APPLICATION OF TENSEGRITY TO TENSILE-TEXTILE CONSTRUCTIONS: FORMFINDING AND STRUCTURAL ANALYSIS

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Editor's Note: Manuscript submitted 19 October 2009; revisions received 30 July 2010 and 4 January 2011; accepted 27 February. This paper is open for written discussion, which should be submitted to the IASS Secretariat no later than December 2011.

ABSTRACT

This paper applies tensegrity to create an architectural structure such as those that could be used for sports arenas or other buildings requiring large, open spaces. This proposal generates an external tensegrity ring with a central dome, free of any interior support, by formfinding a diamond-shaped membrane with discontinuous struts in a double layer structure that finds its equilibrium through the pretension of the membrane. The tendons that are used in traditional tensegrity structures are replaced by membranes and this proposal is the main contribution of this work. Structural equilibrium was analyzed using the WinTess software and wind-tunnel testing was used to determine the Cp-pressure coefficient.

Keywords: *Tensegrity unit, tensegrity ring, formfinding, continuous membrane pattern, diamond-shaped membrane pattern, pretension, wind tunnel, pressure coefficient.*

1. INTRODUCTION

Tensegrity geometry is defined by the equilibrium of tensile and compressive forces and is characterized by having discontinuous compression bars, which remain in equilibrium by tensed cables. The balance is achieved because all the compression and tension forces are perfectly distributed, that is to say they work jointly, where the structural form is guaranteed because the final system is closed and auto-balanced, as Fuller [1] said "Islands of compression in an ocean of tensions".

Tensegrity is a developing and relatively new system (less than 50 years old). Three people have been considered the inventors of tensegrity: Richard Buckminster Fuller (USA-1962), David Georges Emmerich (France-1964) and Kenneth D. Snelson (USA-1948). Emmerich reported that the first proto-tensegrity system, called "Gleichgewichtkonstruktion", was created by Karl Ioganson (Russia-1920). In 1976, Anthony Pugh of the University of California did a classification of the diverse existing typology [2]. He described three models, or basic patterns, with which the tensegrity structures can be constructed: a diamond pattern, a zigzag pattern, and a circuit pattern. This classification originates from the relative position of the bars amongst themselves and the ends of the tendons [3].

The current research (Fig.1) is built on Anthony Pugh's classification of the diamond pattern and the position of the bars aligned in a single layer or a double layer, and proposes models using a continuous membrane and a diamond pattern.

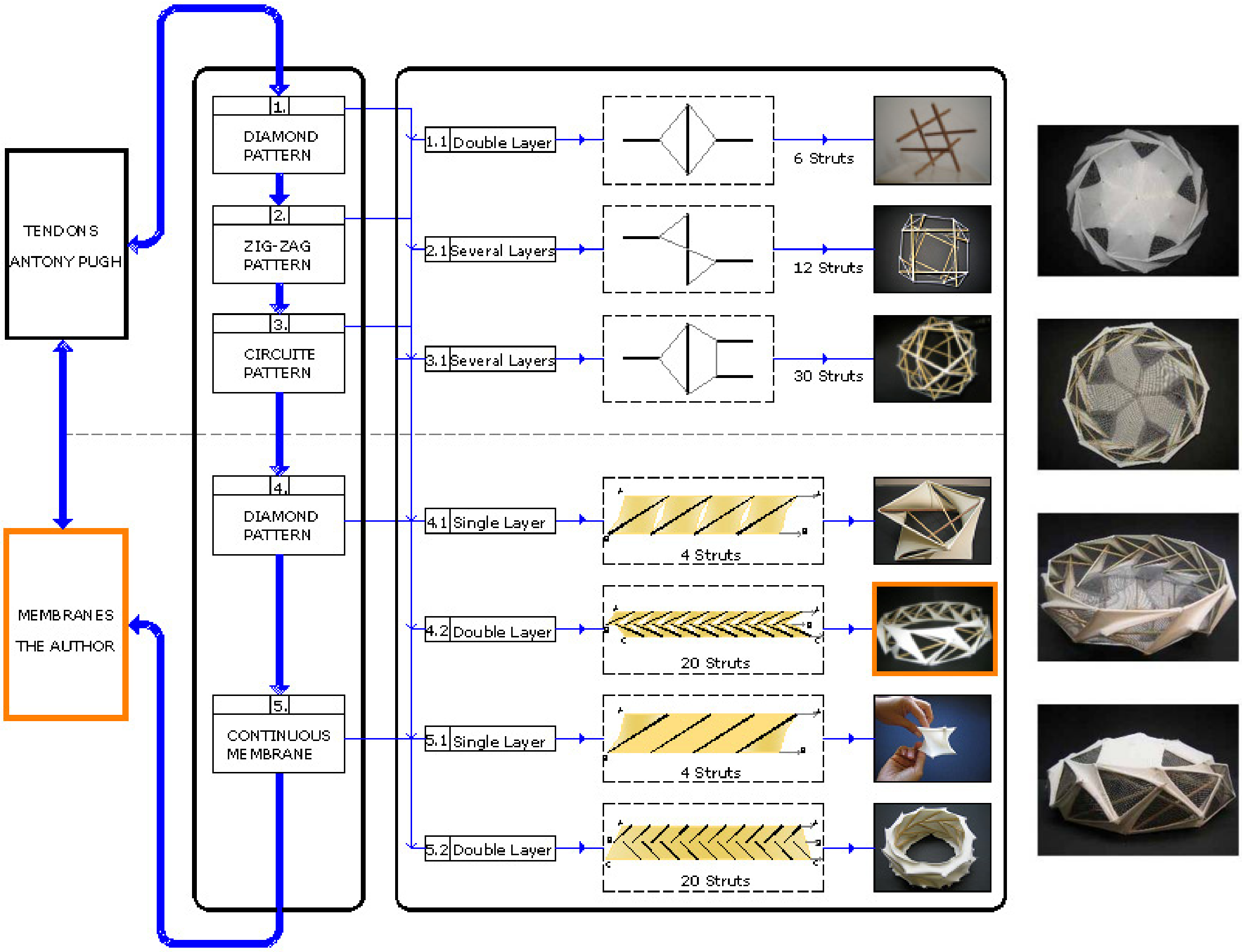


Figure 1. *A comparison of the work of Anthony Pugh and that proposed by the author.*

2. FORMFINDING

The tensegrity geometric construction of this research is based on:

- The concept of a basic module or tensegrity unit built from polygons and polyhedrons (prisms and anti-prisms) as well as Platonic and Archimedean solids. [4]
- The substitution of geometric components (such as edges and vertices) with bars, cables, joints, and membrane faces.
- Forming more complex systems from groups and variations of the basic module (tensegrity unit).

In the below pictures (Fig. 2 and Fig.3) we can observe different scale model examples in tensegrity with cables and membranes constructed from a variety of materials, that use these principles of geometry.

After they were assembled, we chose some of the models to define a classification and to do the structural analysis:

Figure 2. *Examples of sixty scale models in tensegrity. Models developed using an intuitive and experimental method based on the geometry.*

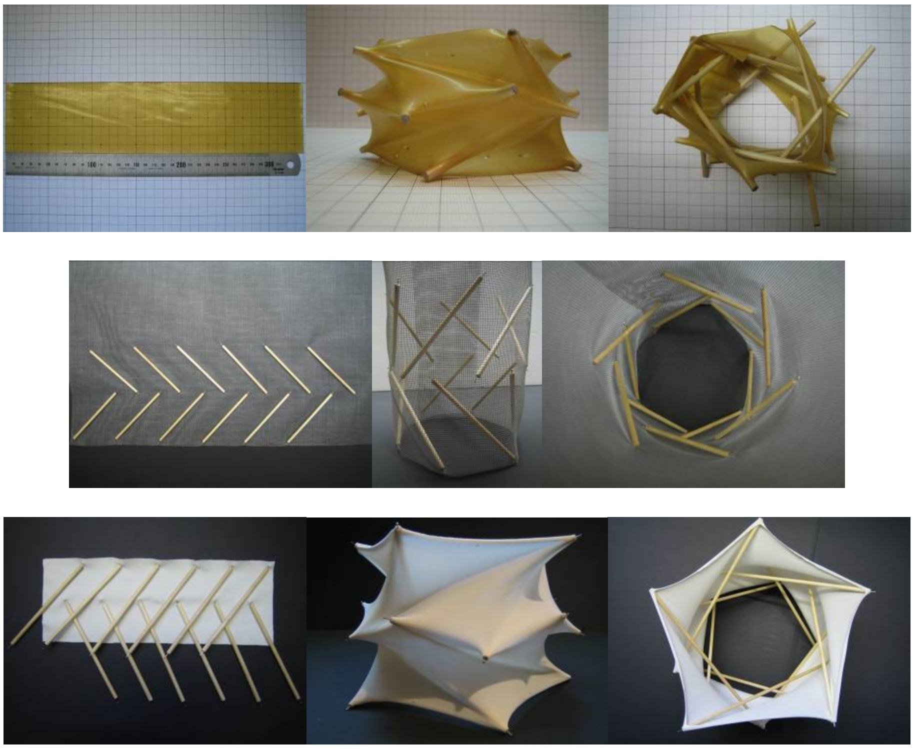


Figure 3. *Examples of scale models in different materials. A spandex membrane was chosen as the material to construct the scale models (1:100).*

3. CLASSIFICATION

Model types – Membrane patterns

a. Diamond-membrane pattern pieces and struts in a single layer

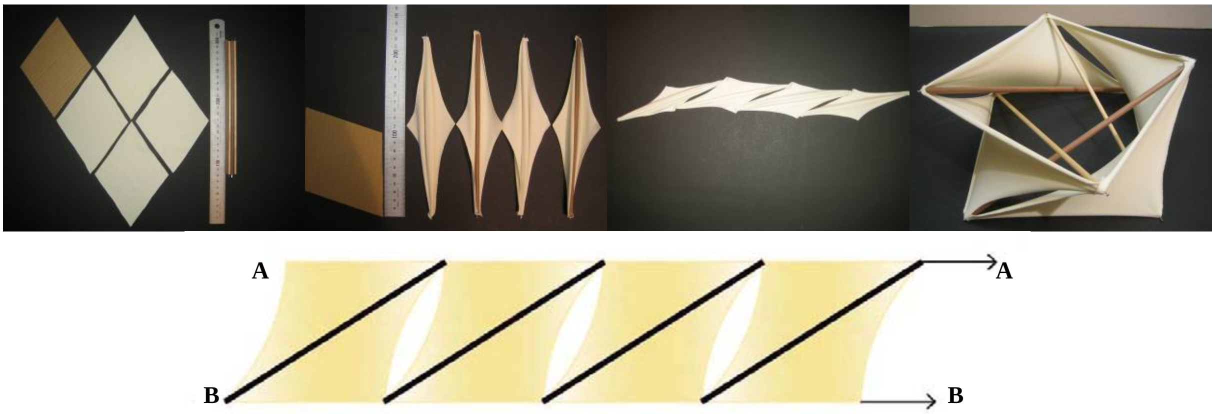


Figure 4. A tensegrity unit with a diamond-shaped pattern (an anti-prism of 4 struts) – scale model 1:100

The process is generated by cutting textile membranes into rhombus or diamond shaped patterns (rhombus= major axis 17 cm, minor axis 12 cm) for the basic anti-prism unit of four bars (L=22 cm), which are then arranged in an oblique direction or diagonal position. The bars are joined to the end points of the membrane as shown in Fig 4. The bars are tied to the adjacent pattern piece on one of its vertexes, and so on. The tied up units can be closed by joining the first bar and the last membrane pattern. The final anti-prism form has four parabolic surfaces constructed from a flat rhombus. The initial position of the bars in this case is a single layer.

b. Continuous-membrane pattern piece with struts in a single layer

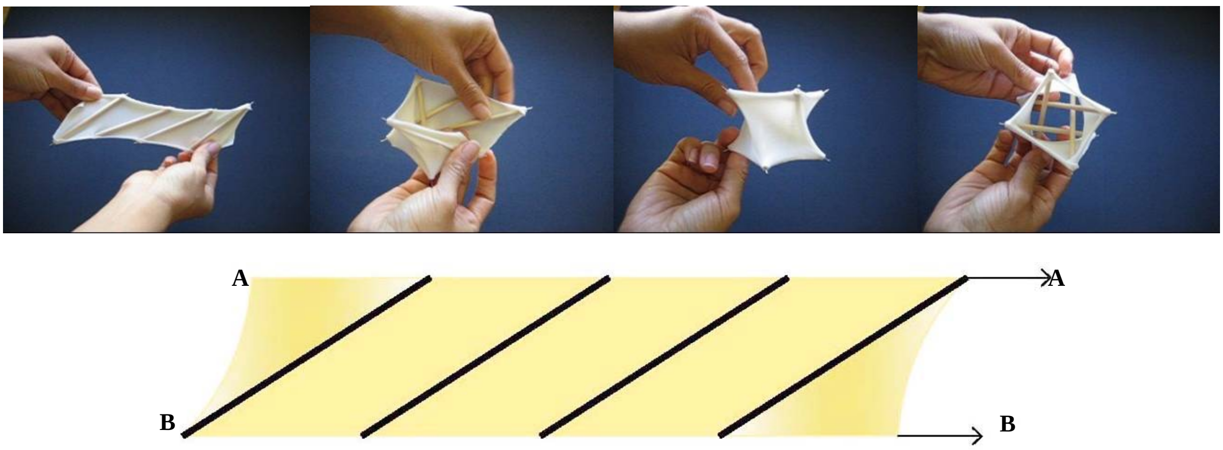


Figure 5. A tensegrity unit formed from a continuous membrane (an anti-prism with 4 struts) – scale model 1:100

One can depart from the previously described process and use a continuous, single-piece, rectangular-shaped membrane (15 cm x 3.75 cm) to find the form. The bars (L=10 cm) arranged in a single layer and joined to the end points of the membrane as shown in Fig 5. The system is then closed by joining the first bar and the last corner of the membrane. The initial location of the bars was determined by an orthogonal single mesh (3.5 cm x 3.5 cm). The equilibrium of this unit tensegrity anti-prism with four bars and single-piece membrane is achieved through the tension of the membrane. The final form is a continuum of four paraboloids.

c. Continuous-membrane pattern piece with twenty struts in a double layer

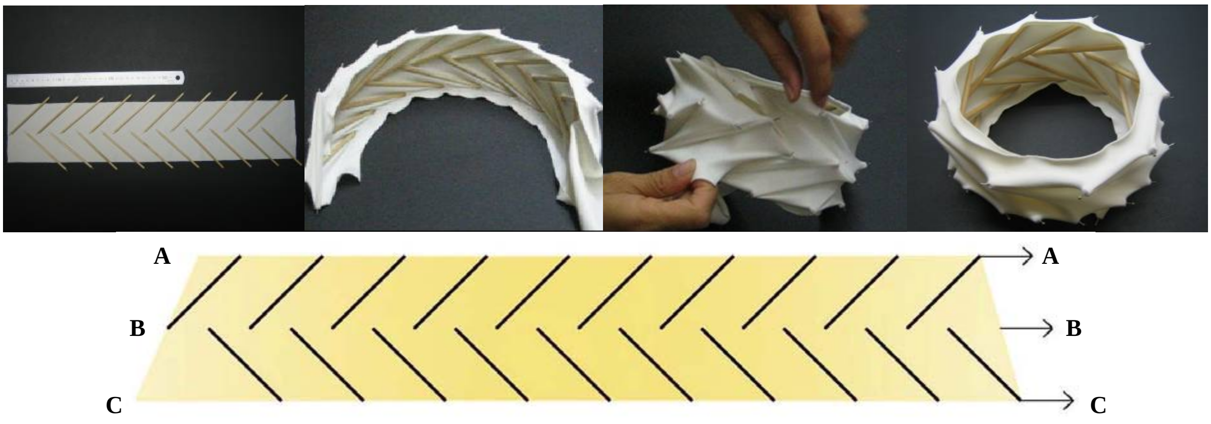


Figure 6. *A tensegrity ring with a continuous membrane and 20 struts - scale model 1:100*

In this tensegrity ring, formfinding is generated by means of a single-piece membrane (7.00 cm x 36.75 cm), which has an initial rectangular shape. For this model of twenty bars (L=10 cm) in a double layer, the bars are arranged in an oblique direction or diagonal position, in an alternating pattern and are joined to the end points of the membrane like shown in Fig. 6, and resemble the veins of a leaf. The system is then closed by joining the first bars and the last corners of the membrane. The initial location of the bars was determined by an orthogonal double mesh (3.5 cm x 3.5 cm), whose distance was defined by the elasticity of the membrane relative to the length of the diagonal bar. The final form is a continuum of ten upper paraboloids and ten lower paraboloids below.

d. Diamond-membrane pattern pieces with mesh and twenty struts in a double layer

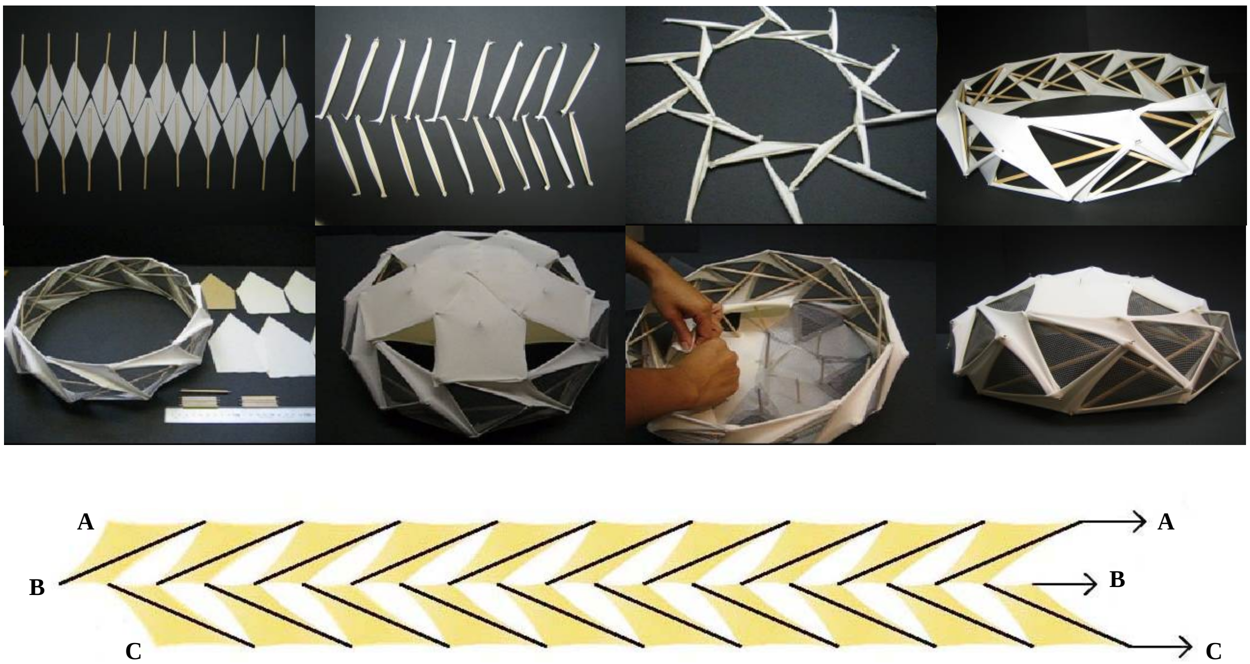


Figure 7. *Photos showing the components and final structure as well as a diagram of the tensegrity-ring construction method – scale model 1:100*

The ring structure is made up of a continuum of ten upper-level paraboloids and ten lower-level paraboloids with a diameter of 40 cm. Formfinding for the ring structure is generated by means of a diamond-shaped membrane pattern pieces (rhombus = major axis 11.5 cm, minor axis 4 cm) formed by two layers of twenty bars (L=20 cm), which are arranged either in an oblique or a diagonal position. The bars are connected to the end points of the membrane as shown in Fig 1 and then to the adjacent membrane piece at the corresponding end point.

This procedure is repeated for all adjacent membrane pieces, while at the same time, the upper section is interlaced with the lower section creating one continuous ring structure when the last two bars are put into place.

A dome is created by combining the above ring structure with a “roof” consisting of one central mast (L=9 cm) and ten minor masts (L=6.5 cm) placed in a circular form held in place by the tension of the membrane itself. The membrane balances the system and joins the dome with the tensegrity ring. The final structure is a dome free of any internal supports.

If one compares the model in Fig. 7 with the continuous membrane in Fig. 6 it can be observed that, though they have the same number of bars, the diameter of model in Fig. 7 is larger (approximately double) and this is why the diamond-pattern model was ultimately selected for structural analysis.

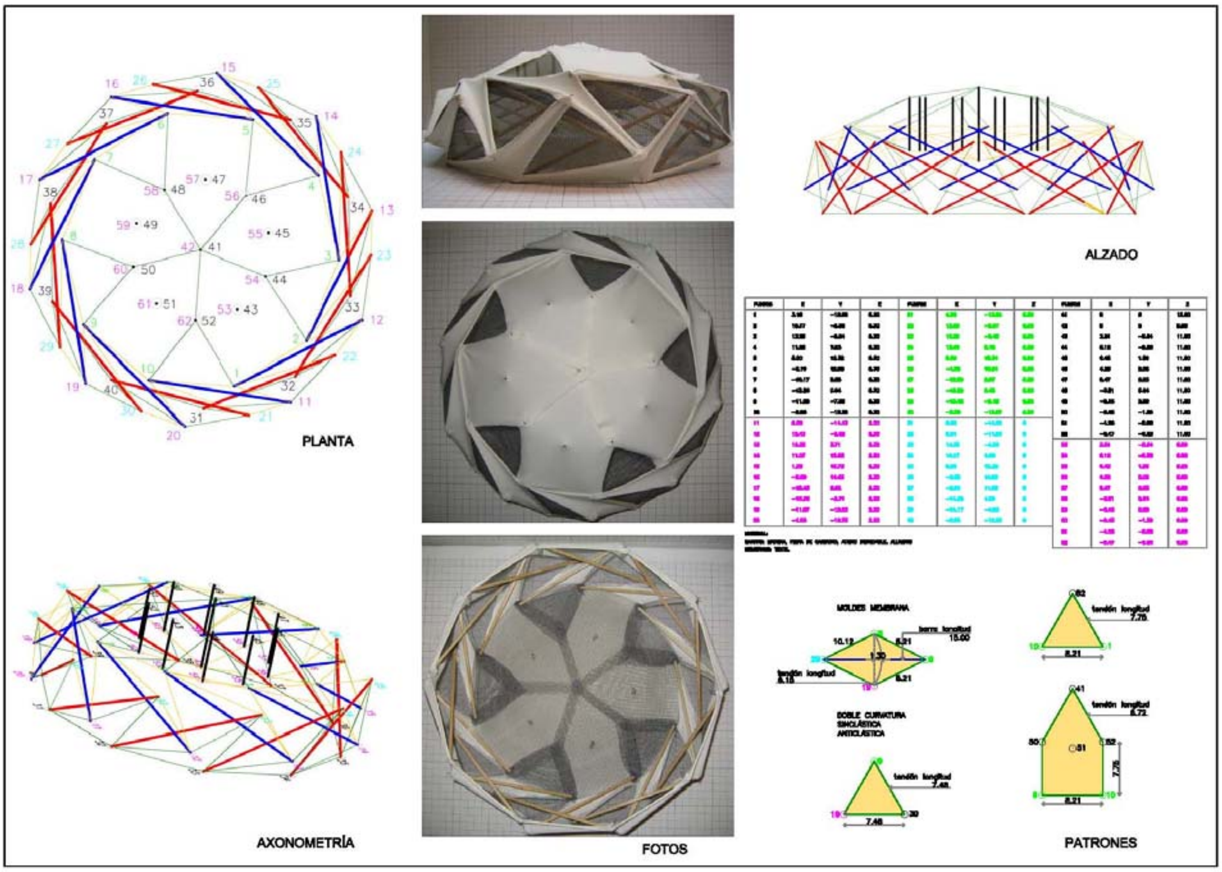


Figure 8. *Technical and geometric drawings of the structure. The tensegrity ring and central dome are shown with the membrane and external support cables.*

The final structure can be scaled as needed. To make a larger diameter, there are two options. First, the quantity of bars would have to be increased proportionally to the elasticity of the membrane used. Second, if the length of the bars is increased, the ring diameter will be larger. A larger prototype was assembled using 20 struts (L=50 cm) in a double layer resulting in an overall diameter of 100 cm (Fig. 9). The ratio of length of the bars to the overall diameter is 1:2.

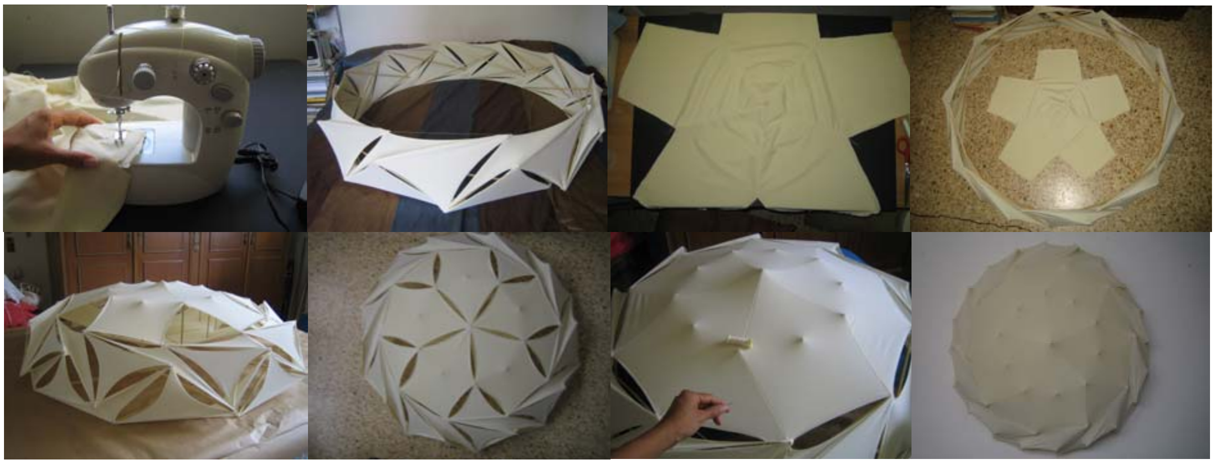


Figure 9. *Tensegrity dome with a diameter of 100 cm – scale model 1:100*

4. STRUCTURAL ANALYSIS

Tensegrity structures are characterized by: [5]

- Discontinuous elements that work under compression
- Pre-stressed structural membrane
- Auto-balanced structure

The proposed structure was first tested via WinTess software [6]. Testing demonstrated the following:

- It allowed the structural elements (membrane, tubes, and cables) to be analyzed and optimized for dimensional stability.
- That the structure is closed, in equilibrium (all the compression and tension forces are perfectly distributed via a 650 kg/m pretension of the membrane), and able to support its own weight.
- That, during extreme external wind conditions of 170 km/h, the maximum inward (horizontal) displacement of the bar free nodes is 95 cm, which was decreased to 17 cm after being reinforced. (The bar free nodes are located on the side of the structure between the upper and lower levels of the tensegrity ring. They are not directly connected to the upper dome or to the foundation nodes. The bars of the tensegrity ring are shown in blue and red in Fig 8).
- That the maximum reaction in the foundation nodes is 24 tons.
- That, during external snow loads of 50 kg/m, a maximum (vertical) displacement of 60 cm is found in the minor dome masts (the minor masts are shown in black in the drawings in Fig. 8) and the maximum reaction in the foundation nodes is 22 tons.
- That the large displacements must be countered by the use of external tubes and cables if the structure is to be built in the real world.
- The exterior tubes are placed surrounding the ring so that they continue in the direction of the forces coming from the top membrane dome. The pretensioned cables increase the stiffness of the structure and contribute to support and balancing of the system.
- In some analyses, distortions and/or irregularities were used to see if the structure remained balanced. In our case, we tested the irregularities and they had no impact on the structural balance. In addition, the structure is not symmetrical to wind; the tensegrity of the position of the bars has a twisting motion like a windmill, and therefore, the reactions are different.

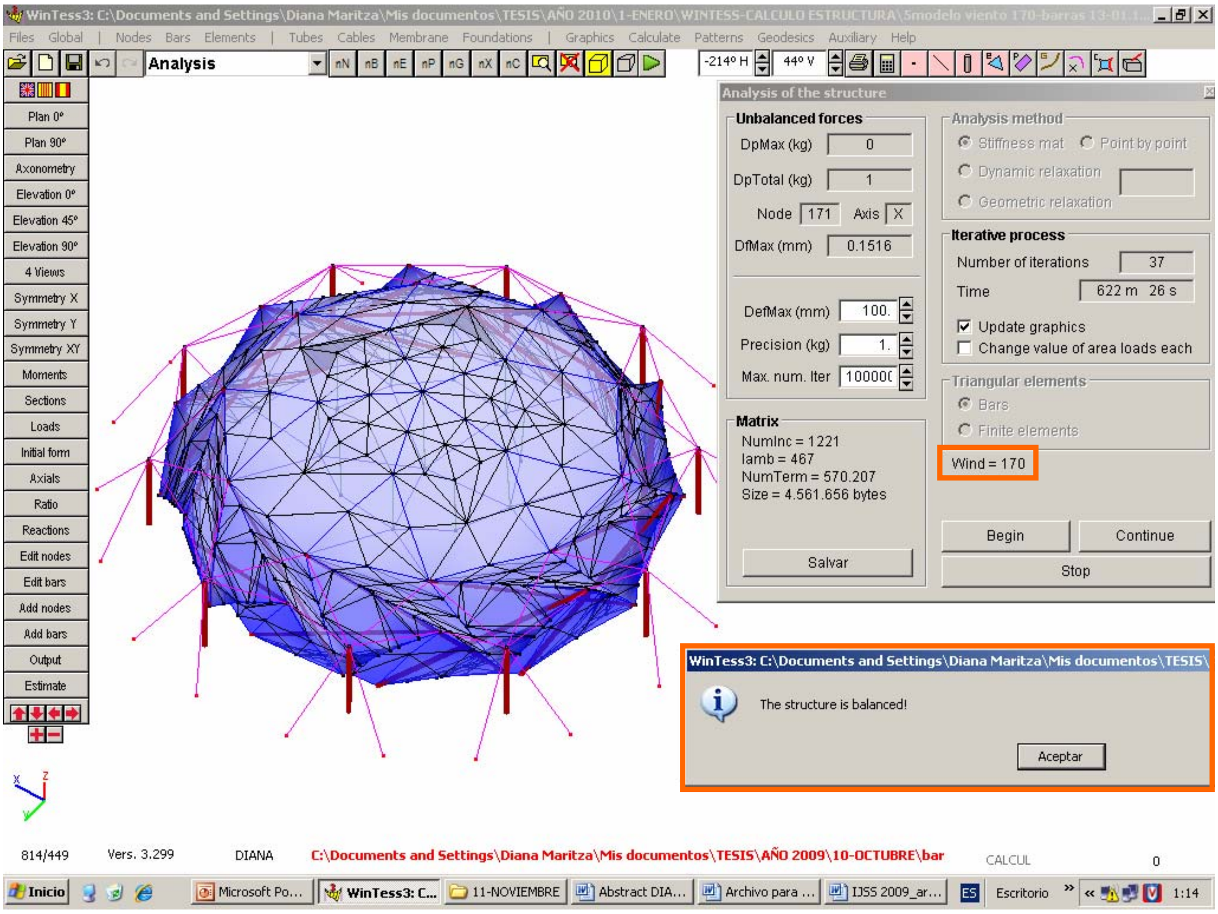


Figure 10. Structural analysis using WinTess software. Note that the computer model is shown with both the membrane and cables, which prevent the structure from moving in the real world. The structure remains balanced when wind of up-to 170 km/h is applied. (diameter 40 m - scale model 1:1)

Structural characteristics of the model elements [7]:

- **Membrane:** Ferrari Fluotop T2 1202 – **Pre-stress** 1% = 32.5 daN/5cm = 650 kg/m **Resistance** Rk = 560/560 daN/5cm = 11200,0 kg/m - **Safety factor** (5) = Rd = Rk / 5 = 112 daN/5cm = 2240 kg/m
- **Border cables (Boltrope):** 1x91 (36mm) Inox ∅ 36 - **Section** 753 mm^2 - **Elasticity modulus** 1.380 t/cm^2 = 138 kN/mm^2 - **Q=** 87,21 t = 872,1 kN
- **External cables (Guyrope):** WS-2 (36mm) Galv ∅ 36 - **Section** 855 mm^2 - **Elasticity modulus** 1.635 t/cm^2 = 163,5 kN/mm^2 - **Q=** 125,46 t = 1.254,6 kN
- **Ring tubes:** L=20 m - ∅ 400-10_S235 - **Section** 122,522 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3
- **Dome central mast:** L=9 m - ∅ 110-5_S235 - **Section** 16,493 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3
- **Dome minor masts:** L=6,5 m - ∅ 90-4_S235 - **Section** 10,807 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3
- **External tubes:** L= 8 m - ∅ 250-8_S235 - **Section** 60,821 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3

Table 1. *Structure general data*

Number of nodes	447
Number of bars	1296
Number of tubes	41
Number of elements	709
Number of cables	305
Covered surface	1177 m²
Volume (between membrane and plane Z=0)	15818 m³
Membrane surface	2959 m²
Membrane elongation modulus	65 T/m
Weight of the bars	53807 kg
Weight of the membrane	3848 kg
Total weight of the structure	**57655 kg**
Weight of the structure per m²	49 kg/ m²

5. WIND-TUNNEL TESTING

Figure 11. *Wind-tunnel testing – scale model 1:250*

The proposed structure was then tested in a wind tunnel. Due to the nature of tensile-textile construction (lightweight structures), the ability of the structure to withstand external loads relative to weight of the structure itself is much greater that of conventional construction [8]. It is important to note, though, that small changes in wind pressure or snow loads can have a major impact on the size and shape of the structural elements and the deformations that occur. For this reason, it is important to understand the pressure and suction coefficients that impact the structure: vertical force (lift coefficient) and horizontal force (drag coefficient).

Description: The wind tunnel is open, and works by aspiration (Eiffel style); that is, undisturbed air is accelerated through a nozzle and sent to the model; thus the flow profile is laminar. However, the model size is 0.17 m (scale 1:250), and free stream speed ranged between 5 and 20 m/s, that is Reynolds numbers from 5x10^4 and 2x10^5, which is a fully turbulent regime, which corresponds to the a real-world-sized building.

The model is made from a rigid plastic material, while the real-world structure would have a flexible cover. The forces measured with the model have been scaled to the real-world-sized structure assuming that it acts as a rigid body, due to the beams that support the building in tension. The wind tunnel tests were used to determine the lift and drag coefficients. Drag coefficient was used in WinTess to calculate the structure to wind up-to 170 km/h.

5.1 Lift coefficient

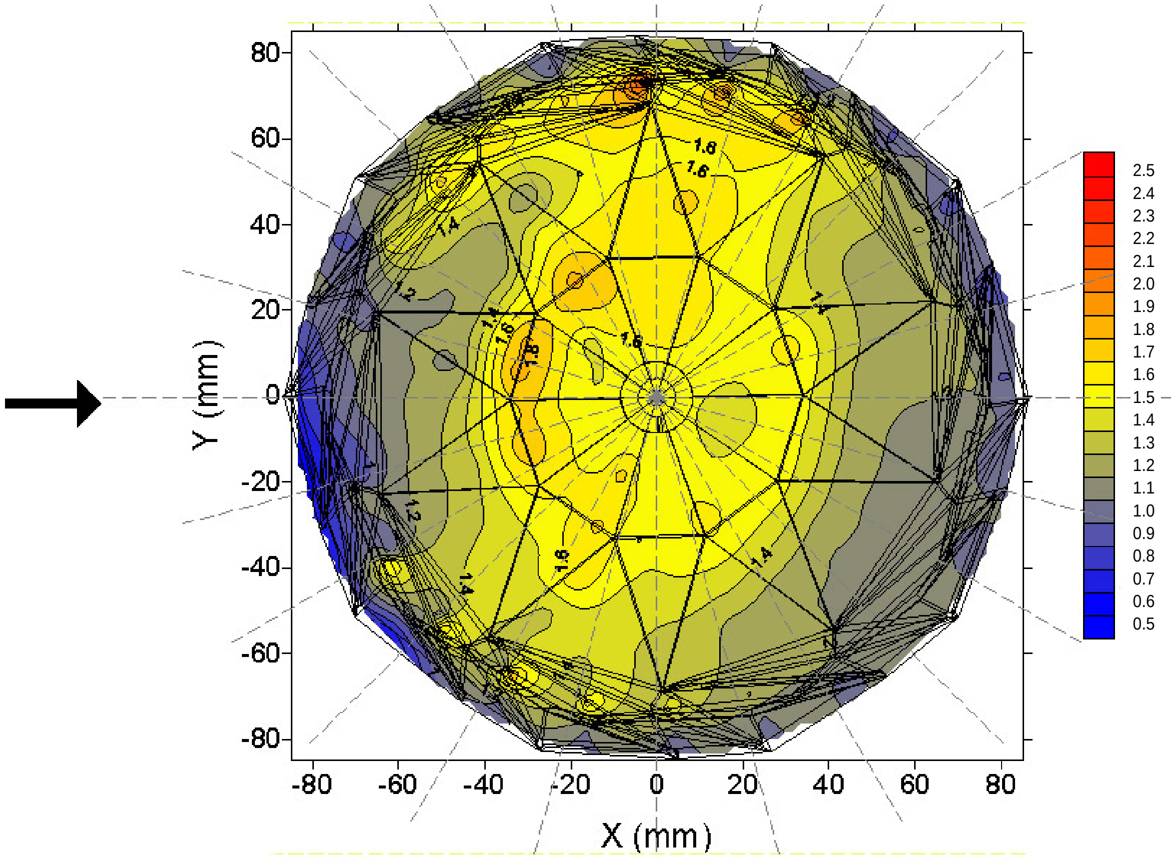


Figure 12a. *Lift- coefficient model plan view.*

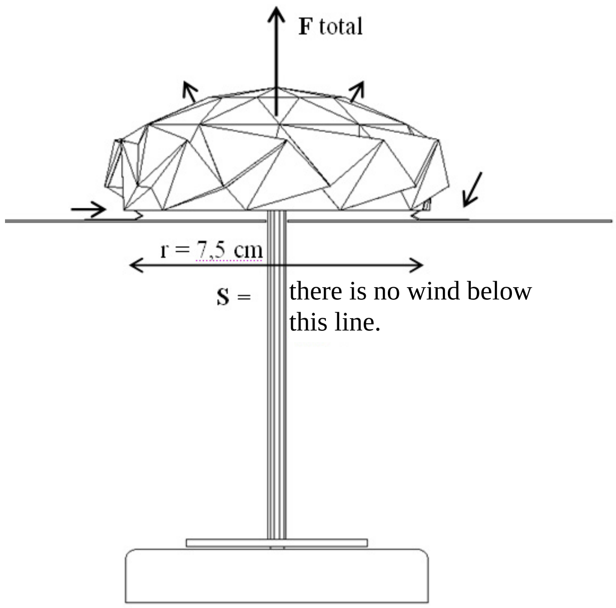


Figure 12b. *Lift-coefficient testing diagram.*

The value of the global lift coefficient obtained from the experimental measurements was C_l ~0.86. Local measurements of the lift coefficients, determined in small holes on the model surface, reach values up to 1.5. Given the size of the wind tunnel testing section (40 cm x 40 cm cross section) and the diameter of the model (17 cm) the statistical error is estimated to be approximately 15%.

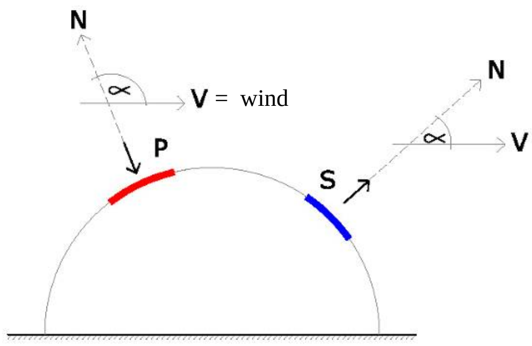
C_l can be estimated from: (1)

$$C_l = \frac{2F_{vertical}}{\pi \cdot (7.5\,cm)^2 \cdot \rho \cdot v^2}$$

Where $F_{vertical}$ is the vertical component of the force acting on the model, ρ is the air density and v is the free stream speed.

5.2 Drag coefficient

The amount of suction or pressure depends on the velocity of the wind and the angle of incidence.



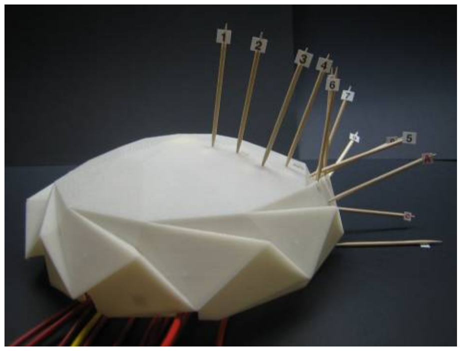


Figure 13. *Surface normal angle in the model (**p**=pressure and **s**=suction).*

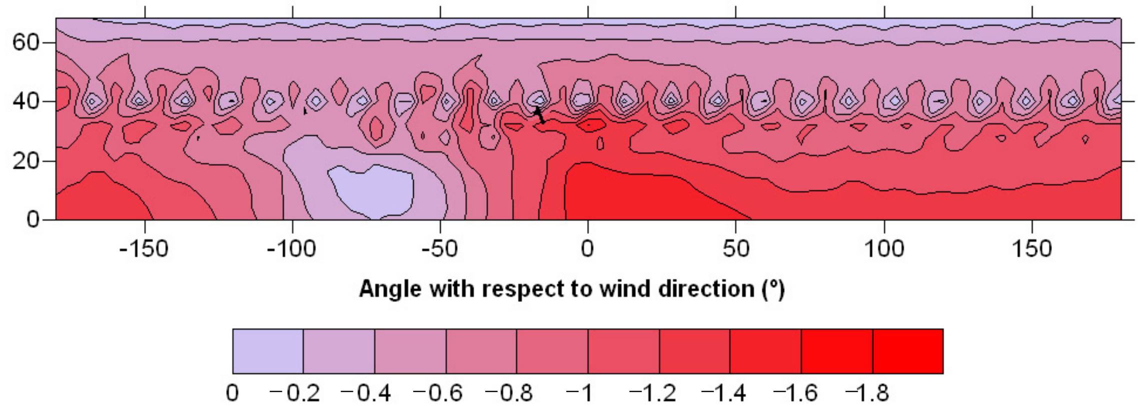


Figure 14. *Drag-coefficient diagram. Pressure coefficients relative to the lateral wall of the building.*

The entire wall was found to have negative-pressure coefficients, which shows that the effect of wind on the wall is that of suction. Negative values closer to zero (in red) indicate less suction and are mostly found for angles closer to zero relative to the direction the wind. Negative values farther from zero (in blue) indicate greater suction and are mostly found for angles lower than -90 degrees and greater than 90 degrees relative to the direction of the wind.

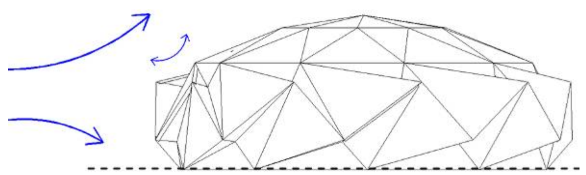


Figure 15. *Drag-coefficient diagram.*

The model has a very aerodynamic structure relative to wind coming from the side due to the suction created as a result of negative coefficients of pressure. The convex forms allow wind to freely pass by.

Drag coefficient: The global drag coefficient obtained experimentally was C_d ~0.30. Local pressure coefficients show a significant dispersion, as shown in Fig 14.

$$C_d = \frac{2F_{drag}}{\pi \cdot S_e \cdot \rho \cdot v^2} \qquad (2)$$

Where S_e is the elevation surface *(model 0,008718 m^2)*

After wind-tunnel testing, we found that there is an overload of forces on the model and we had to re-optimize the structural elements. The elements that changed were:

Wind up-to 170 km/h:

- **Membrane:** Ferrari Fluotop T2 1302 - **Prestress** 0.8 % = 32,6 daN/5cm = 652 kg/m **Resistance** Rk = 800/700 daN/5cm = 16000,0 kg/m - **Safety factor** (5) = Rd = Rk / 5 = 160 daN/5cm = 3200 kg/m

- **Border cables (Boltrope):** WS-2 (36mm) Galv ∅ 36 - **Section** 855 mm^2 - **Elasticity modulus** 1.635 t/cm^2 = 163,5 kN/mm^2 - **Q=** 125,46 t = 1.254,6 kN

Table 2. *Structure general data*

Membrane-elongation modulus	80 T/m
Weight of the bars	56720 kg
Weight of the membrane	4144 kg
Total weight of the structure	**60864 kg**
Weight of the structure per m²	52 kg/ m²

The weight of the structure increased from 57655 kg to 60864 kg. The maximum reaction in the foundation nodes was 24 tons.

Snow up-to 50 kg/m^2:

- **Border cables (Boltrope):** WS-2 (42mm) Galv ∅ 42 - **Section** 1160 mm^2 - **Elasticity modulus** 1.635 t/cm^2 = 163,5 kN/mm^2 - **Q=** 171,36 t = 1.713,6 kN

- **Ring tubes:** L=20 m - ∅ 450-10_S235 - **Section** 138,23 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3

- **Dome central mast:** L=9 m - ∅ 200-5_S235 - **Section** 30,631 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3

- **Dome minor masts:** L=6,5 m - ∅ 110-5_S235 - **Section** 16,493 cm^2 - **Elasticity modulus** 2.100 t/cm^2 = 210 kN/mm^2 - **Density** 7,85 t/m^3 = 78,5 kN/m^3

Table 3. *Structure general data*

Membrane-elongation modulus	80 T/m
Weight of the bars	64880 kg
Weight of the membrane	4144 kg
Total weight of the structure	**69024 kg**
Weight of the structure per m²	59 kg/ m²

The weight of the structure increased from 60864 kg to 69024 kg. And the maximum reaction in the foundation nodes was 22 tons.

Results: In the next analysis (Table 4) we can compare the different results of the model with different options through the WinTess software. The nodes displacements in the tensegrity ring and the dome, the weight of the structure, reactions, dimension of the structural elements. All tested under loads of wind, self weight and snow take in account the pressure coefficient. The comparison between structure with only cables, structure with only membrane, and structure with both membrane and cables, which demonstrated major efficiency in the structure tested, to wind 170 km/h (minor displacements) that the structure tested to snow 50 kg/m, (less efficiency, major displacements). After the analysis the proposed structure's aerodynamic and load-bearing features would be helpful if building in an area frequented by high winds and in areas with little-to-no snow.

Table 4. *A comparison of the results between structure with only cables, structure with only membrane and structure with both membrane and cables.*

TENSEGRITY STRUCTURE DATA SUMMARY

		Structure with only cables			Structure with membrane and cables			Structure without cables - membrane only		
		self weight	self weight	self weight	self weight	wind 170 km/h	snow 50kg/m2	self weight	wind 170km/h	snow 50kg/m2
		without reinforcement	reinforcement - without ext. tubes	external tubes and cables	with reinforcements, external tubes, and external cables					
		case 1	**case 2**	**case 3**	**case 4**	**case 5**	**case 6**	**case 7**	**case 8**	**case 9**
	Displacement Averages (mm)									
Tensegrity Ring	Foundation nodes - lower bars	0	0	0	0	0	0	0	0	0
	Lower bar free nodes	950	903	107	140	179	109	328	573	1547
	Upper bar free nodes	941	888	115	142	198	133	285	725	1420
	Upper bar nodes connected to the upper dome.	349	353	178	149	73	277	464	127	2504
Tensegrity Dome	Central mast top node	164	422	344	172	54	690	349	151	4109
	Central mast low node	164	422	340	172	54	689	356	105	4106
	Upper nodes of the minor masts supported with 5 cables	345	322	163	289	217	729	575	158	3923
	Lower nodes of the minor masts supported with 5 cables	345	320	147	216	147	651	576	141	3901
	Upper nodes of the minor masts supported with 4 cables	2533	275	103	254	182	759	1302	450	4217
	Lower nodes of the minor masts supported with 4 cables	2500	287	118	183	147	656	1320	478	4184
Auxiliar elements	Lower nodes of the external tubes supported with 2 cables	-	-	0	0	0	0	0	0	0
	Upper nodes of the external tubes supported with 2 cables	-	-	36	72	24	23	71	23	192
	Structure Results									
	Total weight of structure (kg)	27064	27558	29350	57655	60864	69024	29759	52391	48865
	Structure weight per m²	23	23	25	49	52	59	25	46	42
	Loads (tons)	-	-	-	-	254	143	-	254	127
	Foundational Reactions (tons)	5	5	5	11	15	22	5	9	20
	External-tube reactions (tons)	-	-	2	6	18	14	4	20	16
	External-cable reactions (tons)	-	-	2	9	25	17	5	22	19
	Average ratio of the tubes	0,5 a 0,05	0,5 a 0,05	0,5 a 0,05	0,5 a 0,05	0,5 a 0,05	0,7 a 0,05	0,7 a 0,05	0,5 a 0,05	0,7 a 0,05
	Average ratio of the cables	0,5 a 0,05	0,7 a 0,05	0,5 a 0,05	0,5 a 0,05	0,7 a 0,05	0,7 a 0,05	-	-	-
	Membrane ratio	-	-	-	0,5 a 0,05	0,7 a 0,05	0,5 a 0,05	0,5 a 0,05	0,7 a 0,05	0,9 a 0,05
	Structural Elements									
	Membrane Ferrari Floutop	-	-	-	TP-1202	TP-1302	TP-1302	TP-1202	TP-1302	TP-1302
	Border cables	Inox ∅ 24	Inox ∅ 24	Inox ∅ 24	Inox ∅ 36	Galv ∅ 36	Galv ∅ 42	-	-	-
	Ring tubes (L=20m)	∅ 300-8_S235	∅ 300-8_S235	∅ 300-8_S235	∅ 400-10_S235	∅ 400-10_S235	∅ 450-10_S235	∅ 300-8_S235	∅ 400-10_S235	∅ 400-10_S235
	Central masts (L=9m)	∅ 110-5_S235	∅ 110-5_S235	∅ 90-4_S235	∅ 110-5_S235	∅ 110-5_S235	∅ 200-5_S235	∅ 110-5_S235	∅ 150-5_S235	∅ 150-5_S235
	Minor masts (L=6,5m)	∅ 70-4_S235	∅ 70-4_S235	∅ 70-4_S235	∅ 90-4_S235	∅ 90-4_S235	∅ 110-5_S235	∅ 70-4_S235	∅ 110-5_S235	∅ 110-5_S235
	External cables (guyrope)	-	-	Inox ∅ 12	Galv ∅ 36	Galv ∅ 36	Galv ∅ 32	Inox ∅ 18	Galv ∅ 38	Inox ∅ 36
	External tubes (L=8m)	-	-	∅ 150-5_S235	∅ 250-8_S235	∅ 250-8_S235	∅ 250-8_S235	∅ 150-5_S235	∅ 300-8_S235	∅ 200-5_S235
		case 1	**case 2**	**case 3**	**case 4**	**case 5**	**case 6**	**case 7**	**case 8**	**case 9**

Case 5 more efficient minor displacements

Case 9 less efficient major displacements

6. APPLICATION

There exists a need for roof structures that can cover large surfaces and spaces and that are free of any interior supports. After doing the pertinent calculations, a tensegrity ring is proposed with a central dome, using diamond-shaped membranes patterns with twenty struts in a double layer, to cover a 40 m diameter sports arena, which has a surface of 1.200 m^2 and can be occupied by approximately 626 people.

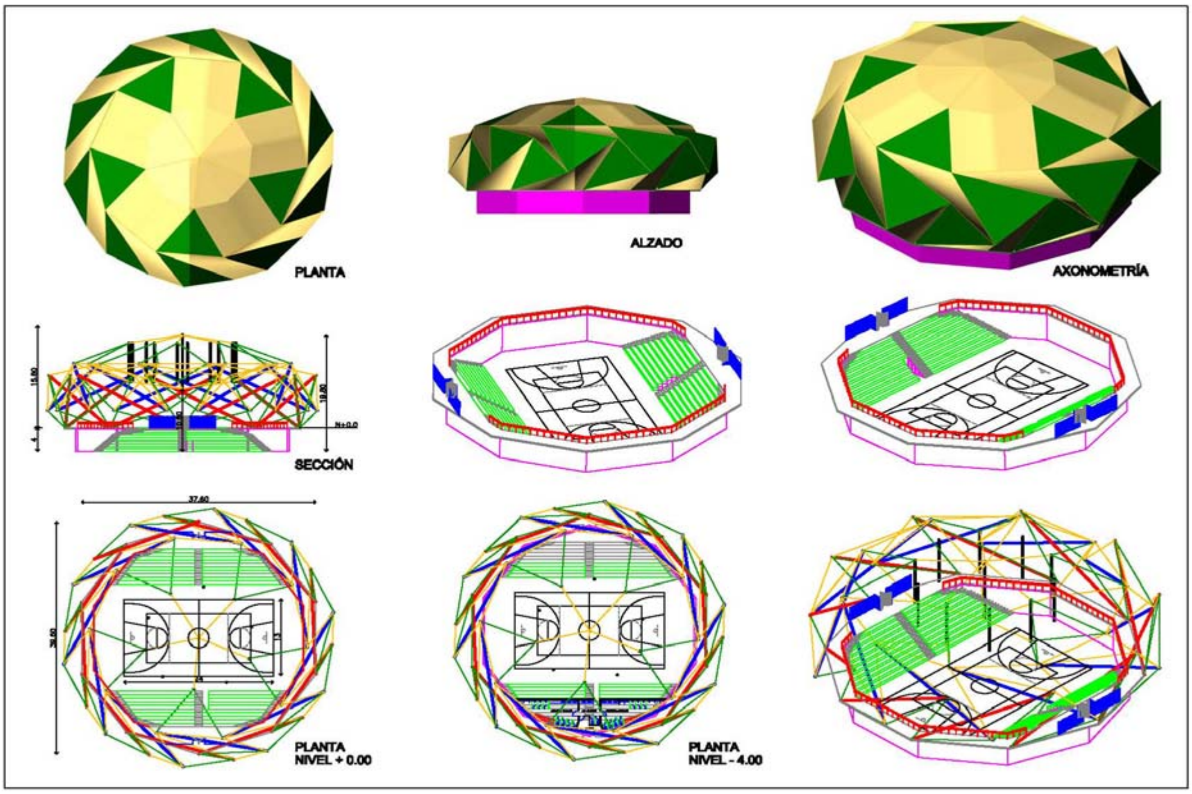


Figure 16. *Application of the tensegrity ring to cover a sports arena.*

7. CONCLUSION

The current research demonstrates that the equilibrium of the proposed tensegrity dome is achieved by formfinding and pretensioning a diamond-membrane pattern used in conjunction with bars in a double layer.

Testing demonstrated that to successfully develop the proposed structure, it is important to analyze the forces in the components, and to consider endogenous factors such as the internal prestress of the structure, and exogenous factors such as external loads, points of support, anchorages, etc.

The major stress data distribution produced by the WinTess software shows the importance of the proper definition and selection of the structural elements.

The uniqueness of these structures is, even though they are auto-balanced for external loads such as wind and snow, that it is sometimes necessary to increase the stiffness of the structural elements and/or reinforce them with external tubes and cables to prevent a collapse due to extraordinary conditions.

Small changes in wind pressure or snow loads can have a major impact on the size and shape of the structural elements and the deformations that occur. The impact of these issues during our wind-tunnel testing led to the re-optimization of the structural elements, which resulted in a structure that remained in equilibrium in spite of the wind and snow loads.

As demonstrated with the scale model, tensegrity-dome structures allow for large, unobstructed spaces such as are required in sports arenas.

The comparative analyses of the structure with only cables, with only membrane, and both cables and membrane tested under loads of wind, self weight, and snow concluded that larger displacements were observed before the structure was reinforced with external tubes and cables. The wind-load displacements went from 950 mm down to 179 mm in the tensegrity-ring bar free nodes.

The proposed structure was found to perform best when used in conjunction with external cables.

The proposed structure's aerodynamic and load-bearing features would be helpful if building in an area frequented by high winds. It would not be optimal for use in areas that experience heavy snow.

ACKNOWLEDGEMENTS

Thanks to my thesis tutor, Professor Josep Ignasi Llorens, for his support throughout my thesis project.

Thanks to Professor Sastre for use of his WinTess software as well as his never-ending support.

Thanks also to Professor Daniel Crespo Artiaga (Physics) in the Department of Applied Physics and Professor Joshua Martínez Tristancho (Aeronautical Engineering) in the Computer Architecture Department at Universitat Politècnica de Catalunya for their work and assistance performing the wind-tunnel testing.

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