Desert City bubble roof

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ABSTRACT

Desert City Ltd, Spanish pioneer xeriscaping company is settling its Headquarters office in San Sebastián de los Reyes, Madrid (Spain). The building is composed by two volumes connected by walkways, having the main building a 1,575 m^2 (37 m x 42 m) exhibition cactus courtyard intended to be covered by a light a permeable roof.

The roof consists in a rigid steel frame with four longitudinal steel beams as Primary Structure. The void between beams is filled with ETFE cushions reinforced with Transverse Tensigrity Beams, made-up by cables and steel strut-masts due to the span.

KEYWORDS: ETFE cushions, form finding, tensegrity, cables, air.

1. Architectural concept

Desert City LTd, Spanish pioneer xeriscaping company, entrusted to García-Germán Architects Studio the design of their Headquarters in San Sebastián de los Reyes, Madrid (Spain). The building is composed by volumes connected by means of peripheral walkways, freeing the in-between space existing after having built such volumes and generating a first cactus open-air showroom. The main volume has got an inner courtyard, intended to be the principal cactus exhibition and wished to be covered by a light and permeable roof.

What better solution than an ETFE foil roof to provide a perfect showroom inside a bubbling greenhouse? So, this was the seed of the covering design.

The Desert City Headquarters is being built by Spanish Contractor Isolux-Corsán, who outsourced the roof erection to the specialist tensile-structure Contractor Lastra&Zorrila, who contacted us, Arenas&Asociados Bridge Designers, as their Structural Engineers, as both companies have collaborated in several tensile-structure projects such as PVC membranes and ETFE cushions.

Based on the conceptual sketches made by the Architectural team, we provided the architectural, structural design and erection sequence that fitted the most to such conceptual sketches, with a feeling of being open air but being sheltered from weather by an almost transparent layer.

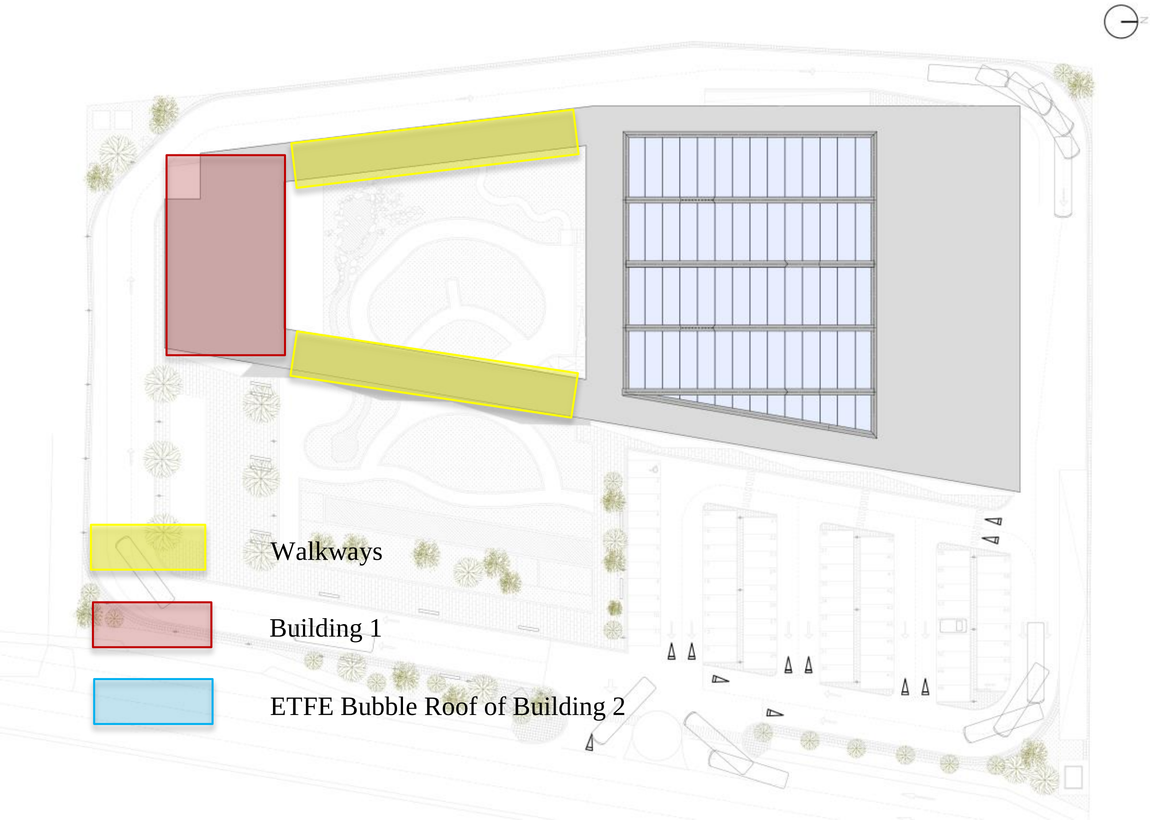

Figure 1: Plan view of Desert City [Architectural drawing courtesy of García-Germán Architects]

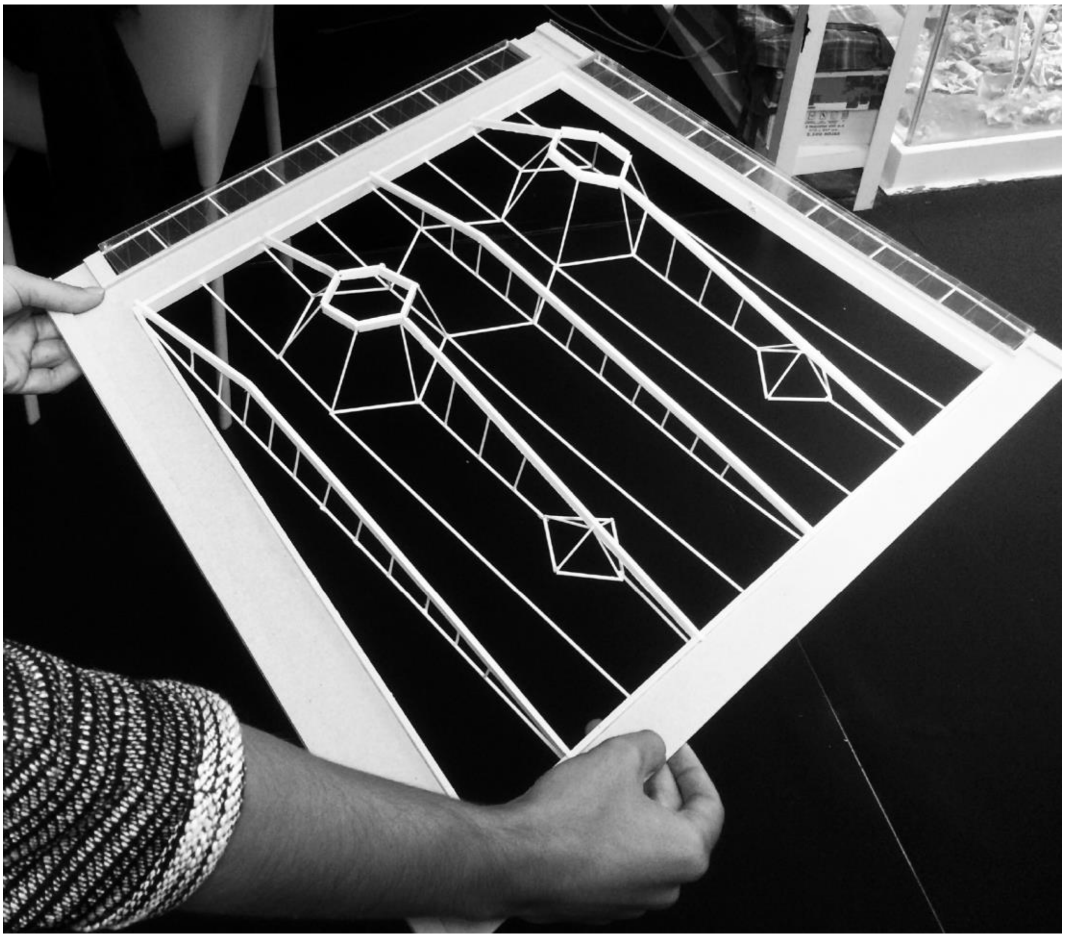

Figure 2: Conceptual mock-up of primary structure [Picture courtesy of García-Germán Architects]

The roof consists in a rigid steel frame with four longitudinal steel beams as Primary Structure. This Primary Structure generates a void between the longitudinal beams which is filled with ETFE cushions reinforced internally with Transverse Tensegrity Beams, made-up by cables and steel strut-masts due to the span, 9.5 m, that those ETFE cushions must cover between the longitudinal beams.

These masts, observed from the courtyard will provide a sensation in the spectators of a sea of scattered cactus spikes floating inside Cumulus Clouds.

Figure 3: 3D view [Courtesy of García-Germán Architects]

2. Structural concept

The Desert City Bubble Roof structure is arranged in three levels, the main steel frame, composed by four longitudinal sloped beams fixed to a peripheral steel frame; a second level, composed by the tensegrity transversal beams and the ETFE cushions.

It must to be said that the covering roof had to be designed once the building supporting structure was already built and this conditioned the roof covering structural concept.

2.1. Primary structure. Steel frame support

The Primary Structure, framing support of the bubbles, bears in the existing building supporting structure, and this conditioned the design of the mentioned Primary Structure.

This Primary Structure is composed by a peripheral Ø900 mm steel tube which receives the four longitudinal beams and provides the bearings that makes rest the roof on the existing steel structure.

The bearings were designed in a way that the horizontal forces transferred to the existing supporting structure were minimized, as they hadn't enough capacity to resist them and the displacement obtained were also out of an allowable value. Thus, PTFE sheets were provided to the elastomeric pads, and a low friction contact PTFE-steel was successfully provided. Due to the lightness of the roof an in order to avoid undesired uplifts, all the bearings were clamped, being this connection designed by Arenas&Asociados. The use of PTFE sheets allow also an optimal behavior of the longitudinal beams, as they are externally posttensioned by means of a high grade steel cable. Bow-String concept, applied by Arenas&Asociados in some of their most well-known bridges, as Barqueta in Seville and Third Millennium Bridge in Zaragoza, is also used here, allowing a rational use of materials and spanning 37 m with 840 mm depth steel slender beams (ratio height-span 1/44).

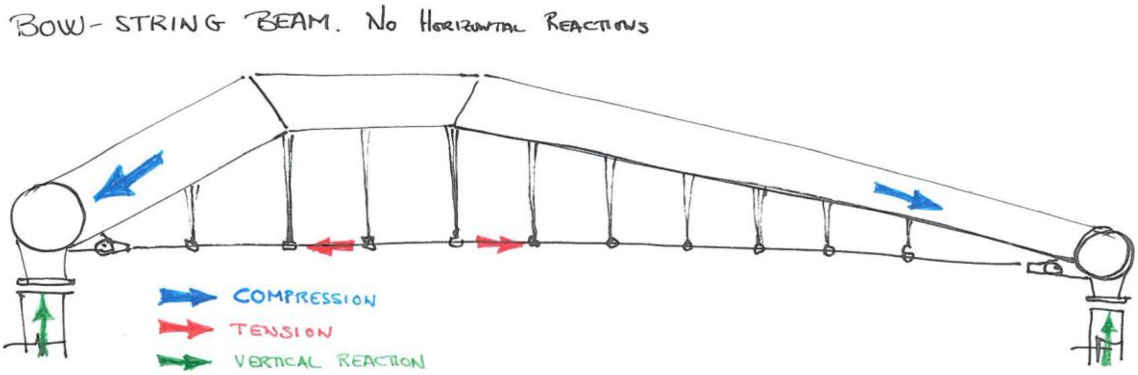

Figure 4: Longitudinal beam structural concept [Sketch by Arenas&Asociados]

The bow-string concept forcing the steel beam to behave as the compression chord and forcing the steel cable to behave as the tension chord, is the responsible of the lightness of the Primary Structure, and also allows avoiding the transmission of horizontal forces to the existing structure.

2.2. Secondary structure. Transverse beams

The longitudinal belonging to the Primary Structure divide the roof in 5 sectors. These sectors are those covered by the ETFE cushions. Due to the external loads, weather loads mainly as wind and snow, makes necessary the reinforcement of the ETFE bubbles by means of cables beams. As the bubbles span 9.5 m and as per the ETFE cushion analysis and the recommended tensile strength or 21 MPa in ETFE sheets in order to avoid plastic deformations in the material, cables beams are used as bubbles reinforcement.

These beams, still in design at the time of the redaction of the present Proceeding follow the schematically concept shown in *Figure 5*. Two main cables are used, one for snow and wind pressure and the other one for wind suction, having stressed both cables in order to avoid the slackening, so the cables will be always under tensile forces.

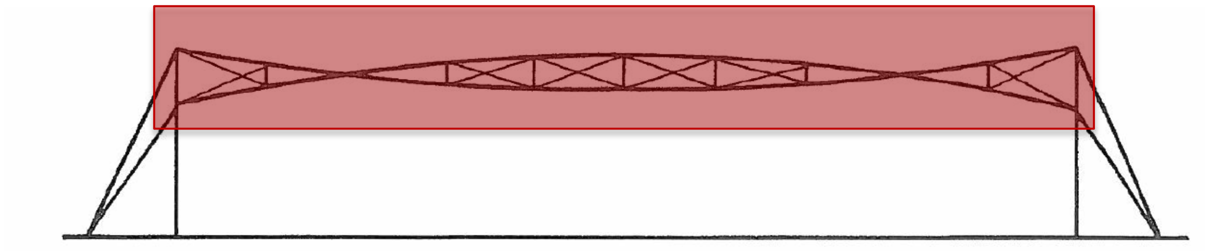

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Figure 5: Transversal Beams Structural Concept [1]

The main cables resist together the bending forces in the bubble beam to transmit the loads to the longitudinal beams, which unload the external actions through the bearing devices in the existing supporting structure of the building.

But these main cables require embracements, diagonals, to improve the structural behavior, resisting the shear forces and overall, providing lateral stability during the transversal beam erection and during its lifetime. These embracements, shear resistant elements are composed by rigid steel struts and cable diagonals, with spacer-clamps, which provide the above mentioned stability. The conjunction of struts and cables makes these beams in tensegrity beams, and oneiric spikes floating in the air, a cactus deconstruction.

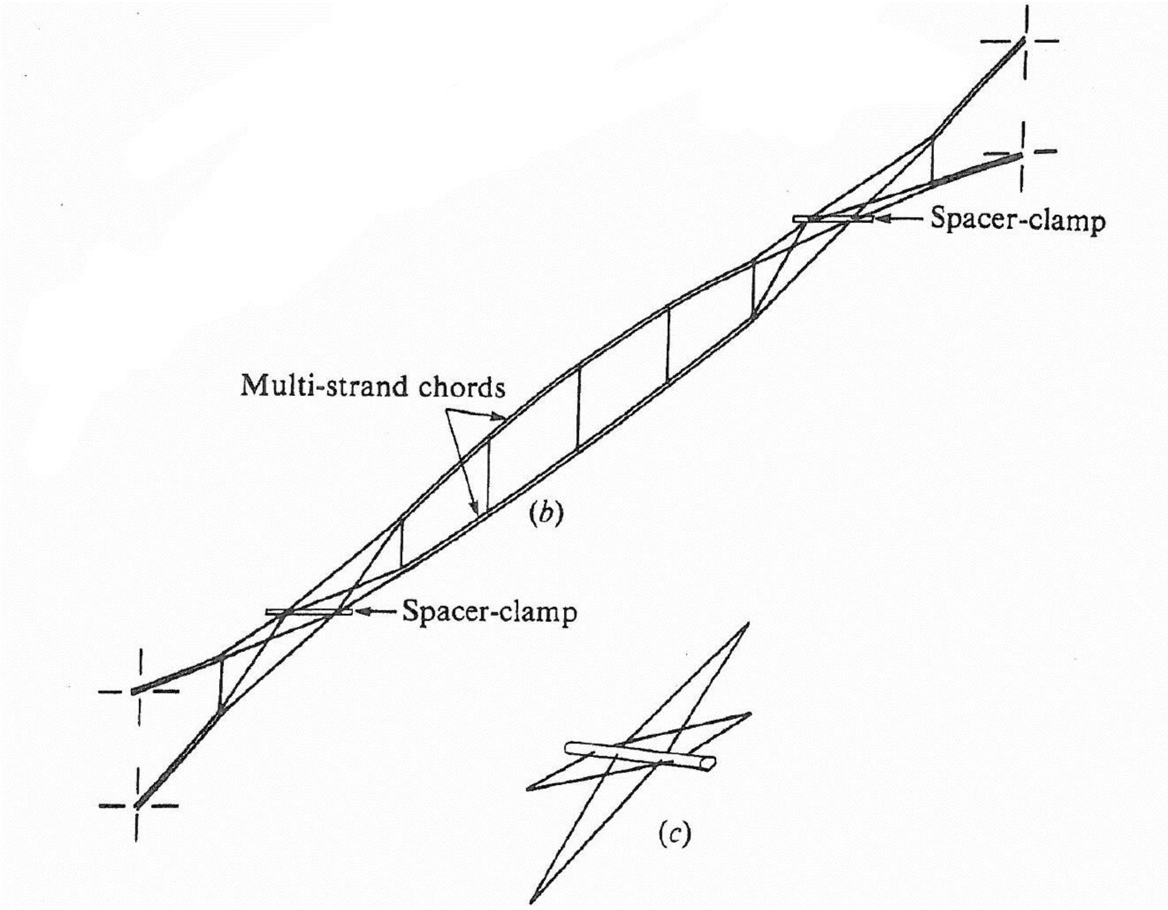

Figure 6: Transversal beams structural concept. Lateral Stability [1]

2.3. Tertiary structure. ETFE cushions

The last element that constitutes the Desert City roof are the ETFE cushions, which are reinforced by mean of the transversal beams.

Two layer cushion is used with transparent sheet in the top layer and hexagonally grey doted pattern in the bottom layer.

A system to regulate the internal pressure to counterweight the effects of snow and wind shall be provided in the roof. The air supply will be developed by means of flexible pipes introduced in the main steel structure.

3. Conclusion

The following images show the comparison between the conceptual idea of what was expected to be obtained (Fig. 7), and the real achievement (Fig. 8 & 9).

Figure 7: 3D view [Courtesy of García-Germán Architects]

Figure 8: Real view of the cactus courtyard bubble roof [Courtesy of García-Germán Architects]

Figure 9: Bubble roof detail view [Courtesy of García-Germán Architects]

4. Acknowledgements

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- José María Lastra, from Lastra&Zorrilla. Expertise tensile structures manufacturer.

5. References

[1] Buchholdt H.A., Introduction to Cable Roof Structures. Cambridge Company. University Press, 1985.