Title:
Optimization of the Exoskeleton of a Cochineal to Analyze its Behavior in Medium-scale Models and Prototypes

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Introduction:
In this work, we present the research carried out at the Autonomous Metropolitan University Campus Cuajimalpa in México City, which consisted in the analysis of the biological form of the Cochineal exoskeleton to optimize its geometry and use it in medium-scale models and prototypes to observe the behavior of the structure when a weight is applied.

In this project, we work with the Cochineal of moisture that belongs to the Oniscidea family. We find, from the geometric Morphometrics technique [4] the numerical values of the coordinates "x", "y" and "z" of the points in space and we model the solid from meshes. We build a physical cardboard model, one prototype in 3D printing, and three virtual models.

For the virtual models, three proposals were proposed to perform the stress analysis: (1) a 5 mm thick stainless-steel sheet, (2) a 5 mm thick ABS plastic and (3) a 15mm thick ABS plastic solid with an intermediate structure.

Above the cardboard model, the weight of 17 boxes of DVDs was placed and, the prototype in 3D printing was simulated as if it were a canoe, its waterline was calculated and it was placed in the Xochimilco Lake to observe its behavior in the water.

Main Sections:
In 1987, UNESCO declared Lake Xochimilco a cultural heritage site. Xochimilco is characterized by preserving the traditions and customs of the pre-Hispanic era, mainly by the trajineras, also known as canoes or chalupas. The canoes are used to transport people and for the trade of food, flowers and handicrafts and, their measures go from 1000 mm to 1500 mm long by 400 mm wide, with a thickness ranging from 4 mm to 7 mm (Fig. 1).

Fig. 1: Canoes in the Lake of Xochimilco.

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From the investigation that was carried out, the hypothesis of our project arises: The shape of the cochineal exoskeleton is a viable alternative to create a model that has the characteristics of a canoe.

The Cochineal body is divided into three regions: head, thorax and abdomen (Fig.2 (a)). It has a rigid exoskeleton, segmented into 14 parts and has seven pairs of legs.

Since it is difficult to scan or digitize the cochineal exoskeleton due to its size, 11mm long X 6 mm wide, it was decided to use other techniques to find its geometry and optimize its shape. “Structural optimization is an inverse process in which parameters are implicitly/indirectly optimized to find the geometry of a structure such that an objective function or fitness criterion is minimized” [1].

To achieve the optimal results, it was simulated the orthogonal projection with five photographs: top, front, back, right and left sides [3]. (Fig.2 (b)). It was divided the exoskeleton into 14 parts in the longitudinal direction (Fig.2 (c)), same as the cochineal. Each of these axes was divided into 20 parts in the transverse direction to create the curve as accurately as possible. With fewer divisions, the form could be lost, since it is not a perfect ellipsoid.

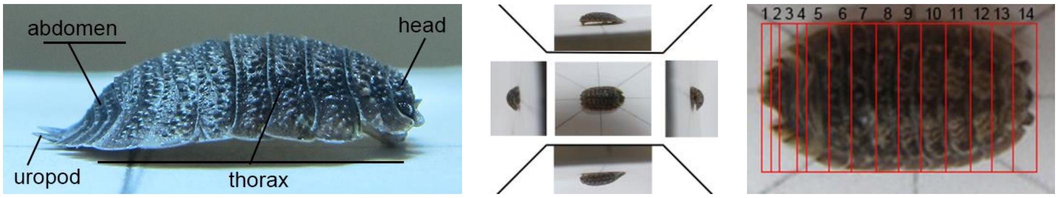

Fig. 2: (a) Cochineal of moisture, (b) Orthogonal projection and (c) Divisions.

The model was traced with forty triangular sections in the transverse direction with connection nodes (Fig.3 (a)). The meshes, the surfaces and the volume were traced (Fig.3 (b)). The model was scaled with the following measures: 610mm long X 328.25mm wide X 129.89mm high and 5mm thick and, only four points touch the ground, two in front and two in the back (Fig.3 (c)).

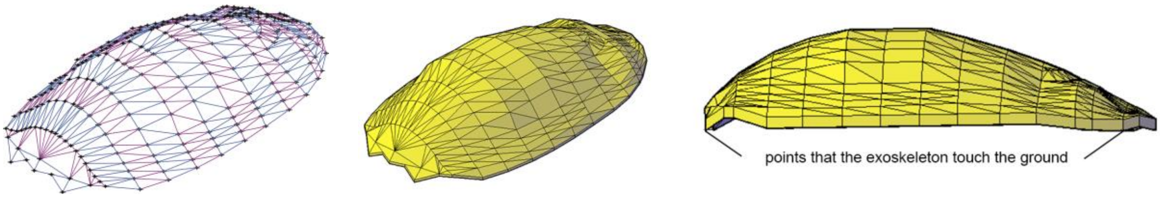

Fig. 3: (a) Triangles and nodes, (b) Modeling and (c) Points in the ground.3.

The objective of this research is to make the necessary tests with different materials, sizes and weights to evaluate the behavior of the cochineal exoskeleton in models and prototypes at a medium scale.

Cardboard model

To build the cardboard model, the development was traced (Fig.4 (a)) and cut in the CNC laser cutter. This model has a thickness of 5mm and weathered 1.228kg.

For the deformation analysis, two tests were carried out. In the first test, the model was placed on the table and in the second, the model was placed on four bases supporting the four points that touch the ground. In both cases, the weight of the 17 boxes of DVDs was used.

The results show that in the first test, the model is deformed 20mm in the upper part and the lateral parts open outwards 25mm on each side, since having no constrains, the model slides on the table (Fig. 4 (b). In the second test, the results show that the triangular planes change their position in space, so the model is deformed in the upper and lateral parts and in the center (Fig.4 (c)). These deformations were not possible to measure.

The model does not return to its original shape when the weight is removed due to the malleability of the cardboard.

Fig. 4: (a) Development, (b) First test and (c) Second test.

Prototype in 3D printing
The prototype in 3D printing (Fig.5 (a) and (b)) was printed with the PLA material, whose density is 1250kg/m³. The prototype measures 200mm long X 107.62mm wide X 47.07mm high, has a thickness of 5mm, the filling was 100% and has 85,539.8095mm³ of volume.

Fig. 5: Prototype in 3D printing (a) Top view and (b) Front view.

In the study of the waterline, it was considered the mass of the prototype, 0.1069 kg plus 0.50 kg of dead load. The results show us that with a mass of 0.6069 kg 72% of the prototype is submerged, that is 32mm with a volume of approximately 61,928mm³ of water (Fig.6 (a)). We went to the lake of Xochimilco and placed the prototype in the water with a mass of 0.25 kg of clay to observe its behavior (Fig.6 (b)). The canoe did not sink and moved according to the movement of the water.

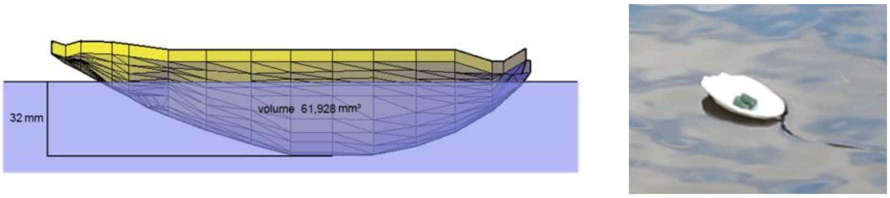

Fig. 6: (a) Flotation analysis and (b) Prototype in the lake of Xochimilco.

First virtual model
In the study of stress analysis, the virtual model measures 1200mm long X 656.5mm wide X 260mm high, has a thickness of 30mm two benches were placed to place people and sacks that simulate the weigh.

The simulations were carried out in the Inventor program. An ABS plastic was used, with an elastic limit of 2900.75psi and, density of 0.038lb/inch³. The model has a mass of 40.949lb (18.36kg) calculating a maximum of the efforts of 51.501psi. The results show, we exemplify one case that the displacement of the model with a weight of 50lb (22.679 kg) goes from zero to 0.012 inches (0.032 mm) (Fig. 7).

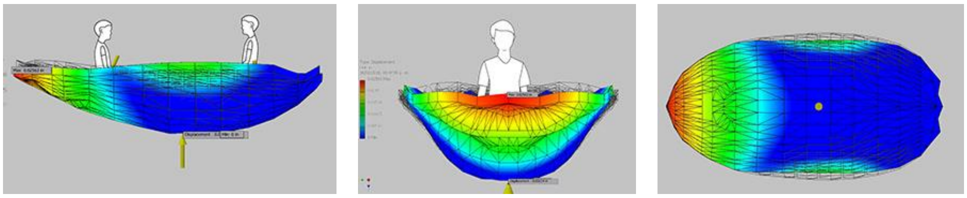

Fig. 7: Displacement of the canoe with the weight of a child (50lb each (22.679 kg)).

Two virtual models of 5mm thickness and their comparison with an ellipsoid

The virtual models measures 610 mm long X 328.25 mm wide X 129.89 mm high. In the first virtual model, a stainless steel 18/8 sheet was used, with an elastic limit of 36259.4psi and, a density of 0.289lb/$inch^3$. The model has a mass of 14.268lb (6.47kg) calculating a maximum of the efforts of 62.4psi. The results show that the displacement of the model goes from zero to 0.0169 inches (0.4305mm) (Fig.8 (a)).

In the second virtual model, an ABS plastic was used, with an elastic limit of 2900.75psi and, a density of 0.038lb/$inch^3$. The model has a mass of 1.890lb (0.857kg) calculating a maximum of the efforts of 62.4psi. The results show that the displacement of the model goes from zero to 1.452 inches (36.884mm) (Fig.8 (b)).

The deformation in both cases is in the lower lateral parts and in the center.

An ellipsoid was modeled with the same measurements and specifications like the two previous models to compare the behavior of the structure. The results show that the ellipsoid has a mass of 23.213lb (10.53kg), calculating a maximum of the efforts in the model of 24.9706psi. The displacement of the ellipsoid ranges from zero to 0.0075 inches (0.1924mm) using an 18/8 stainless steel sheet (Fig.8 (c)) and, from zero to 0.669 inches (17.001mm) using an ABS plastic (Fig.8 (d)). The deformation is in the lower lateral parts.

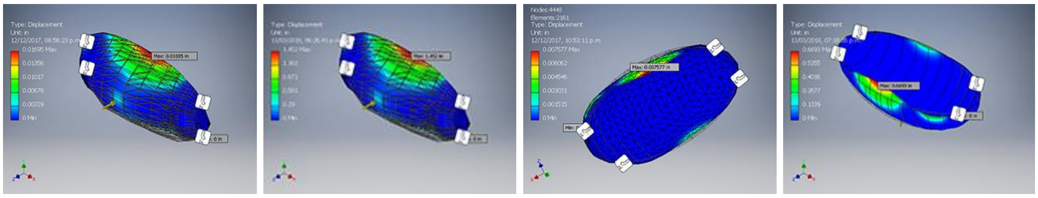

Fig. 8: Displacement (a) Stainless steel model (b) ABS plastic model, (c) Ellipsoid stainless steel and (d) Ellipsoid ABS plastic.

Third virtual model 15mm thick

The 15mm thick virtual model is formed by two equal pieces and an intermediate structure, where each piece measures 5 mm thick (Fig.9 (a)). The model measures 610 mm long X 328.25 mm wide X 129.89 mm high, the filling was 100% and has 1,777,474.720mm^3 of volume.

An ABS plastic was used, with an elastic limit of 2900.75psi and, a density of 0.0382lb/$inch^3$. The model has a mass of 4.153lb (1.88kg) calculating a maximum of the efforts of 51.5013psi. The results show that the displacement of the model goes from zero to 0.232 inches (1.93mm) (Fig.9 (b)). The deformation is from the lower lateral parts to the center.

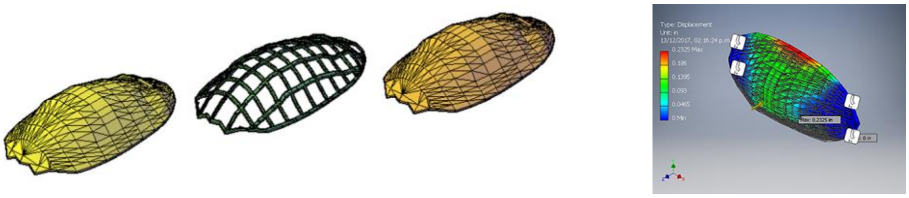

Fig. 9: (a) Third virtual model and (b) Displacement.

Contribution:
Nature has been one of the sources of inspiration for scientists, architects and engineers for hundreds of years. Among the architectural constructions, we can mention the CDC complex in Taiwan inspired by the Nautilus shell. Frank Gehry was inspired by a fish to make the Olympic Village in Barcelo and Thomas Klumpp designed the Universum Science Center in Germany inspired by a clam.

The making of prototypes by Leonardo Da Vinci is just one example of how technology can take advantage of the world around us [2].

However, not much has been studied about the exoskeletons of animals so this work, will help researchers and students to think that the structures of the exoskeletons can be useful to improve the life of the human being and, recover the pre-Hispanic tradition of the canoes of Xochimilco.

Conclusions*:*
We conclude that the cochineal exoskeleton can be used to create small and medium scale models. It does not deform at the edges due to the peculiarities of the crustacean shape. The two materials, stainless steel and ABS plastic can be used to create canoe models and prototypes, and, could be used, for example in addition to the canoe (Fig.10 (a)) as a backpack (Fig.10 (b)), or a structure of a building. (Fig.10 (c)).

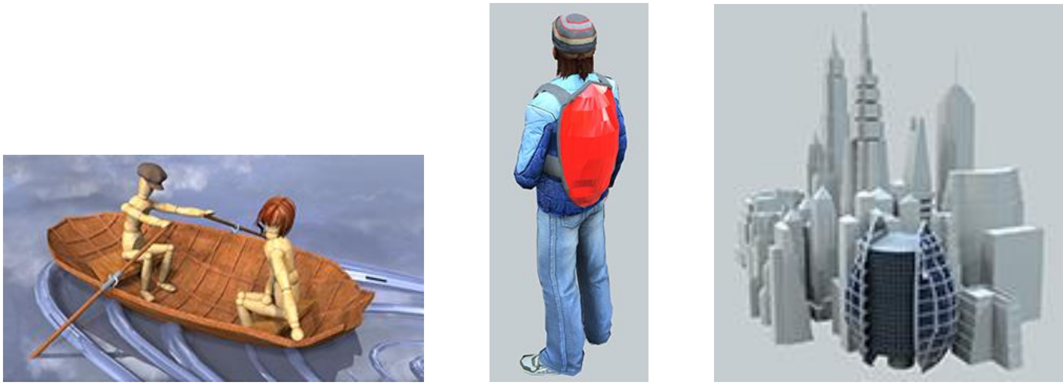

Fig. 10: (a) Canoe, (b) Backpack and (c) Building.

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