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Integrated Design and Architectural Geometry for the Southern Dunes Canopy

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Abstract

Situated a short distance inland from the Red Sea coast, Southern Dunes is a new resort completed in 2023 within a vast desert landscape. This research paper presents the architectural geometry of the central canopy, its integrated design, and subsequent computational implementation. Specifically, the canopy comprises four petal typologies consisting of vertical steel columns and curved ring beams interconnected via eloquent tensile systems of rope-clad steel wires. The 3-dimensional geometries resulting from the multitude of overlapping linear elements in each petal are reminiscent of 19th century mathematical models and 20th century avant-garde sculptures. The density and position of the rope system was informed by its environmental performance in terms of shading. In particular, a site-specific sun analysis was performed to ascertain the optimal comfort levels both for humans and the Oasis' flora underneath throughout the year. This was achieved by developing an integrated computational design framework which also guided the construction of the thousands of ropes.

Keywords: conceptual design, spatial structures, architectural geometry, integrated design, canopies, sun analysis, tensile structures

1. Introduction

Situated a short distance inland from the Red Sea coast, Southern Dunes is a new resort completed in 2023 within a vast desert landscape (figure 1). Located in a spectacular setting, where the dunes meet the mountains, the entrance to the resort is marked by a distinctive flower-shaped canopy, sheltering a lush oasis. Planted with local species of flora, it cools the space naturally and enhances its environmental qualities. The lightweight, rope-clad petals accommodate the welcoming area and many other amenities surrounded by panoramic views of the mountains and desert beyond. The structures have been carefully planned and sited to minimize environmental impact.

In terms of developing the architectural geometry of the canopy, at a first instance the radial configuration of ring beams and columns was defined (figure 2). Subsequently, a shading system was designed to connect said ring beams and columns whilst providing the necessary sheltering from the sun. Furthermore, the primary structural system needed to be seamlessly integrated within the canopy geometry. The intended effect was for the ring beams to 'float' in space supported from a lightweight yet voluminous, tensile system. To achieve this, a rope system was devised for each one of the four petal typologies. This comprised several straight 1-dimensional elements the configuration of which resulted in an eloquent 3-dimensional structure in space. In other words, by using simple lines we sought to achieve a complex and expressive architectural geometry which would address the brief whilst being aesthetically distinctive.

Figure 1: Southern Dunes resort in the context of the surrounding vast desert landscape. Image credits: Foster + Partners.

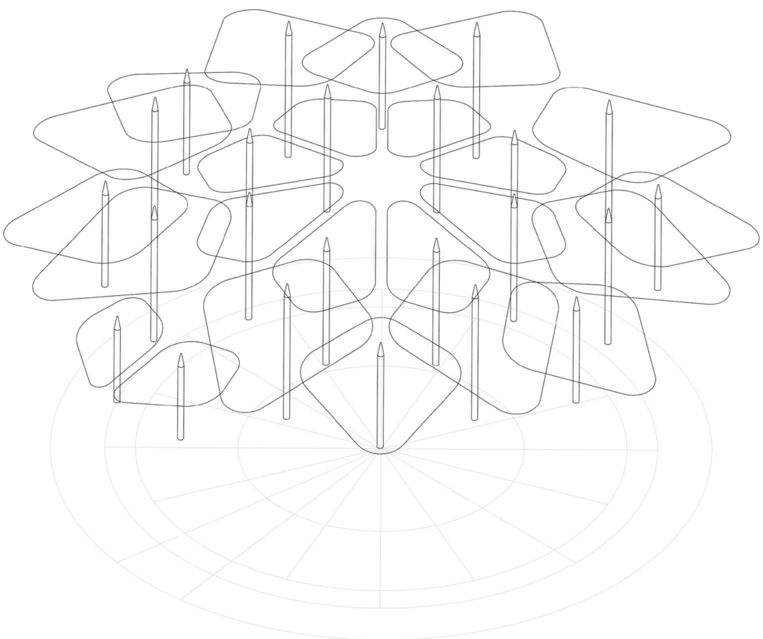

Figure 2: Axonometric view of the ring beam and column configuration. Image credits: Foster + Partners.

2. Precedents

The origin of this type of geometries known as ‘string models’ can be traced to 19th century mathematical models (figure 3 Top Left) (The Royal Society [1]). Specifically, to the development of ruled surfaces by French mathematicians Gaspard Monge and Théodore Olivier for pedagogical purposes. It is interesting to note that at the time, these models constituted the latest in design technology; similar to today’s advancements in Computer-Aided Design (CAD). Also, they related to mathematical developments such as descriptive geometry and, at a later stage, catastrophe theory (Thom [2], McRobie [3]). The interest in such geometric forms, where 3-dimensional shapes are born from simple 1-dimensional elements, drew the attention not only of scientists but also of artists such as Henry Moore (figure 3 Top Right), Barbara Hepworth (figure 3 Bottom Left), and Naum Gabo (figure 3 Bottom Right) (Sidlina [4]).

Figure 3: Top Left: String surface mathematical model: Conoid in contact with a hyperbolic paraboloid by Fabre de Lagrange, 1872. Image credits: The Science Museum, London; Top Right: Stringed figure by Henry Moore, 1960. Image credits: The Henry Moore Foundation; Bottom left: Orpheus by Barbara Hepworth, 1956. Image credits: Sotheby’s; Bottom right: Linear construction in Space No.2 by Naum Gabo. Image credits: Nina & Graham Williams/ Tate.

3. Computational Design Method

The computational design method was implemented in the parametric modelling tool 'Grasshopper' in the Rhino CAD environment. The various elements of the system were initially defined in terms of their centerlines and were fully parametric in terms of their geometry, dimension, location, and density. This facilitated the early conceptual design explorations as well as the integrated analysis and design workflow where the geometry was directly informed by its performance. Furthermore, the parametric model was used for communicating the geometry to the Foster + Partners teams involved such as the Architectural Studio 4 team, the Specialist Modelling Group, and the Structural Engineering team. Lastly, the final model was documented as a 'Geometry Method Statement' (GMS) (figure 4) to inform the construction process of the Oasis canopy.

3.1. Design Systems

The canopy comprised three seamlessly integrated systems (figure 4): the ring beams and columns; the rope system; and the structural cables. These were the constituent elements for each one of the four different petal typologies. The petals were arranged in a radial configuration based on concentric circles to form the resort's welcoming area and central Oasis around which various amenities were arranged.

The Geometry Method Statement approach developed by Foster + Partners, was used to describe the form of this non-standard geometry. This is a way to communicate the design intent so that the geometry of relevant building elements can be described using the simplest possible series of steps. This allows the local collaborating architect, contractors, fabricators, or surveyors to produce the same geometry independent of what software is used. In a sense, this represents the geometry DNA.

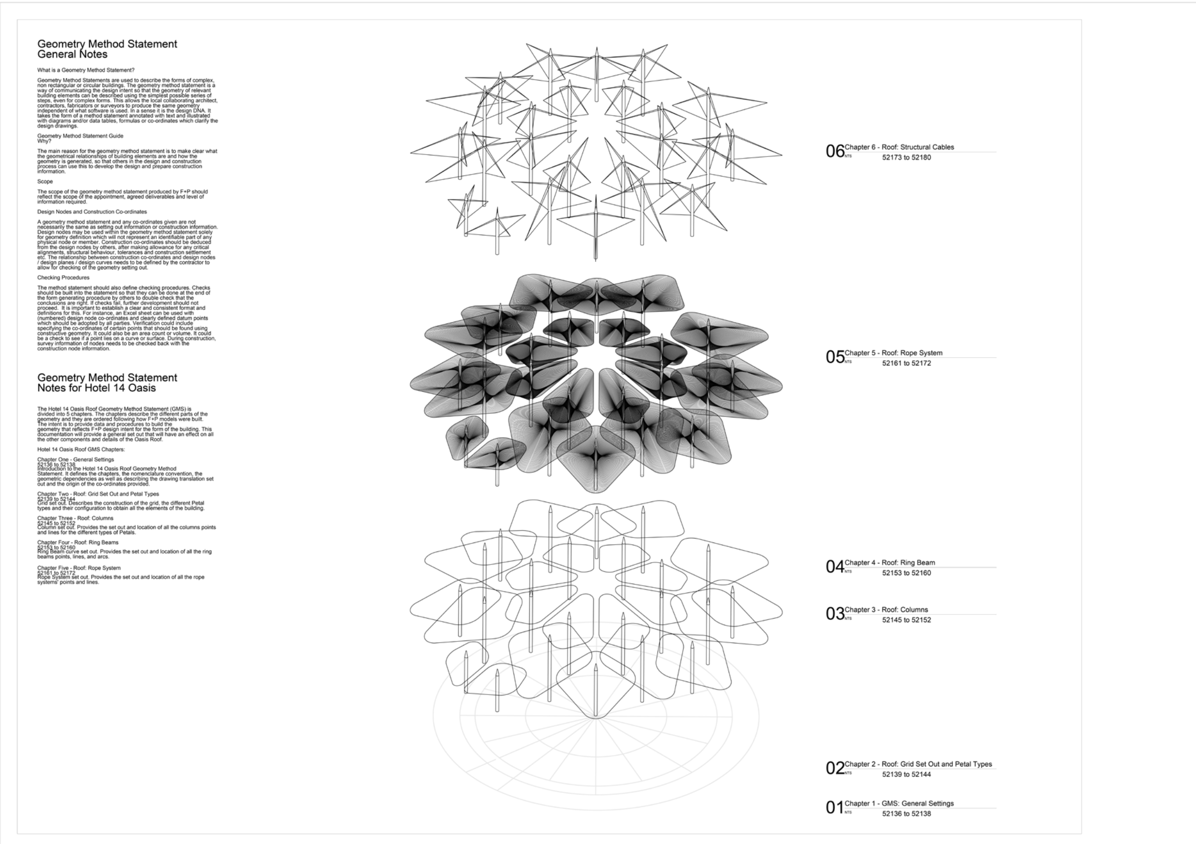

Figure 4: Page from the Geometry Method Statement highlighting the constituent design systems forming the Oasis canopy. Image credits: Foster + Partners.

3.2. Integrated Design

The integrated design of the Oasis canopy included a target shadow coverage of 70% which was deemed adequate for guest comfort given the sun analysis and the wellbeing of the local flora underneath. This in turn defined the density of the rope system and the dimensions of the ropes in terms of their diameter. Furthermore, each petal comprised two interconnected layers of ropes to achieve the target coverage performance. Apart from achieving the environmental performance target, the shadow pattern in itself was of interest. This is due to the resulting eloquent 2-dimensional patterns (figure 5, figure 7 Right) which result from the projection of the 3-dimensional structure via the sun's rays. This shadow pattern, which changes with the time of the day and year is an intrinsic aesthetic quality of the Oasis' architectural geometry. Given the above constraints and requirements the final CAD model was derived and encoded (figure 6).

Figure 5: Shadow pattern study for the 21st Dec 2020. Image credits: Foster + Partners.

4. Structural Considerations

Two of the main structural challenges for this system were torsion and efficiency given the petals' geometrical constraints. As such, the configuration of the structural steel cables connecting the ring beam to the column was extensively studied. Initially, the span of the rope system (the vertical distance on the column from the first to the last rope) was relatively shallow resulting in non-optimal overall performance. Consequently, the span was significantly increased, and the configuration of the cables altered to more efficiently address torsion requirements given the constraint that they needed to seamlessly blend within the ropes. These structural considerations enabled a two-fold optimisation; both in terms of structural and environmental performance. The latter was due to the fact that the increased span allowed for the inclusion of many more ropes (the density of which was limited by their dimensions and detailing, figure 7 Left). Therefore, the shadow performance of the canopy was substantially boosted and hence the wellbeing of the Oasis' local flora underneath and overall experience and comfort of the guests in this central focal point of the resort.

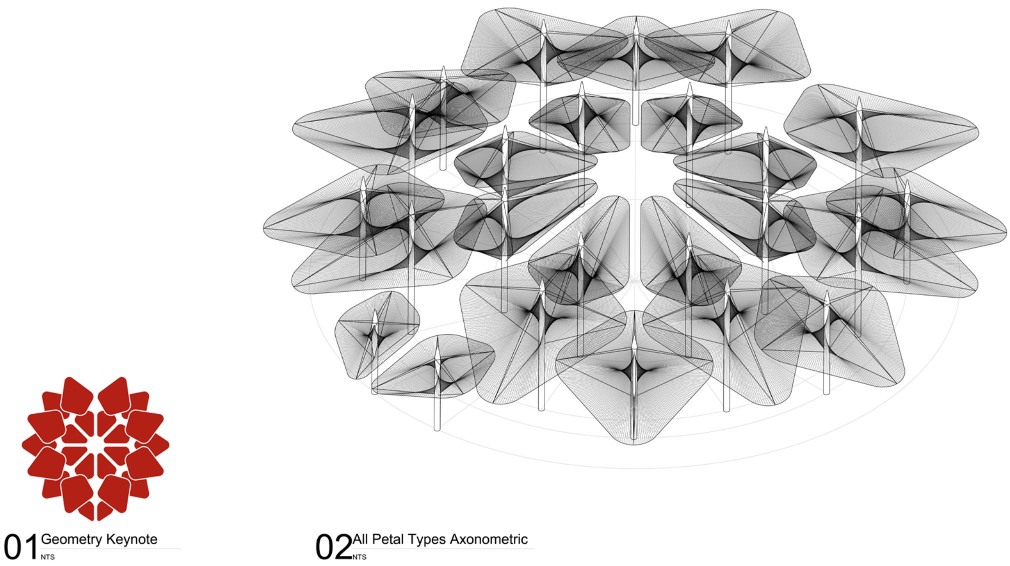

Figure 6: Page from the Geometry Method Statement of the final geometry configuration. Image credits: Foster + Partners.

5. Construction and Manufacturing

The construction of this complex canopy required the use of 4cm diameter steel core ropes which were tensioned to 4kN. This was in addition to the 28 structural steel cables per petal which connected the ring beam to the column. The ropes were attached individually to the column via fixed connections (figure 7 Left) and to the inside of the ring beam via concealed adjustable connections that would allow for tensioning. In total, approximately 13,000 ropes were used resulting to a total length of 92.5 km. Additional optimization steps taken in terms of manufacturing include the two-fold simplification of the ring beam: its curve comprises only straight and circular segments; its cladding was removed resulting in an exposed steel section.

Figure 7: Left: Construction detail showing the attachment of the ropes to the column; Right: Photo of the resulting shadow pattern as projected to the Oasis floor and flora. Image credits: Foster + Partners.

6. Conclusion

This paper presented the architectural geometry of the Southern Dunes Resort Oasis canopy (figure 8). The main design systems were outlined along with relevant design references spanning 19th century science and 20th century art. The resulting rope system was discussed in terms of its performance and aesthetic quality. Lastly, it was highlighted how the parametric CAD model facilitated the collaboration and communication between the several teams that worked together to realize this project from the early conceptual design stages to its construction.

Figure 8: Photo of the built project. Image credits: Red Sea Global.

References

[1] The Royal Society, "Intersections - Henry Moore and stringed surfaces", newton.ac.uk. https://www.newton.ac.uk/files/attachments/1063471/179161.pdf 2012 (accessed 01 April, 2024).

[2] R. Thom, *Structural Stability and Morphogenesis*, CRC Press, 1989.

[3] A. McRobie, *The Seduction of Curves: The Lines of Beauty That Connect Mathematics, Art, and the Nude*, Princeton University Press, 2017.

[4] N. Sidlina, *Naum Gabo*, Tate Publishing, 2012.