the pavilion absorbs the blue of the sky and the color of the ground. On cloudy days, the pavilion becomes gray in color. The curvature of the cones results in a dynamic view on the interior of the pavilion.