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Puffer Dome

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Abstract

Puffer Dome demonstrates the use of a distributed system of individually inflatable cushions for cladding space frame structures. The main innovation is a 3D-printed tube connector which links incoming structural members and integrates electronic fans and details for attaching inflatable cushions. The demonstrator borrows its shape from a dome lattice realised by Gerhard Garstenauer in Bad Gastein. It innovates on universal joints by integrating multiple functions into each 3D-printed connector. The authors identify a research gap between fully framed systems like the ETFE cushions [1] and fully self-supportive inflatable structures like projects by Pneuhaus [2]. Such a distributed system has the benefits of being more rapidly deployable than framed cushions and structurally independent of inflation status in contrast to pure inflatable structures.

Keywords: space frame, inflatable, pneu, 3D-printing, node connector

Figure 1: Puffer Dome inflated with integrated LED illumination.

1. Introduction

The work is situated in the context of a longer standing design research interest in 3D-printed tube and plate connectors for space frame structures which integrate multiple functions. Previous work includes topologically optimised tube connectors for push through tubes and plates (Fig 2.1) and connectors for a structurally active double layered shingle system Space Shingles by Becker [3] (Fig 2.2).

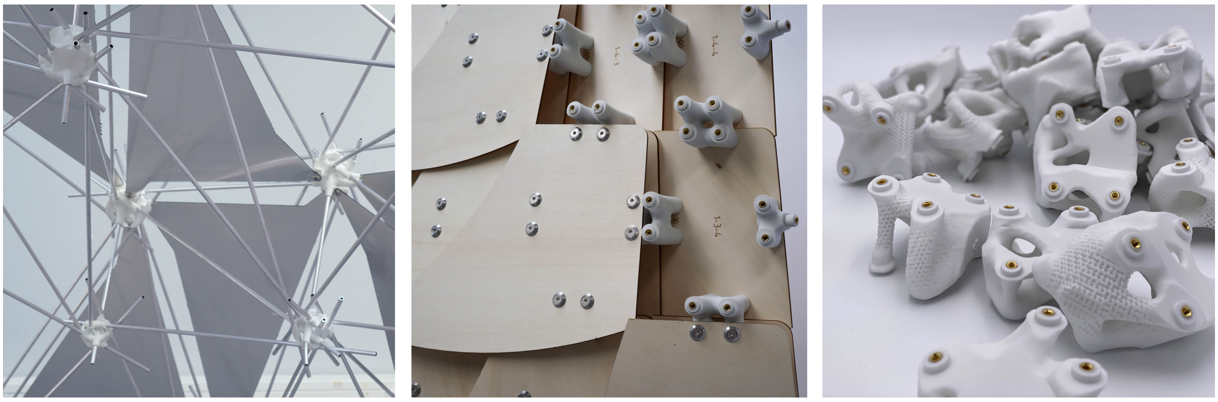

Figure 2: Universal Super Joints, push through connector (1); Space Shingles doubled layered structure (2) and topologically optimized nodes (3)

1.1 Universal Connectors

Universal joints, which have their origins in the work of Konrad Wachsmann [4] and Max Mengeringhausen [5] in the early 1940s, got widely used in the 20th century and gained renewed attention with the emergence of computational design and digital fabrication strategies in the 2000s for example in the Heydar Aliyev Center [6]. A particular niche has developed around 3D-printed connectors such as Bespoke Metal Connections by Meibodi [7]. Our overarching design research interest and project presented here focus more on advances of the connectors and less so on the performance of and applications of the overall system. Our particular interest lies in integrating multiple aspects in the design of the joint such as: parametric variability, mechanical interfaces for fastening tubes and plates, topological optimisation. **Puffer Dome aims to integrate the fixings and fans for a distributed system of inflatable cushions to cover a space frame / lattice structure.**

1.2 Inflatables

Inflatable or pneu structures have been systematically introduced into architecture by Frei Otto [8]. There are two types of pure inflated membrane structures: One where the functional inside space is pressurised by 150 – 300 Pa and separated from the outside by an airlock. This type is often used for large span structures such as tennis air domes / tennis bubbles. The second type where structural elements made of membranes are pressurised to form beams, walls, or columns. These types work at pressures of around 1000 – 2000 Pa and are mostly found in bouncy castles or temporary architectural projects such as Skum big BIG, 2016 [8]. A third application of inflatables in architecture are hybrid systems where the main structural work is done by a frame and inflated cushions provide the cladding. These systems have been used widely in form of inflated ETFE cushions, most prominently with the Eden Project 2001 [9]. ETFE cushions are fixed in sealed frames attached to the main conventional structure and pressurised with 200 – 300 Pa. **Puffer Dome aims to build on the type of inflatable cladding cushions implementing a decentralised pressurisation system of fans integrated in the structural connectors.**

1.3 Historic view on Garstenauer

The domes by Gehard Garstenauer in and around Bad Gastein, Austria (1972/74) [10] are based on a spherical lattice structure where all nodes align on horizontal circles. Instances of this system for domes designed to be used in different sizes and for different uses are built as lift stations, viewing platforms and lounges in a convention centre (Fig. 3). They are made of tubes, joints, and panels which are hung from the node points towards the inside. There is no connection between the edge of the panel profiles and the structural tubes. **Puffer Dome uses the geometry and structural system of a Garstenauer-Sphere for prototyping 3D-printed connectors with integrated fans for individual cushion inflation in replacement of the rigid panels.**

Figure 3: Three instances of Garstenauer domes. Bus shelter Sportgastein (1), Kongresshaus Bad Gastein (2), Garstenauerkugel Kreuzkogel (3)

2. Methods

The Garstenauer sphere served as the base geometry for the Puffer Dome. The geometric sphere was cut off at the second horizontal circle from the bottom. Out of the triangular tessellation a layout of hexagonal and trapezoidal cushion (Fig. 4) was developed. This resulted in two types of connectors: one which holds a fan and one without. The connector and cushion design were developed in a series of prototypes and simulations. Prototyping was mostly done on a 1:1 hexagon.

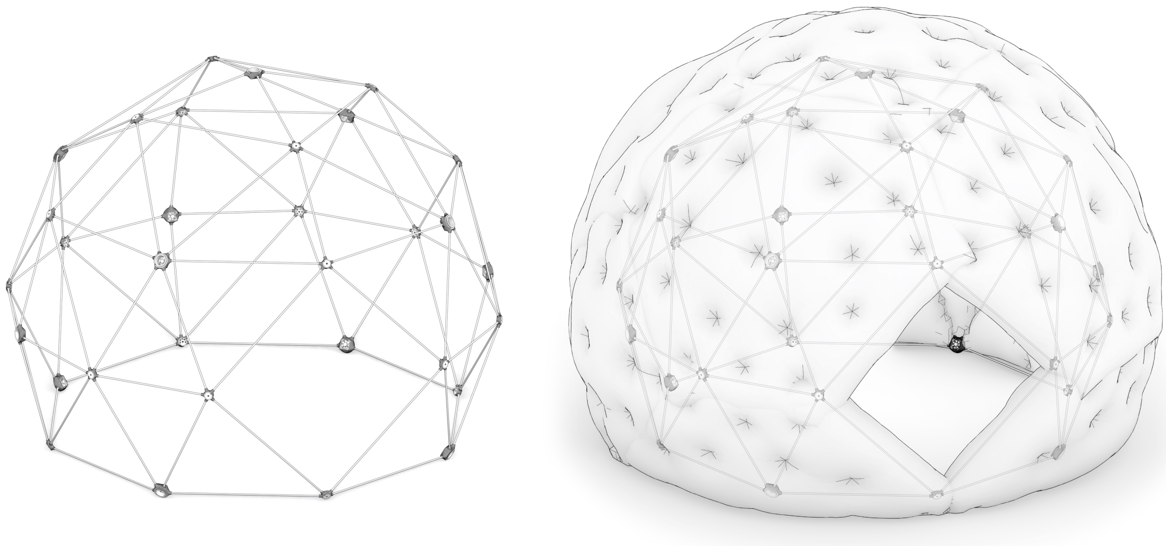

Figure 4: Puffer Dome; lattice and nodes (1), 12 cushions attached to the structural frame (2)

2.1 Connectors

The connector design features a larger hole at the centre which allows to move each tube back and forth during installation. Once all tubes are inserted, they are fixed with a lockring (Fig. 6.1). The fan connector type is enlarged to hold a 120 x 120 mm fan. In a series of prototypes different fans and cushions were tested to match fan specification to required performance. The lockring also has details to attach the cushions with rubber strap. The connectors were 3D-printed in PLA. (Fig. 5)

Figure 5: Two connector types. One with fan and without.

2.2 Cushions

The inflation of the cushions was simulated in Grasshopper Kangaroo to develop and optimise fabric cutting patterns (Fig. 6). Each hexagonal cushion has 20 pinch points connecting outer and inner membrane with a fixed length thread and keeping the cushion relatively flat. Details such as LED lighting strips, zippers, straps, and eyelets follow outdoor gear design principles were integrated into the cushion design. Exhibition graphics showcasing novel and historic space frame connectors are printed directly on the textile. (Fig. 9). The cushions are made from regular rip stop fabric and sewn on a regular sewing machine without tape or sealant. In total there are 12 cushions with, each one inflated individually by a fan.

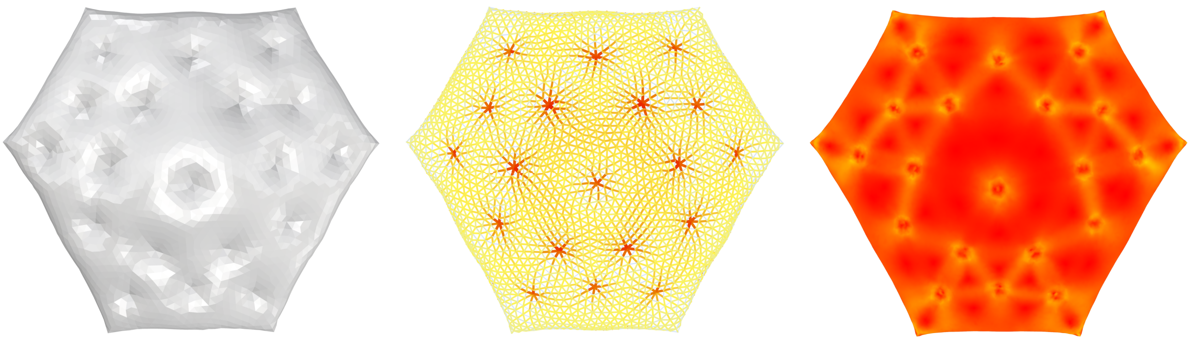

Figure 6: Inflation simulation with Grasshopper Kangaroo

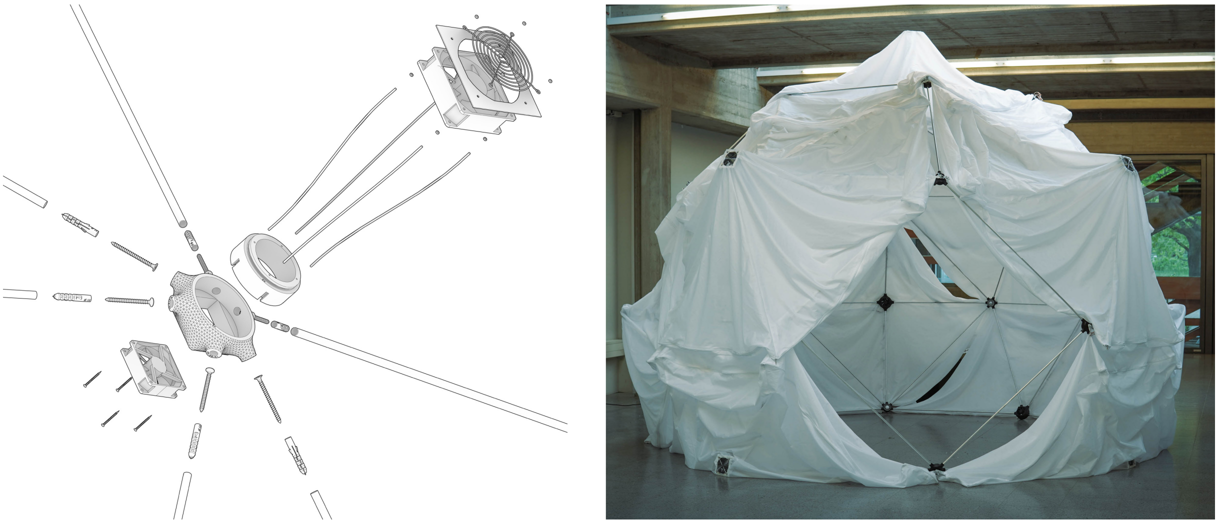

Figure 7: Details of the Puffer Dome node (1); cushions before inflation (2)

3. Results and Discussion

The assembly of Puffer Dome is fast and relatively easy. At first the structural frame is erected by inserting the tube into the connectors and locking them. This can be done in one go or in segments which are then joint later. Once the frame is up the cushions are connected (Fig. 8). At the perimeter of each cushion is a zipper to insert the LED strips. Inflation of the cushions happens in parallel and takes less than 30 second. The pressure of the cushions is around 50 -100 Pa. When the fans were turned of the cushions deflated within 2 minutes. A switch and timer allowed visitors and users to inflate Puffer Dome at their convince. More advanced sensor driven modes of inflation are possible but not implemented at the early instalments of the project. The fans have an electrical power of < 10 W. Overall the project showed custom connectors can take additional functions beyond providing a fixing for structural members.

Figure 8: Inflation simulation with Grasshopper Kangaroo

Figure 9: Textile prints of different space frame connector types on the inside of Puffer Dome

4. Outlook

The practical applications of such system of distributed inflatable façade cushions could be in special cases were a fragmented surfaces have to be temporarily covered. This could be at the construction sites for the restauration of historic buildings or temporary coverings between remains of other structures. The relatively low power consumption could be further improved by having a better airlock at the fan and better sealing of the fabric seams.
The most promising aspect of such structures is their capability to control inflation statutes of the cushions individually which offer the opportunity for play, expression, and user interaction towards a responsive architecture.

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