Title:
Application of the Tensegrity system to create the 3D impression of the butterfly body Heliconius Doris obscurus as a floating compression structure.

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Introduction:
In this paper we present the research carried out at the Metropolitan Autonomous University of Cuajimalpa Mexico, which consists of developing a floating structure of the body of the Heliconius Doris obscurus, worldwide knows as Laparus Doris obscurus (Weymer, 1891), based on the invention of Karl Ioganson "The Tensegrity" [3].

In this project, we made three prototypes to study the way can be performed the structure of floating compression of the butterfly body. The first prototype is a solid and performed in the 3D printer. This prototype we used it to analyze the curvature of the butterfly body.

In the second and third prototype, we divide the butterfly body in 24 parts. To tension and join each of the parts, in the second prototype we use a three-dimensional network of nylon monofilament, and plastic straws as separators between each part.

In each part, of the third prototype two holes 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 objective of this project is that students studying the design career use the techniques of geometric morphometrics, descriptive geometry and tensegrity for their terminal projects.

Main Sections:
Karl Ioganson, Latvian artist belongs to the circle of constructivist artists. Between 1914 -1917, its main and transcendental innovation was the system of tensegridad denominated in German Gleichgewicht konstruktion [3].

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

Anthony Pugh described Tensegrity as follows: "A tensegriy 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].

The tensile structures characterized by having bars that work in discontinuous compression, which maintained in equilibrium by cables tensioned [1].

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Development the floating compression structure of the butterfly body Heliconius Doris obscurus.

The Heliconius butterfly has a body measuring 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.1).

Fig 1: Heliconius Doris obscurus butterfly.

We take five photographs of the butterfly body, from above, front, back, right side and left side, and to simulate the orthogonal projection we arrange the photographs according to their position (Fig. 2(a)).

We used the technique of geometric morphometrics [4] to find the numerical values of the coordinates "X" and "Y" of each of the points of the 24 parts in which the body of the butterfly was divided. We find the numerical value of the "Z" coordinate from the numerical values of the "X" and "Y" coordinates and concatenate them.

We pass the numerical values concatenated to the vector program to project in three dimensions the points and the polylines of each one of the parts of the body of the butterfly (Fig. 2(b)).

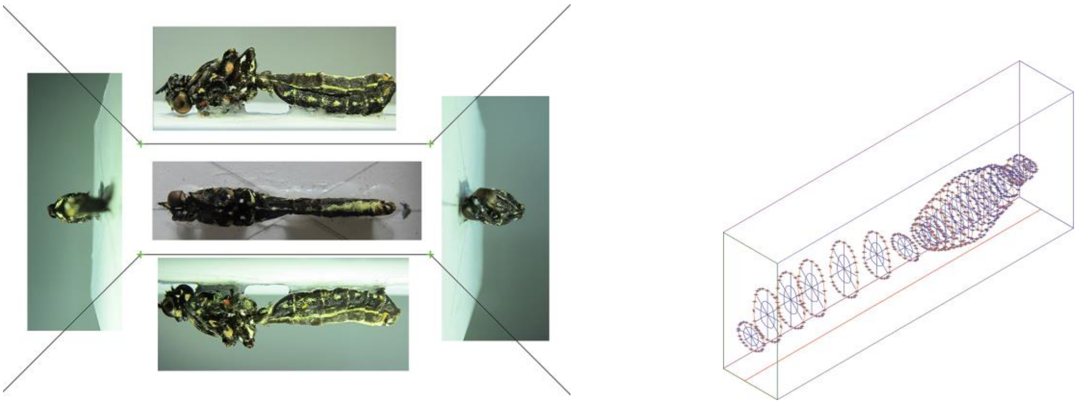

Fig 2: (a) Orthogonal projection and (b) Points in space of the butterfly body.

In the first prototype, the body of the butterfly measures 144mm and was modeled by means of 3Dface to create the triangular mesh to form the solid (Fig.3 (a)). The wings, legs and antennae modeled by means of polylines (Fig.3 (b)). Figure 5 (a) shows the 3D printing prototype

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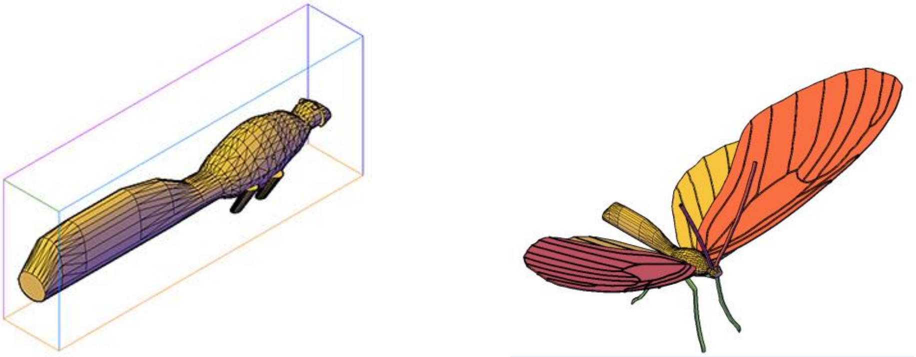

Fig 3: First prototype: (a) Modeling of the body and (b) Butterfly.

In the second prototype, the butterfly body measure 240 mm. Each part modeled by means of polylines, extruding the curves 4mm (Fig.4 (a and b). The body, legs and antennas performed in the 3D printer. The wings are made of cardboard with a plastic sheet (Fig. 5b).

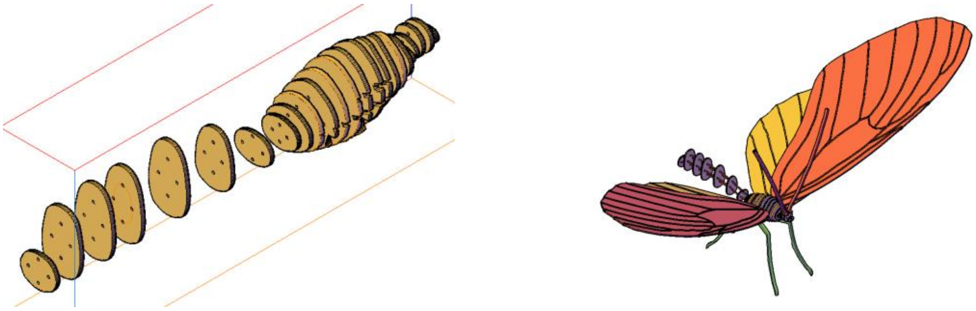

Fig 4: Second prototype: (a) Modeling of the body and (b) Butterfly.

Was performed 3D printing of the parts, and was assembled the butterflies (Fig.5 (a and b)).

Fig 5: Butterfly: (a) First prototype and (b) Second prototype.

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To tension and join each of the parts, in the second prototype, we used a three-dimensional network of monofilament of nylon, and plastic straws as separators between each part (Fig.6 (a and b). This prototype does not meet the tensegrity characteristics, but the body of the butterfly is under tension and compression, and the structure is firm and balanced.

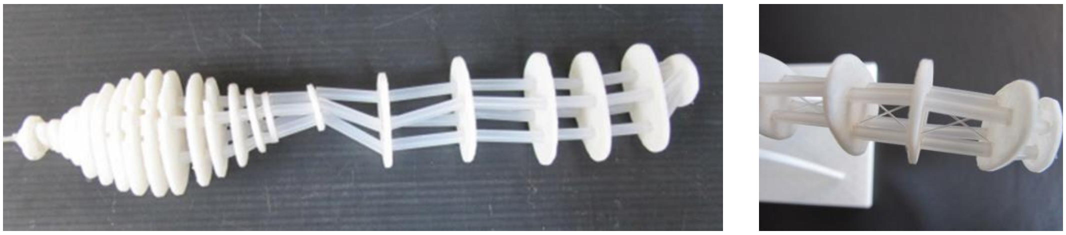

Fig 6: (a) Butterfly body second prototype and (b) Detail.

In the third prototype, the body of the butterfly measures 960 mm and we used the same 24 parts with which it divided the body of the butterfly. We modeled the 24 parts by means of polylines extruding the curves 2mm (Fig. 7 (a and b)). The wings, the legs and the antennas not realized due to the scale that worked.

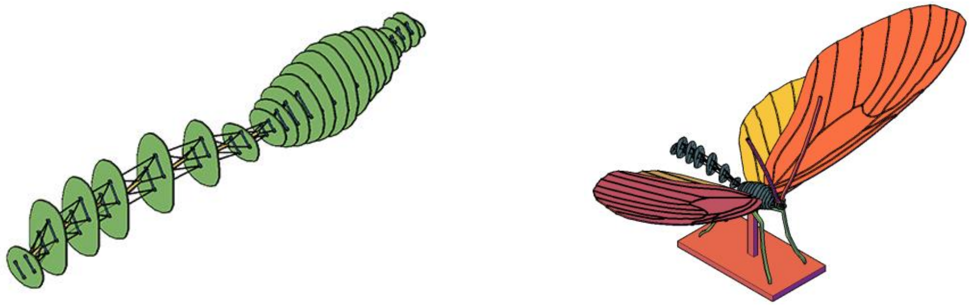

Fig 7: Third prototype: (a) Modeling of the body and (b) Butterfly.

In each part, of the third prototype two holes opened to place two cylinders with four holes (Fig. 8 (a)), and between each of the parts placed a cylinder, with eight holes. In passing, through the holes of the cylinders the nylon monofilament formed a triangulation mesh that tensioned the body of the butterfly (Fig. 8 (b), 9 and 10)).

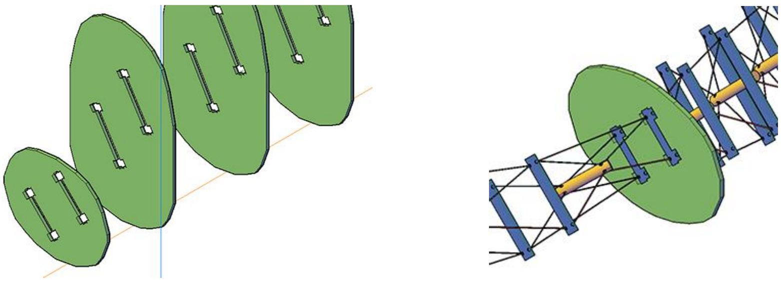

Fig 8: Third prototype orthogonal projection: (a) Each part with the holes and (b) Detail.

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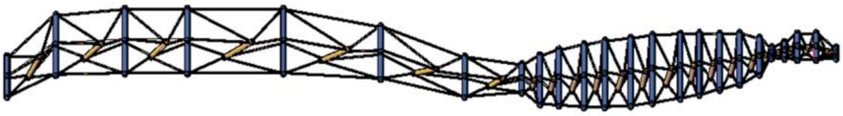

Fig 9: Tensegrity by means of cylinders.

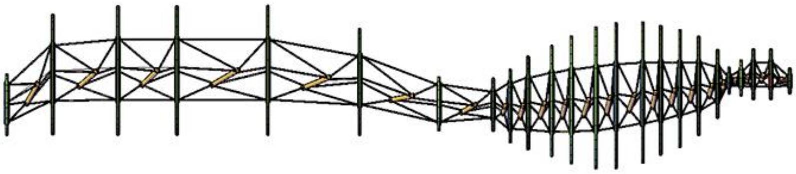

Fig. 10: Tensegrity with cylinders and curved parts.

Components and assembly of the floating structure.
We print 24 geometric shapes and 71 cylinders. We glued to each of the geometric forms the pair of cylinders with cyanoacrylate. We design, cut and assemble the guide template of 3mm thick MDF wood. With the students, we work on the assembly of the body of the butterfly; we first place the geometric shapes in the guide template (Fig. 11).

Fig. 11: Students assembling the butterfly body.

Next, we passed the nylon monofilament through the holes of the cylinders following the pattern that we realized in the vector program, forming the triangulation that would tension the structure of the butterfly body (Fig. 12(a and b)).

Fig. 12: Floating compression structure: (a) Guide template and (b) Detail.

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When we remove the structure of the guide template, the structure is not stressed (Fig. 13 a and b).

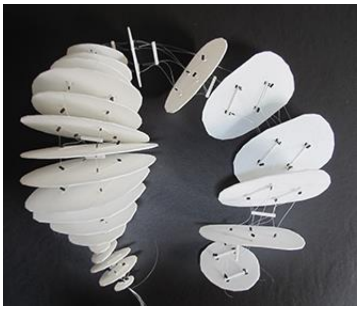

Fig. 13: Unstressed structure.

When we place the structure on the supports is tense and remains floating. For security, we place a support in the third part of the total size of the structure (Fig. 14 and 15).

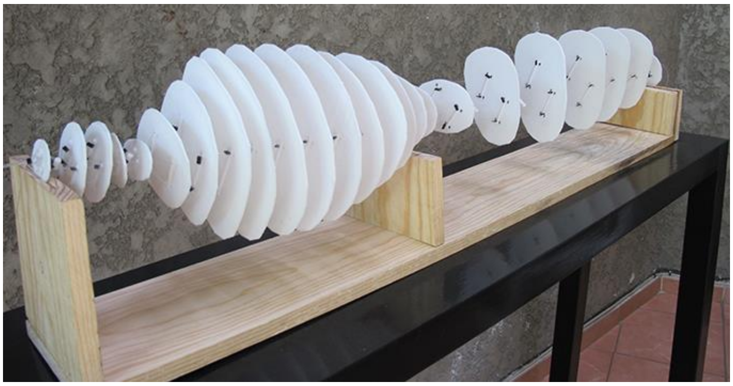

Fig. 14: Floating compression structure.

Fig. 15: Detail.

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We can say that the third prototype meets 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), is a stable structure, the bars (cylinders) are not connected to each other and there are no rigid joints (Fig. 13 and 14).

Contribution:

In art, engineering and architecture have been done tensegrity works, 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 innovative work in areas related to robotics, mechatronics and industrial design.

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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[5] http://www.kennethsnelson.net.

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