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Application of the tensegrity system to create 3D impression of the butterfly body heliconius doris obscurus as a floating compression structure

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ABSTRACT

In this paper we present the research carried out at the Metropolitan Autonomous University Campus Cuajimalpa, which consists of developing a floating structure of the body of the Heliconius Doris obscurus, worldwide known as Laparus Doris obscurus (Weymer, 1891), based on Karl Ioganson invention "Tensegrity".

In this project, we made three prototypes in order to study the way the structure of floating compression of the butterfly body is performed. The first prototype is a solid structure printed in 3D. This prototype was used to analyze the curvature of the butterfly body. In the second and third prototype, the butterfly body was divided in 24 parts. In the second prototype, we use a three-dimensional network of nylon monofilament and plastic straws as separators between each part to tense and join each of the parts.

In each part, in the third prototype two holes were open to place two cylinders with four holes; between each part one cylinder with eight holes added, in order to pass the nylon monofilament to stress the body. The objective of this project is that design students use the techniques of geometric morphometrics, descriptive geometry and tensegrity for their terminal projects.

KEYWORDS

Tensegrity; butterfly; rapid prototyping

1. Introduction

The Lativian artist, Karl Ioganson belongs to the circle of constructivist artists. Between 1914–1917, his main and transcendental innovation was the tensegrity system denominated in German Gleichgewicht konstruktion [3].

Within constructivism, Ioganson promoted two fundamental concepts: spatial structure and cold structure, where, instead of using the hot rivets, it uses screws and nuts, and simple fasteners.

Ioganson explored two cross stabilization methods: the addition of tensile structural elements (steel wire) (Fig. 1(a and b)) and the filling of the areas with laminar materials, which he exemplified in his constructions.

Anthony Pugh described Tensegrity as follows: "A tensegrity system is established when a set of discontinuous compressive components interact with a set of continuous tensile components to define a stable volume in space" [2].

Kenneth Snelson defines Tensegrity as "floating compression structure". "A closed structural system composed of a set of three or more elongate compression struts within a network of tension tendons, the combined parts mutually supportive in such a way that the struts do not touch one another, but press outwardly against nodal points in the tension network to form a firm, triangulated, prestressed, tension and compression unit" [5].

Valentin Gómez Jáuregui wrote, "Tensegrity systems are light structures, suitable for knock down and foldable structures. Tensegrity systems are composed of cables and right bars and have the following characteristics: the static stability of the structure is the result of pretensioning the cables; the rigid elements (bars) are not connected one to the other and they subjected only to compression strains; there are no rigid joints in the structure, there are only joints" [1].

For this research, we used the tensegrity system to develop the body of the obscure Heliconius Doris butterfly, worldwide knows as Laparus Doris obscurus (Weymer, 1891).

We made three models to study the way that the floating compression structure of the butterfly's body can be performed. The first model (Fig. 2(a)) is a solid structure printed in 3D. We used this model to analyze the curvature of the butterfly body.

In the second (Fig. 2(b)) and third (Fig. 2(c)) models, we divided the butterfly body in 24 parts. To tense and join each of the parts, in the second prototype we

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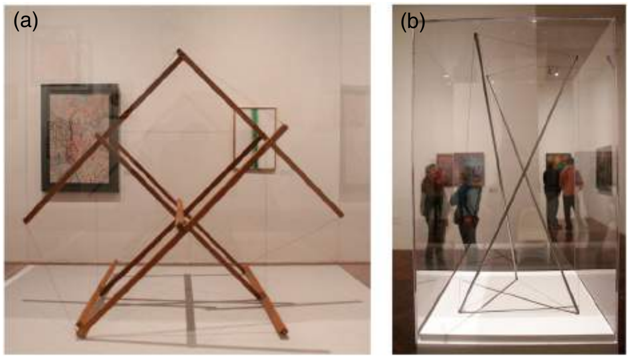

Figure 1. Models: (a) an axel bar structure and (b) a self-supporting construction.

used a three-dimensional network of nylon monofilament and plastic straws as separators between each part. In each part, of the third model two holes were opened to place two cylinders with four holes; between each part one cylinder with eight holes added, in order to pass the nylon monofilament to stress the body.

The Heliconius butterfly has a body measuring of 24mm long, two small wings measuring 26mm long, two large wings measuring 40 mm long, four legs measuring 12mm and two antennas measuring 20 mm long (Fig. 3).

To simulate the orthogonal projection, we took five photographs: top, front, back, right side and left side of the butterfly's body, and place them according to their position (Fig. 4(a)). By means of the geometric morphometrics technique [4], we found the numerical values of the coordinates "x", "y" and "z" of each of the points of the 24 parts in which the butterfly body was divided. These values are concatenated and passed to the vector program. As example, we show curve #10 (Fig. 4(b) and Tab. 1).

This article consist of the following sections: in Section 2, we explain the development of the first prototype. In Section 3, we explain the second prototype development. In Section 4, we explain the third prototype development. Section 5 presents the union of the cylinders with the geometric shapes of the butterfly body. Section 6 presents the floating structure assembly. Section 7 presents the results. In Section 8, we

Figure 3. Heliconius Doris obscurus butterfly.

presents the contributions and finally Section 9 presents the conclusions. All figures presented in this paper are original and created by the authors at the Metropolitan Autonomous University Campus Cuajimalpa.

2. Development of the first prototype

In order to understand the method used in this research, Figure 5(a) shows the accommodation of three of the photographs in the orthogonal projection. We can see that the butterfly body is upwards, so that it rotated 180° in the vector program so that the butterfly is in its real position, i.e. with the legs down. (Fig. 5(b)).

In the first prototype, the measure of the butterfly's body is 144 mm divided into 24 parts with the same number of points. The curves were delimited (Figure 6(a)), the planes were traced with the 3D face (Fig. 6(b)), and the solid was modeled (Fig. 6(c)).

As can be seen in Figure 7(a), on the right side of the butterfly body there are four holes to positionate the two wings. These same holes are on the left side of the butterfly. There are two holes to place the antennas, and there are four supports to assemble the butterfly legs. Figure 7(b) shows the butterfly model and Figure 8 shows the 3D printing prototype.

3. Development of the second prototype

In the second prototype, the measure of the butterfly's body is 240 mm divided into 24 parts. The curves were modeled using polylines and extruded 4mm. Each of the 24 geometric shapes were attached with a nylon

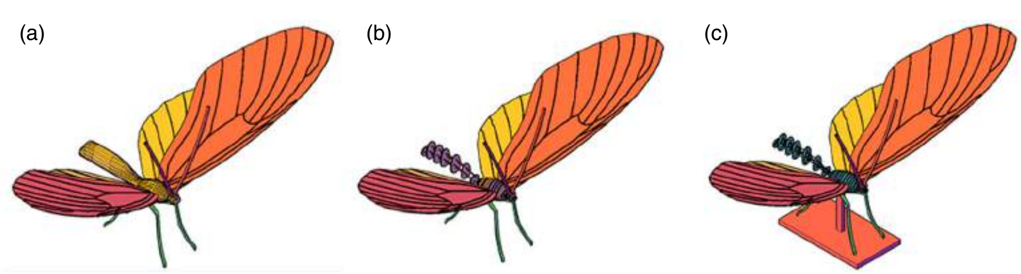

Figure 2. Model: (a) First, (b) Second and (c) Third.

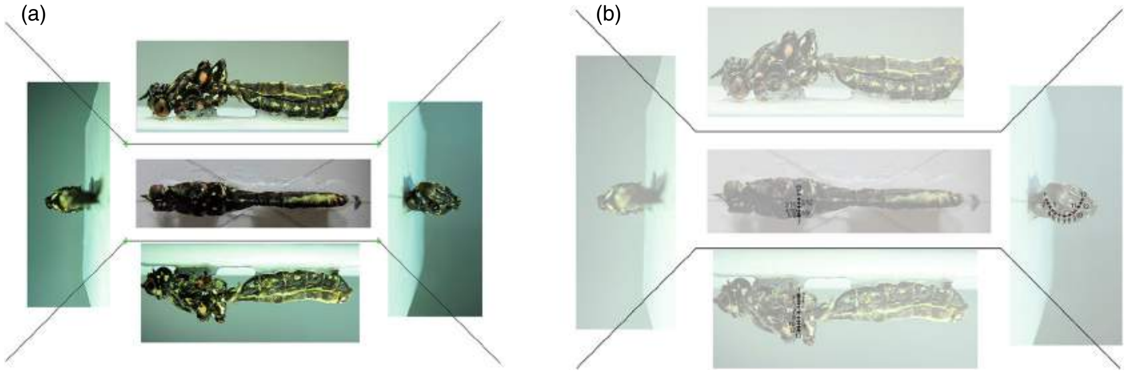

Figure 4. Butterfly body (a) Orthogonal projection and (b) Curve # 10.

Table 1. Numerical values of the axes and numerical values for the curve # 10 of the butterfly body.

				Top view		Front view down		Right view		
Axis	X	Y	Points	X	Y	X	Y	X	Y	Concatenation
1	1728	3273	1	2509	2759	2509	2049	4370	2760	2509,2759,351
2	4016	3273	2	2509	2732	2509	2039	4381	2731	2509,2731,362
3	4016	2398	3	2509	2705	2509	2024	4396	2704	2509,2704,377
4	1728	2398	4	2509	2677	2509	2004	4417	2676	2509,2676,397
			5	2509	2658	2509	1884	4437	2658	2509,2658,417
			6	2509	2641	2509	1956	4466	2641	2509,2641,446
			7	2509	2635	2509	1918	4504	2635	2509,2635,484
			8	2509	2641	2509	1880	4541	2641	2509,2641,521
			9	2509	2658	2509	1851	4571	2658	2509,2658,551
			10	2509	2677	2509	1831	4589	2676	2509,2676,570
			11	2509	2705	2509	1809	4611	2705	2509,2704,592
			12	2509	2732	2509	1793	4627	2732	2509,2731,608
			13	2509	2759	2509	1781	4639	2759	2509,2759,620

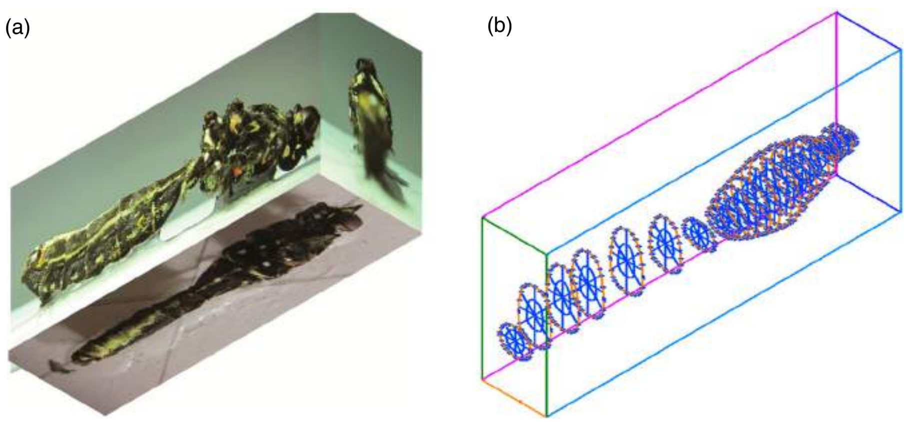

Figure 5. Butterfly body: (a) Simulation of orthogonal projection with photographs and (b) Point and curves.

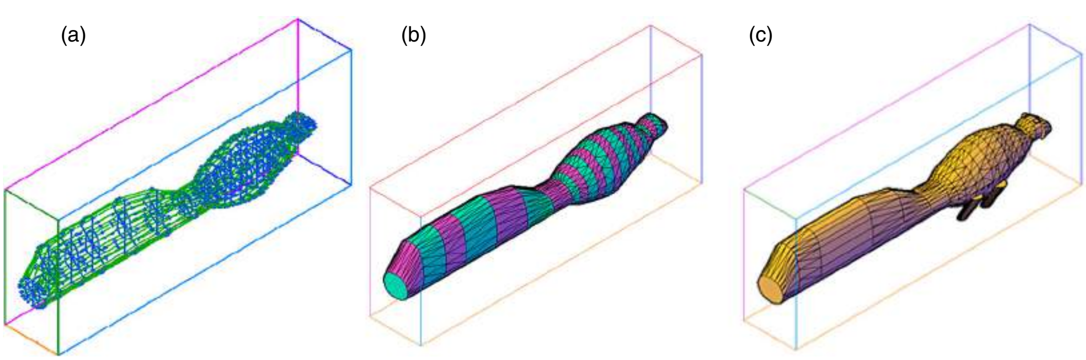

Figure 6. Butterfly body: (a) Axes, (b) Planes in 3D face and (c) Solid.

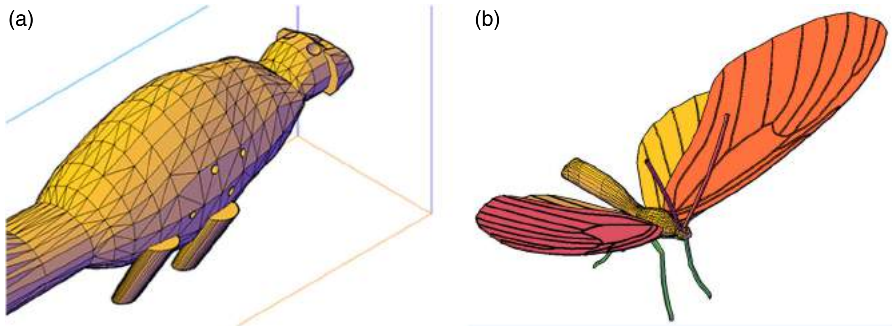

Figure 7. Butterfly: (a) Body detail and (b) Model.

Figure 8. 3D printing prototype.

monofilament and plastic straws as spacers to tense the butterfly's body (Fig. 9 (a and b)).

In order to pass the nylon monofilament between each of the geometric shapes, the center was marked and was trace a circle of diameter between 4 and 18 mm depending on the size of the geometric shapes. The circle was divided into four parts and four holes of 3 mm in diameter were opened. As an example, we show Arc # 8 (Fig. 10).

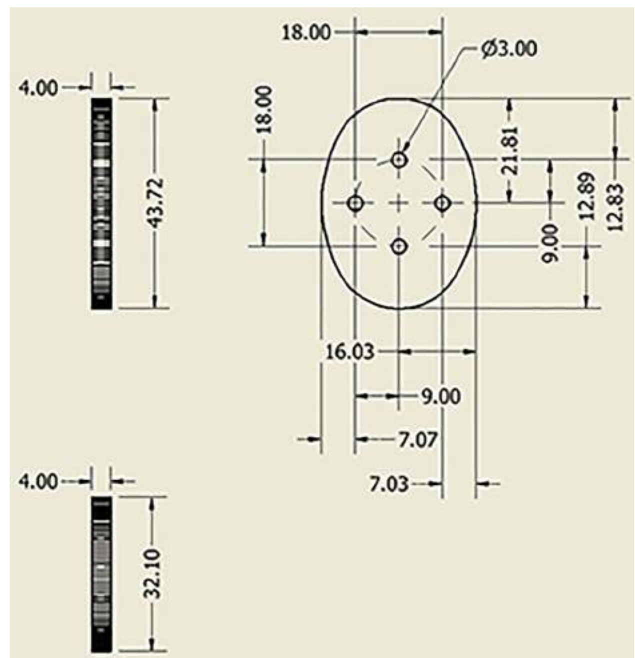

Figure 10. Arc # 8.

A guide was used as template to assemble the butterfly body. (Fig. 11(a and b)). Figure 12 shows the second prototype where we can see that the body, legs and antennas performed in the 3D printer and the wings are made of cardboard with a plastic sheet.

This prototype does not accomplish the tensegrity characteristics, but the body of the butterfly is under tension and compression, and the structure is firm and balanced.

4. Development of the third prototype

In the third prototype, the measurement of the butterfly's body is 960 mm divided in the same 24 parts. The curves

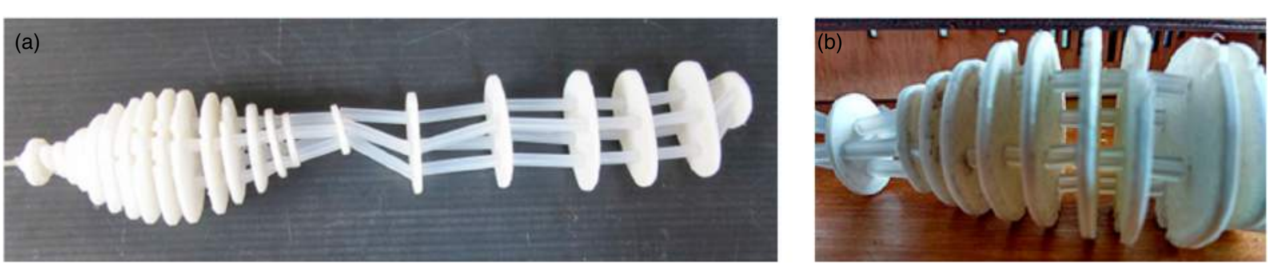

Figure 9. (a) Butterfly body second prototype and (b) Detail.

Figure 11. Guide template.

Figure 12. Second prototype.

were traced using polylines and extruded 2 mm. Wings, legs and antennae were not performed due to the scale.

In each of the 24 geometric shapes, the center was marked. It traced a circle of diameter between 16 and 82 mm depending on the size of the geometric shapes and 2 lines at 90° to find four isosceles Rectangular Triangles. From the hypotenuse of two of the opposite triangles, two cylinders were modeled with eight holes (Fig. 13(a and b)).

The traces made to find the position and inclination of the intermediate cylinders were (Fig. 14):

(a) Two rectangles from the outer quadrant of each of the cylinders. (b) Two triangles, one above joining point C with point A and point B, and the other down joining point F with point D and point E, each line was divided into three parts. (c) An irregular rectangle joining points G, H, I and J, the vertical lines were divided into two parts, and (d) A line joining points K and L.

We finished modeling the intermediate cylinders with eight holes. These cylinders were joined with the other cylinders by tracing lines through the holes to form the triangulation (Fig. 15(a, b and c)).

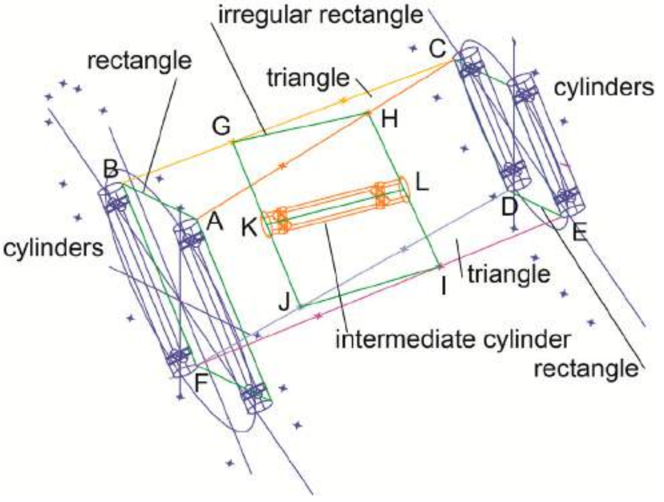

Figure 14. Traces to place the intermediate cylinder.

5. Union of the cylinders with the geometric shapes of the butterfly body

Having resolved the structure of the body of the butterfly, in each of the geometric forms two holes were opened to place the cylinders. As an example, we show Arc # 8 (Fig. 16 (a and b)).

Finally, the body of the butterfly was structured with 24 geometric forms and 71 cylinders (Fig. 17 and 18).

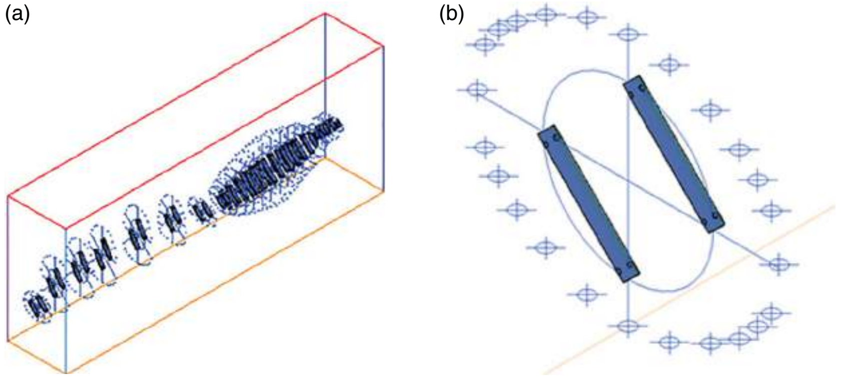

Figure 13. (a) Position of cylinders and (b) Detail.

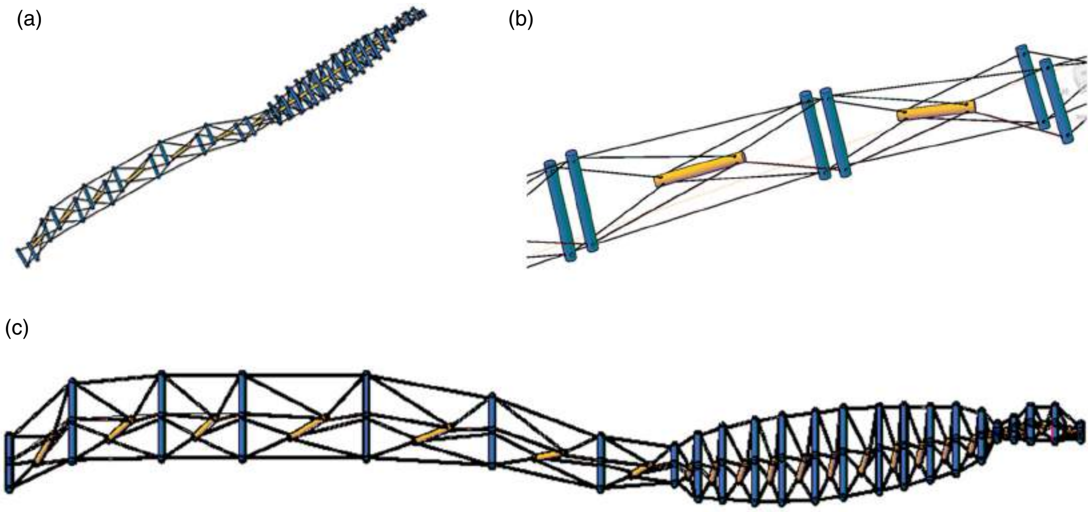

Figure 15. Butterfly body structure (a) Placement of nylon monofilament, (b) Detail and (c) Front view.

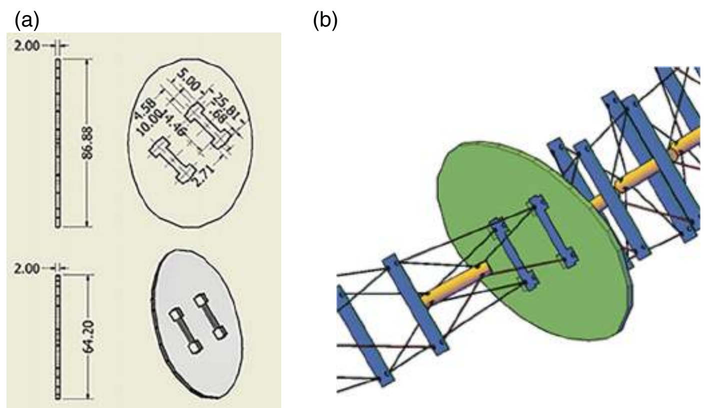

Figure 16. Arc # 8: (a) Measurements and (b) Detail.

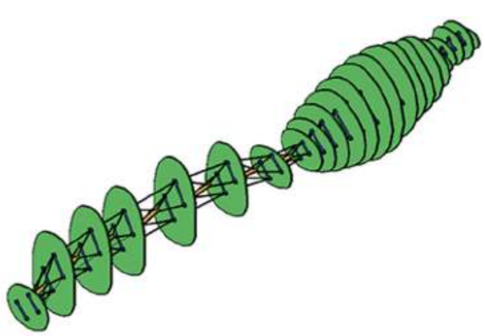

Figure 17. Third prototype.

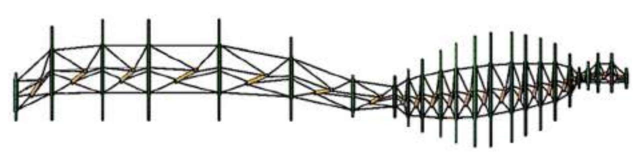

Figure 18. Front view.

6. Assembly of the floating structure

We printed 24 geometric shapes and 71 cylinders. We designed, cut and assembled a 3 mm thick MDF wood guide template. The butterfly body was assembled as follows: First, in the geometric shapes, the cylinders were glued with cyanoacrylate and placed on the guide template (Fig. 19 (a and b)).

Then, following the pattern made in the vector program, we passed the nylon monofilament through the holes of the cylinders (Figures 20 (a and b) and 21).

7. Results

Among the people who have defined tensegrity, we can mention Buckminster Fuller, David G. Emmerich, Kenneth Snelson, Anthony Pugh, Schodeck, Bin-Bing Wang, Kanchanasaratool and Wiliamson. Ariel Hanaor, Valentín Gómez Jáuregui, Miura and Pellegrino.

We chose René Motro's 2003 definition: “Tensegrity system is a system in a stable self-equilibrated state

Figure 19. Students assembling the butterfly body.

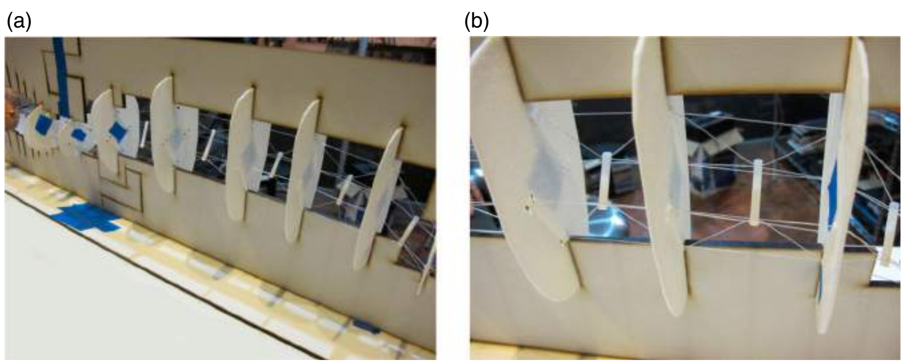

Figure 20. (a) Assembly of the floating compression structure and (b) Detail.

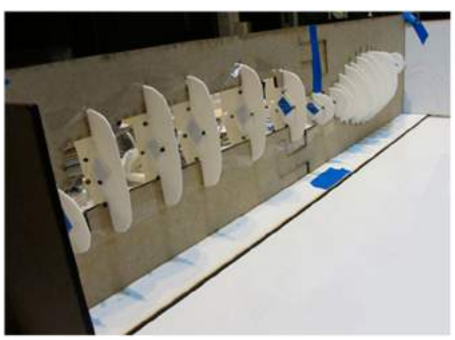

Figure 21. Assembly of all geometric shapes.

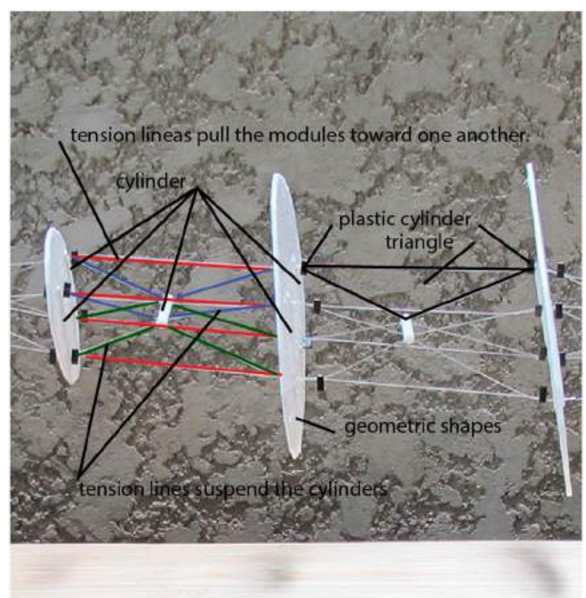

Figure 22. Tension lines.

comprising a discontinuous set of compressed components inside a continuum of tensioned components".

Valentín Gómez Jáuregui wrote in his article, Tensegrity Structures and their Applications to Architecture, that: Tensegrity is a developing and relatively new system (barley more than 50 years old) which creates amazing, lightweight and adaptable figures, giving the impression of a cluster of struts floating in the air.

Jáuregui comments in this same article that the precise and detailed configuration of the "floated compression structures", make it possible to accept the assumption that they have very special characteristics. Among these features is the creation of modules where the same or different figures are used.

From the perspective of Design, a module is an element adopted as a unit of measurement to determine the

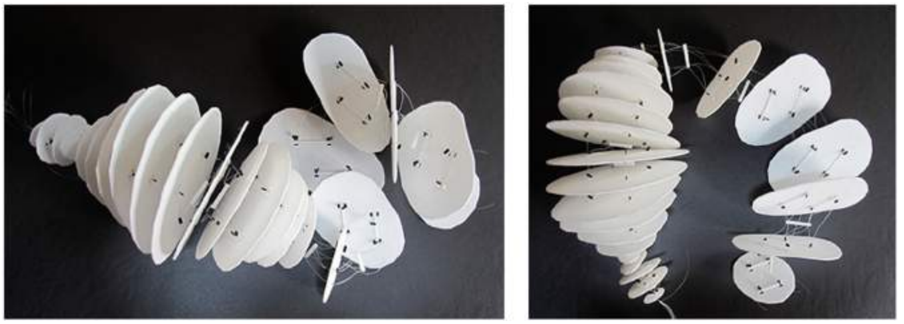

Figure 23. Structure without tension.

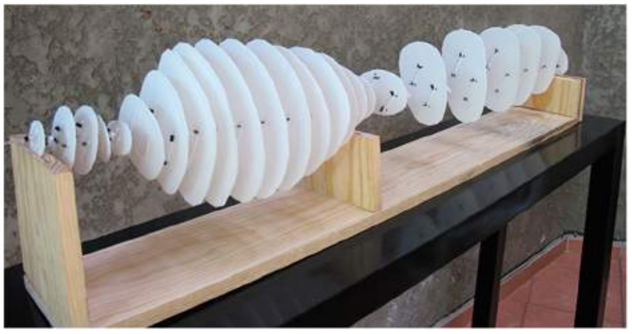

Figure 24. Floating compression structure.

Figure 25. Detail.

proportions between the different parts of a composition and systematically repeated in space.

To create the structure of the butterfly body stable, tensioned and floating, the same module was repeated 23 times. As can be seen in Figure 22, eight nylon monofilaments were used in each module. Four nylon monofilaments suspended the geometric forms in the air, and the other four suspend the intermediate cylinder, because they passed both above and below the holes. With this arrangement four triangulations were formed.

At the beginning and end of each of the triangles formed, a plastic cylinder was placed, and when these were pressed, the nylon monofilaments were tensioned. The plastic cylinders took the place of the knots when a cord is used or the tensioners when using steel cables.

When the structure is not in the guide template, there is no tension. (Fig. 23 (a and b).

When we place the structure on the supports, it is tense and remains floating. For security, we place a support in the third part of the total size of the structure (Fig. 24, Fig. 25 and Fig. 26).

We can say that the third prototype successfully accomplish with the characteristics of tensegrity as it is composed of cables (in this case, we use nylon monofilament) and straight bars (we use 3D printer cylinders), the bars (cylinders) not connected to each other and there are no rigid joints, there are only joints.

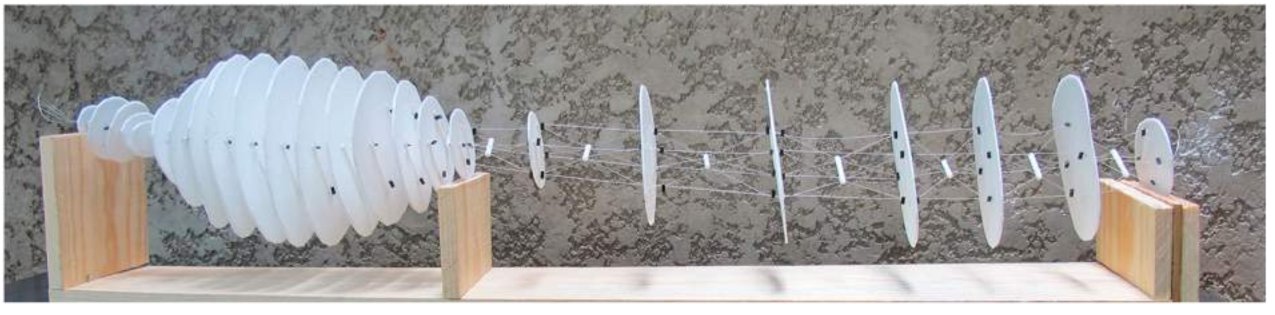

Figure 26. Front view.

8. Contributions

In art, engineering and architecture tensegrity works have been done, but this is the first time that tensegrity is used to create the biological form of an insect. Therefore, this work will contribute to researchers and students to do innovation work in areas related to robotics, mechatronics and industrial design.

9. Conclusions

By combining the techniques of geometric morphometry, descriptive geometry and tensegrity, it was possible to develop the butterfly body as a rigid and stable floating compression structure.

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