Ice Weaving Structure

Introduction

Weaving structure is a bending-active structure which could be constructed by continuous elastic rods. Freeform geometry can be transformed into a weaving structure through re-meshing and optimization. It can adapt to a large variety of forms. Like other bending-active structure, the choices of the construction material are usually elastic materials, such as FRP, PC, and bamboo. On the other hand, ice structures are usually built in cold areas as temporary structures in two ways: one is building the structure by directly laying blocks of ice. The Eskimo Igloo is a fine example of this traditional method. Another way is setting up membrane structure as mold first and spray the fiber-water mixture onto the membrane layer by layer which would later be frozen into reinforced ice structure when the membrane is removed.

By integrating ice with weaving structure, we proposed a new way to build ice structure in this project. This method gives full play to the advantage of both ice and weaving structure. In December 2017, an ice grid shell was built on an ice structure competition. To evaluate the effectiveness of the structure, we developed a structural analysis algorithm using Kangaroo in grasshopper before the real construction.

Project Design

In order to distinguish this new structure among other ice structures which usually comprise arches and domes, we designed it to be a sphere, both eye-catching and seamlessly embedded with the environment.

To generate the weaving structure, a complete set of algorithms was developed. Circle packing was used as a re-meshing algorithm so that the edges could be transformed into weaving rods with minimized curvature. Then, we used mid-edge subdivision on the mesh so that there would only be joints of two intersecting rods, which are much easier to build.

In the design process, the following two perspectives were also taken into consideration: first, the installation should interact with people. Second, the spherical ice structure should be anchored to the ground. Therefore, we designed a circular ice pedestal with spiral stairs. People could step onto the foundation and walk inside the installation.

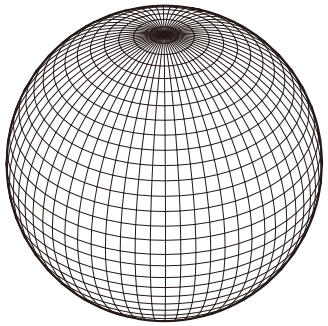
Structural Analysis

A structural analysis was conducted in Kangaroo with real dimension and material property under three circumstances: firstly, the weaving structure before spraying water, secondly, the co-working between ice and the original weaving structure and, finally, the independent bearing condition of the ice. The maximum stress in the structure could be calculated using the simulation algorithm to evaluate if the stress in the structure exceeds the strength of the materials.

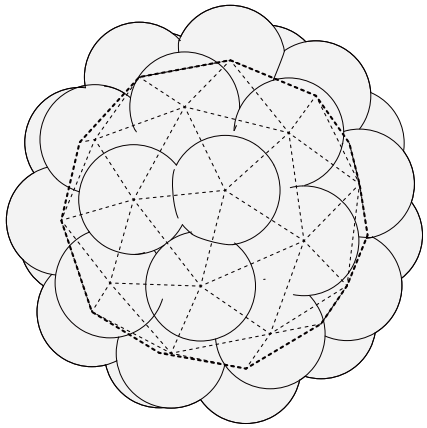
Construction

Before construction, we had disassembled the 3D model into rods and labeled the intersection points on each rod by geometric algorithms. Points with the same label would be tied together in the installation, which means, comprehensive 3D positioning is transformed into labeling positions on the rods. The construction sequence must be well planned in advance. In the beginning, a circular ice foundation was built as a support for the weaving structure. At the early stage, there are insufficient intersections for the structure to maintain its spherical form. Therefore, four rings of FRP rods are connected to form the basic skeleton. Then, we “weaved” the long rods by rolling the sphere in the ice ring pedestal like a wool ball. Finally, we completed the pedestal and sprayed water onto the structure layer by layer which was frozen into ice. In the end, the pedestal and the weaving structure was built in a week by 7 students. It took another week to spray water and froze into ice structure. LED strips were put into the structure in advance. After sunset, the entire structure would be illuminated.

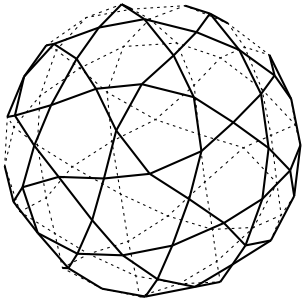

MAPLE
LEAF
VILLAGE



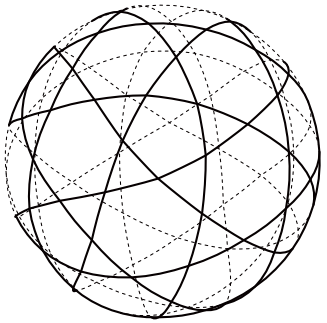
Mesh Sphere



Circle Packing and Re-mesh



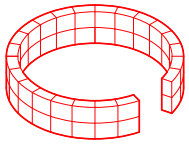
Mid-edge Subdivision



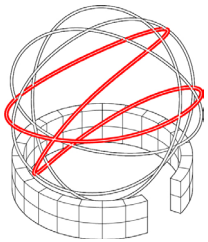
Smooth Polyline

Generating the Weaving Structure

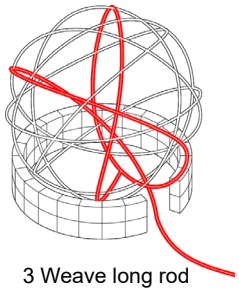
Construction Procedure



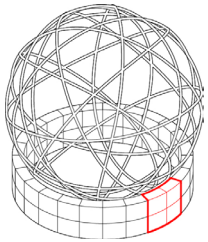
1.Build inner ice ring



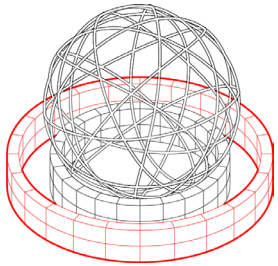
2 Weave short rods



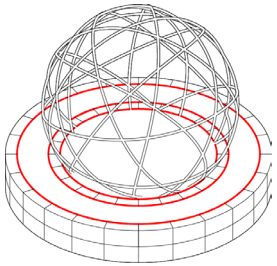
3 Weave long rod



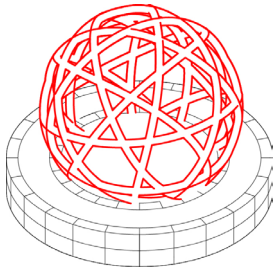
4 Seal the gap



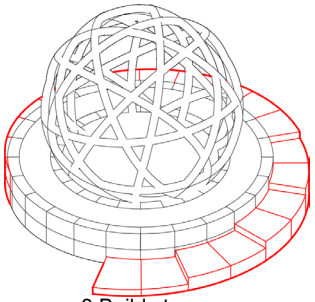
5 Build outer ice ring



6 Fill the slots



7 Spray ice



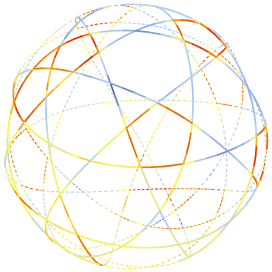
8 Build steps

The Weaving Structure
The final form is a balance of the bending active system, thus is “organic” in its mechanism, rather than merely having organic appearance.

Sprayed Pykrete
The fiber-water mixture was sprayed layer by layer. The procedure is much faster at night since the low temperature.

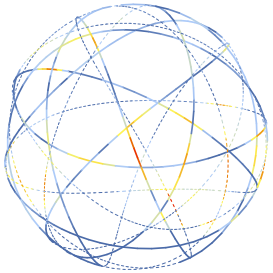
Structural Analysis

Before spraying ice, the maximum tensile stress in FRP rods is well below its strength. In the end, the FRP rods are co-working with ice to bear loads.



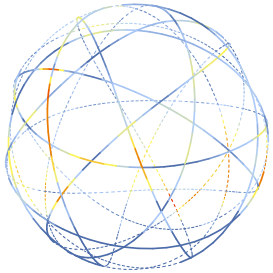
116M Pa 203M Pa

Independent Bearing Condition of FRP



0 Pa 3.53M Pa

Co-Working Bearing Condition of Ice



0 Pa 6.23M Pa

Independent Bearing Condition of Ice