Hedracrete: Prefab, Funicular, Spatial Concrete

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1 Front view of the built structure (Deed Studio ©).

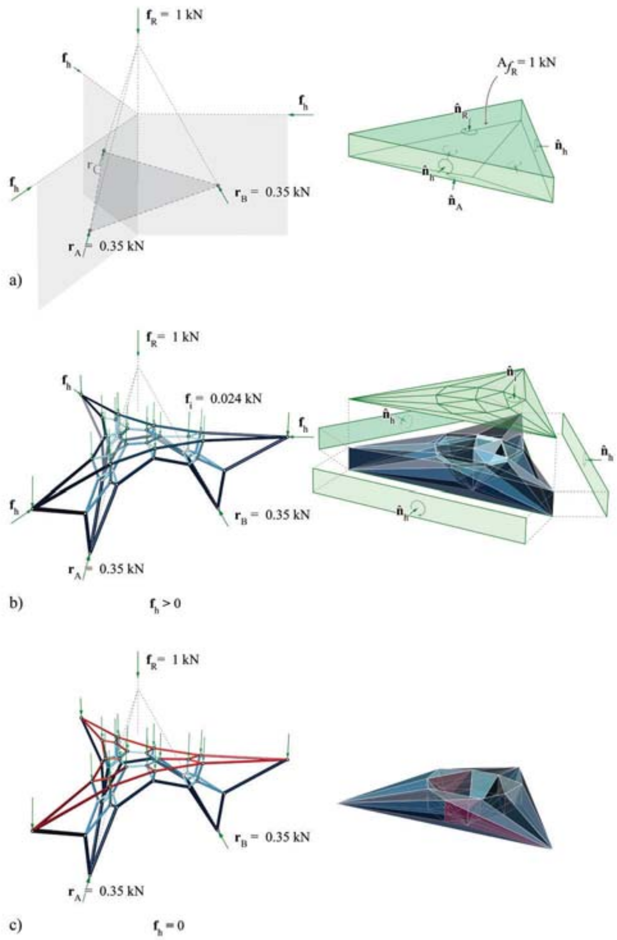
Hedracrete structure is the result of a workshop on 3D graphic statics at the Contemporary Architecture Association of Iran, with 31 participants in collaboration with various material and fabrication service providers. It is a unique research project aiming to address three important topics in the field of digital design and fabrication. These topics include efficient structural form finding in three dimensions, fabrication of complex spatial systems, and the innovative use of conventional construction materials. Multiple aspects of the project will then be described with respect to these topics in the following paragraphs.

PRODUCTION NOTES

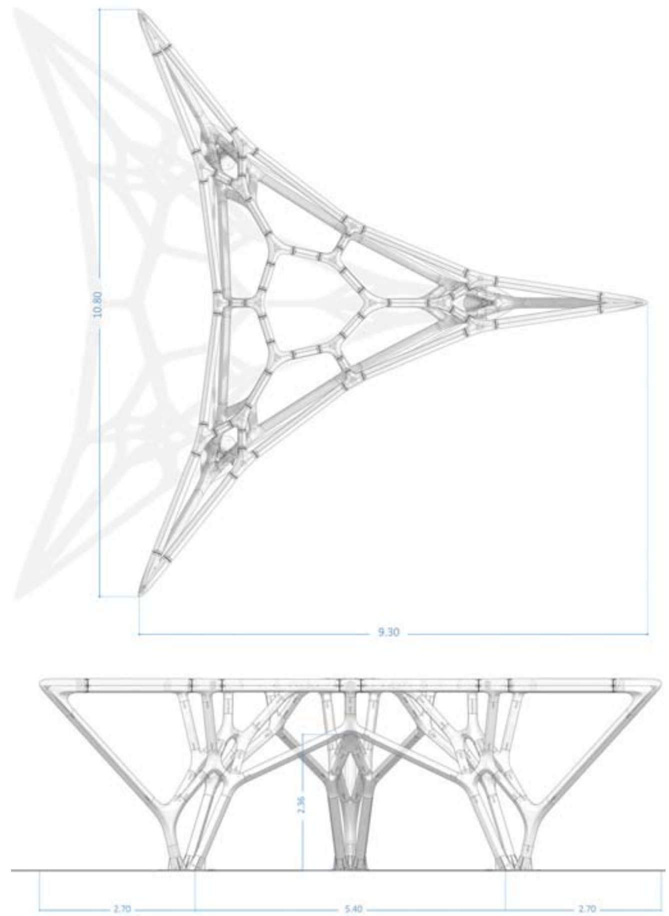
Leads:	Masoud Akbarzadeh Mehrad Mahnia Ramtin Taherian Amir Hossein Tabrizi
Location:	Tehran, Iran
Material:	Glass Fiber Reinforced Concrete, Steel plates
Date:	2016–2017

Structural Form Finding

The form of the structure is a funicular polyhedral frame, which is an efficient configuration of members with compression-only and tension-only axial forces (Figure 1). The maximum height of the structure is 3.33 m, spanning from three supports located 5.4 m from each other. The structure consists of 45 prefabricated joints, 54 compression-only and 30 tension-only members sitting on steel supports connected by steel rods. The structural concept has been developed using 3D graphic statics (3DGS), a state-of-the-art geometric structural design method demonstrating the static equilibrium of forces in three dimensions using polyhedral geometry (Akbarzadeh 2016). This method has recently been developed based on a 150-year-old proposition by Rankine (1864), and Hedracrete is the first built prototype designed using this method. Thus the structure is aimed at proving the theories of 3DGS in practice. What makes the form-finding process in 3DGS quite



2 Structural form finding using 3DGS methods: (a) setting the support locations and the externally applied loads; (b) subdividing global equilibrium to drive the compression-only form; and (c) removing lateral forces to get a form with both compression and tension members.



3 Plan and elevation of the structure, the units are in meters.

unique and intuitive is that the designer has full control over the form of the structure and its internal and external equilibrium of forces. For instance, in this structure, by changing the magnitude of the horizontal forces $\mathbf{f}_h$ to zero in the 3DGS model, a designer can explicitly change the internal forces in the structure from compression-only forces to a system with both compression and tension forces (Figure 2).

Volumetric Design

Once the static equilibrium is achieved and the bar-node structural geometry was developed, it was then translated into a volumetric architectural model (Figure 3). The architectural model consists of discrete elements including spatial nodes connected by linear members. The most challenging task in designing the volume of the structure was to derive the geometry of the nodes where multiple members with various cross sections meet. Ranging from 15 to 25 cm, the diameter of the cross section for each member is unique and corresponds to the magnitude of its internal force derived from the 3DGS model. To find an appropriate geometry for the node that can smoothly combine different member sizes, specific mathematical and geometrical definitions were developed based on the topology of the 3D convex hull for each node and its connected members.

Materialization

To extend the use of concrete in design and fabrication of discrete spatial systems as opposed to its conventional, monolithic use, glass fiber reinforced concrete (GFRC) in prefabricated elements was chosen as the material and the construction method for the project. To reduce the self-weight of the concrete, perlite, pumice aggregate, silica fume and chopped glass fibers were used as the main ingredients. Note that the form of the structure is in static equilibrium if it is subjected to the applied loads on its top chord. Since the finished structure would not have specific applied loads on its top chord, the tension members were also constructed out of concrete to act as the applied loads for the compression members. This keeps the structure in equilibrium and preserves the design consistency

4 Side view of the built structure (Deed Studio ©).

5 Coating foam molds and preparing them for concrete casting.

6 Treating the demolded nodes with water to reduce the cracking rate.

7 CNC bending the steel plates for the supports.

8 A completed support including bent steel plates welded to the base surface.

of the project. To improve the tensile capacity of the members, a single piece of steel rebar (d = 12 mm) was embedded in the cross section of the members of the top chord to carry tensile forces between the joints (Figure 4).

Fabrication

The main objective in the fabrication process was to develop a simple and inexpensive technique to produce the prefab parts of the system. The construction of the project was quite constrained by the total allocated budget ($8500), and the fabrication tools were limited to a 3-axis CNC machine and a CNC foam cutter. To reduce the construction time, and therefore the milling costs, the structure was designed with three planes of symmetry, so that fewer molds would be constructed. The molds were made out of styrofoam and each was used to cast three members (Figures 5 and 6). Therefore, it could cut the mold-making costs by a third.

The supports were made out of CNC-bent steel plates, bolted and welded, first together, then to a base plate at specific angles to receive the members and transfer their axial forces precisely to the ground minimizing any potential moment in the supports (Figures 7 and 8).

Fabrication

Each compression member is dry-placed on a node without mortar. A simple male/female tube was embedded in each piece as a registration point in three-dimensional space to ease the assembly process. In contrast, the tension members were bolted to their adjacent nodes on the top chord. The assembly process of the project was accomplished by initially finishing the compression members and adding the tension members successively on the top (Figures 10 and 11). A simple scaffolding system was used to support the members during the assembly process.

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9 View of the completed structure in Sa'adabad complex, Tehran, Iran (Deed studio ©).

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10 Prefabricated elements and nodes prepared for assembly.

11 Constraining the compressive members with the tensile members in assembly.

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