www.cadanda.com Computer-Aided Design AND APPLICATIONS

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

Dina Rochman[1], América Sánchez[2], Enrique García[3] and Alfredo Almaraz[4]

[1]Universidad Autónoma Metropolitana Cuajimalpa, drochman@correo.cua.uam.mx
[2]Universidad Autónoma Metropolitana Cuajimalpa, red.eyees@hotmail.com
[3]Universidad Autónoma Metropolitana Cuajimalpa, laduamc@gmail.com
[4]Universidad Autónoma Metropolitana Cuajimalpa, somosarte@live.com.mx

Corresponding author: Dina Rochman, drochman@correo.cua.uam.mx

ABSTRACT

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 *Poecellionidae* family. We find, from the geometric Morphometrics technique 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. Three virtual models were proposed to perform the stress analysis : (1) a 5 mm thick stainless steel sheet, (2) a 5mm thick ABS plastic and (3) a 15 mm 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.

Keywords: Exoskeleton, Cochineal, Optimization, Models and prototype, Analysis of efforts.
DOI: https://doi.org/10.14733/cadaps.2019.35-49

1 INTRODUCTION

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 (Fig.1). In the past, the "acaltin" or canoes were carved from a tree trunk, but nowadays they are assembled with several pieces of wood and their shape is flat. They are used to transport people and for the trade of food, flowers and handicrafts. 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). In the revised literature, we found that round bottom canoes exhibit poor resistance to small degrees of inclination, but they are difficult to tumble over, that is, their final stability is good. They are able to pass over obstacles much more easily, due to a smaller area of contact with the obstacle, and have better nautical depth. (The vertical distance between a point on the waterline and the base line or keel, including the thickness of the hull). While a flat bottom canoe has excellent stability, but if it is tilted to a certain point, it becomes unstable and tumble over [3].

Figure 1: Canoes in the Lake of Xochimilco.

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 exoskeleton is the external skeleton of all the animals of the phylum arthropod, as arachnids, insects and crustaceans, to name a few, that covers, protects and supports the body of the animal. Among insects that have a rigid, segmented and calcareous exoskeleton, we find the cochineal of moisture (the Porcellio scaber species, commonly known as "Common Rough Woodlouse") that belongs to the *Oniscidea* suborder.

The Cochineal body is divided into three regions: head, thorax and abdomen (Fig.2 (a)). It has seven pairs of legs, two antennas and two uropod. The thorax is divided into 8 segments, the first is welded to the head and the remaining seven segments (pereonites) usually carry a pair of legs to walk and catch their prey.

The cochineal exoskeleton has two peculiarities. The first peculiarity is that it is formed by two parts, the first part; we could say that it is a truncated ellipsoid that connects with a curve in the opposite direction forming a kind of skirt. The second peculiarity is that before reaching the queue, that is, parts 9 and 10 make a type of connection or tie (Fig.2 (b)).

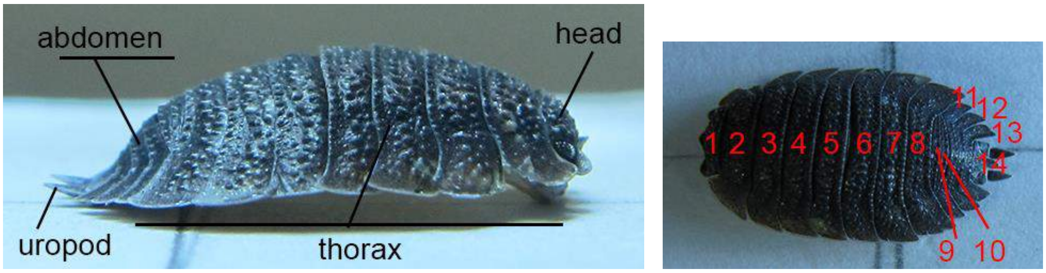


Figure 2: Cochineal of moisture (a) front view and (b) Top view.

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, the orthogonal projection was simulated with five photographs: top, front, back, right and left sides [4]. (Fig.3 (a)). The exoskeleton was divided into 14 parts in the longitudinal direction (Fig.3 (b)), 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.

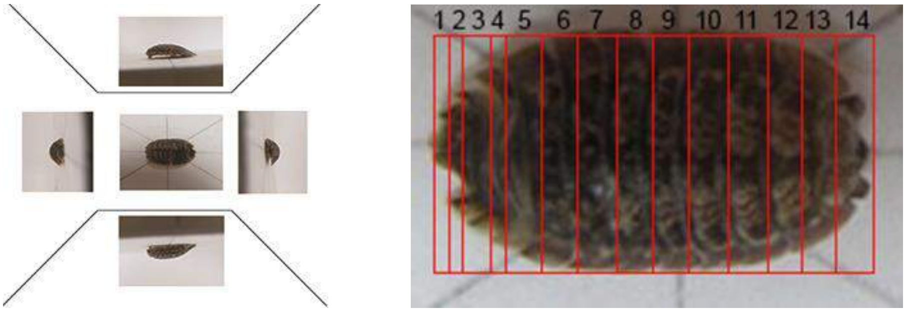


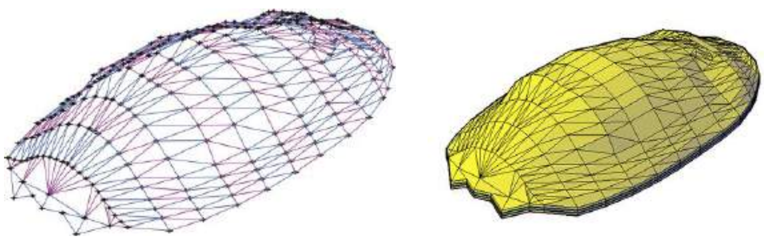
Figure 3: (a) Orthogonal projection and (b) Divisions.

From each of the nodes, the numerical values of the "x" and "y" coordinates were found (Tab.1) by means of the geometric morphometrics technique [4], as example, we show curve #6. For this technique, biologists use the program tpsDig2 (Rolhf 2008 [5]) to find, through photographs, the numerical values of the "x" and "y" coordinates of the morphological points called "Landmarks" [6].

Axis				Top view		Front view up		Left view		Concatenation
	X	Y	Points	X	Y	X	Y	X	Y	
1	831	1889	1	1481	1372	1481	2308	411	1370	1481,1371,419
2	2014	1889	2	1481	1359	1481	2308	411	1359	1481,1359,419
3	2014	855	3	1481	1339	1481	2306	414	1341	1481,1340,417
4	831	855	4	1481	1319	1481	2296	423	1319	1481,1319,407
			5	1481	1306	1481	2288	432	1306	1481,1306,399
			6	1481	1294	1481	2275	445	1294	1481,1294,386
			7	1481	1277	1481	2254	466	1277	1481,1277,365
			8	1482	1269	1481	2244	474	1270	1481,1269,356
			9	1482	1263	1481	2238	481	1263	1481,1263,349
			10	1482	1257	1481	2232	488	1256	1481,1256,343
			11	1482	1250	1481	2222	498	1251	1481,1250,333

Table 1: Numerical values of the axes and numerical values for the curve # 6 of the Cochineal exoskeleton.

The model was traced with forty triangular sections in the transverse direction with connection nodes (Fig.4 (a)). The meshes, the surfaces and the volume were traced (Fig.4 (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 at the back (Fig.4 (c)).



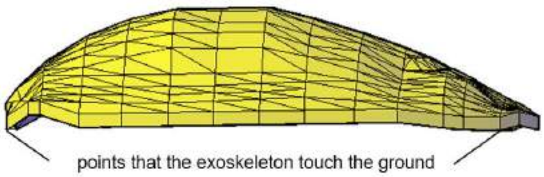


Figure 4: (a) Triangles and nodes, (b) Modeling and (c) Points in the ground.

From the design point of view there are two ways to build and analyze the models and/or prototypes, one is physically and the other virtually. In the specific case of the cochineal exoskeleton structure, which has a complex biological form, the materials that were used to build the physical model and the prototype were:

- Cardboard, since this material is malleable and allows to easily generate the folds and,
- PLA since it is a moisture-resistant polymer, which in 3D printing accentuates the geometry and respects the changes of planes of the geometric shape.

While, in the virtual models with the advance of the technology the advantage that is had is that a variety of materials can be applied to make simulations.

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.

Finally, we built a physical model of cardboard, a prototype in 3D printing and four virtual models. For the virtual models, three proposals were made to perform the stress analysis: (1) a 5 mm thick stainless steel sheet, (2) a 5 mm thick ABS plastic sheet and (3) a solid of ABS plastic 15 mm thick 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.

For the analysis of efforts, the following weights were considered (Tab. 2):

	Pounds	Kilograms
Weight of 17 boxes of DVDs	2.7072	1.22
Child	50	22.67
Woman	100	45.35
Woman	143.3	65
Man	176.37	80
Man	264.555	120
Obese person	350	158.75
Sacks	700	317.51
Sacks	2000	907.18
Sacks	3000	1360.77

Table 2: Weights.

This article has the following sections: in Section 2, we explain the development of the cardboard model and its deformation. In Section 3, we present the analysis of the prototype in 3D printing. In Section 4, we present two proposals of 5mm thick virtual models with two different materials and their comparison with an ellipsoid. In section 5, we present the proposal of 15 mm thick virtual model. Section 6 presents the results. In Section 7, we present the contributions and finally Section 8 presents the conclusions. All figures presented in this paper are original and created by the authors at the Metropolitan Autonomous University of Cuajimalpa Mexico.

2 DEVELOPMENT OF THE CARDBOARD MODEL AND ITS DEFORMATION.

The cardboard model measures 610 mm long X 328.25 mm wide X 129.89 mm high and 5mm thick. The thickness was given according to the proportion of the exoskeleton of the crustacean.

The tracing of the development (Fig.5) was made from the triangular planes of the three-dimensional model that was modeled in the vector program (Fig. 6(a) and 6(b)). Each of the triangular planes were rotated twice until they were parallel to the horizontal plane of the orthogonal projection since these planes are in true form and magnitude in the three-dimensional space and in an oblique position (Fig. 56c)).

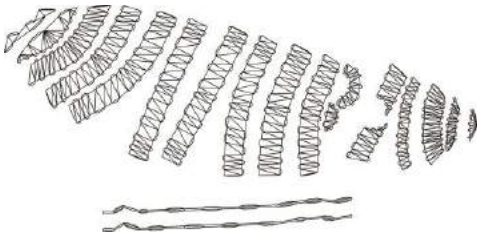


Figure 5: Development.

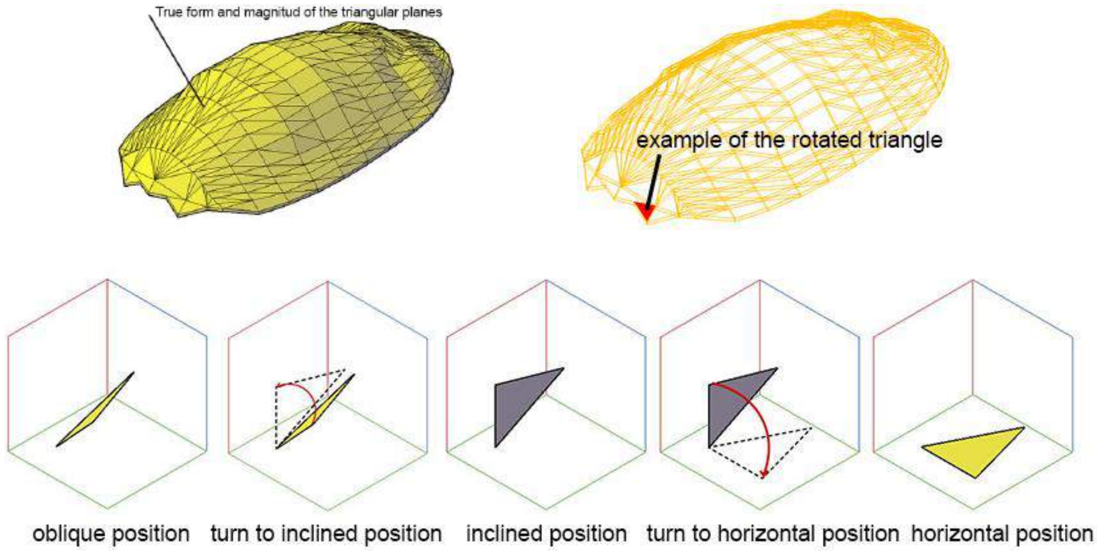


Figure 6: (a) and (b) Three-dimensional model and (c) Rotations.

The development was cut twice in the CNC laser cutter and the model was assembled (Fig.7).

Figure 7: Students assembling the cochineal exoskeleton.

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 strength of the hand that was applied on the cardboard model was difficult to measure (Fig.8 (b)), so the boxes of the DVDs were used because of the similarity they have with the length of the hand (Fig. 8 (a)). The boxes were placed one by one in the cardboard model and finally the model supported the weight of 17 boxes, equivalent to 1.228 kg before collapsing.

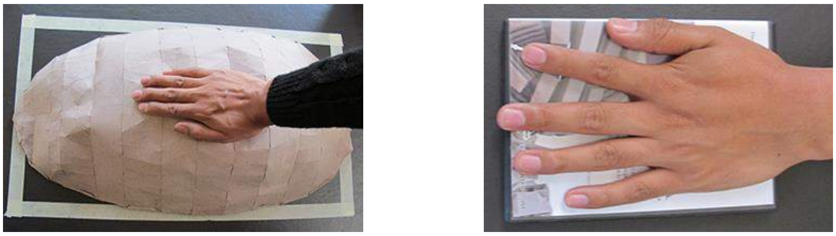


Figure 8: Hand (a) Strength and (b) Size.

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. 9 (a) and (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.9 (c) and (d)). There deformations were not possible to measure. In addition we observe that, in the parts 9 and 10 (Fig.2 (b)) before reaching the cochineal's tail, where the mooring is, the model did not suffer any deformation.

Figure 9: Deformation (a) and (b) First test and (c) and (d) Second test.

3 ANALYSIS OF THE PROTOTYPE IN 3D PRINTING.

The prototype in 3D printing (Fig.10 (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, which is the maximum size that the 3D printer allows us; has a thickness of 5mm, the filling was 100% and has 85,539.8095mm³ of volume.

Figure 10: Prototype in 3D printing (a) Top view and (b) Front view.

For the prototype in 3D printing, three studies were carried out. The first study is the waterline analysis of the prototype simulating a canoe; the second study is the analysis of efforts in virtual models and in the third study, a person climbed on the prototype.

In the study of the waterline, the mass of the prototype 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 32 mm with a volume of approximately 61,928 mm³ of water (Fig.11 (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.11 (b)). The canoe did not sink and moved according to the movement of the water.

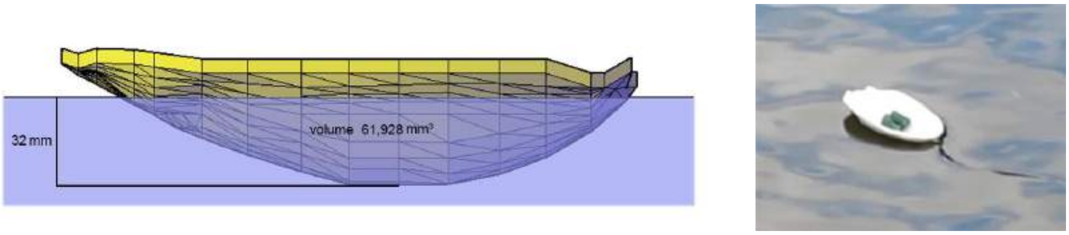


Figure 11: (a) Flotation analysis and (b) Prototype in the lake of Xochimilco.

In the study of stress analysis, the 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 process that took place was the following: (1) The constraint was located in the center of gravity; (2) A force of 1lb was placed on the bottom simulating the strength of the water and (3) A force was placed in each of the benches equivalent to the weights of the people or the sacks (Fig. 12).

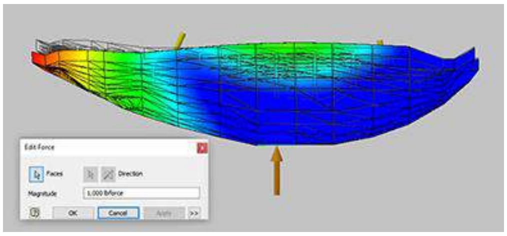


Figure 12: Model with forces.

The simulations were carried out in the Inventor program. An ABS plastic was used, with an elastic limit of 2900.75psi and, density of 0.0382949lb/inch³. The model has a mass of 40.94903lb (18.36kg) calculating a maximum of the efforts of 51.5013psi. The results show, we exemplify two cases 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. 13) and, the displacement of the model with a weight of 2000lb (907.18 kg) goes from zero to 0.51 inches (13.02 mm) (Fig.14).

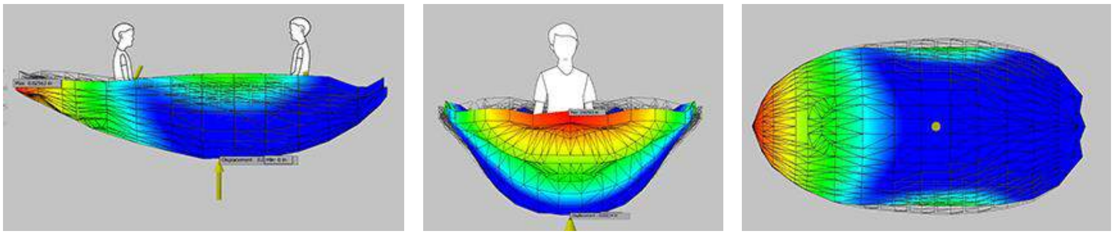


Figure 13: Displacement of the canoe with the weight of a child (50lb each (22.679 kg)).

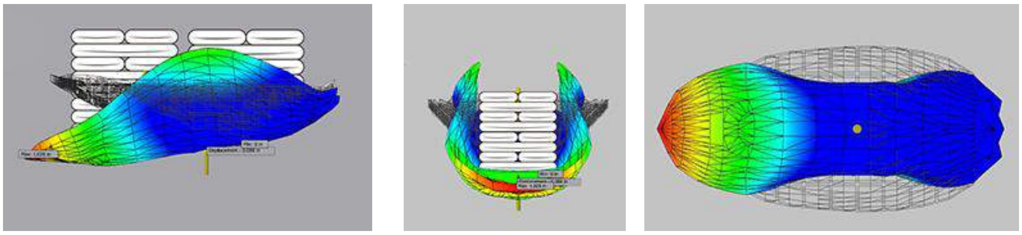


Figure 14: Displacement of the canoe with the weight of the sacks of 2000lb each (907.1847 kg).

In the third study, the prototype was placed on four bases supporting the four points that touch the ground (Fig. 15(a) and (b)). One person with approximately 40kg of weight climbed on top of the prototype, the displacement was significant in the lateral parts (Fig. 15(c)) and as can be seen in Figure 15(d) the foot was coupled to the shape.

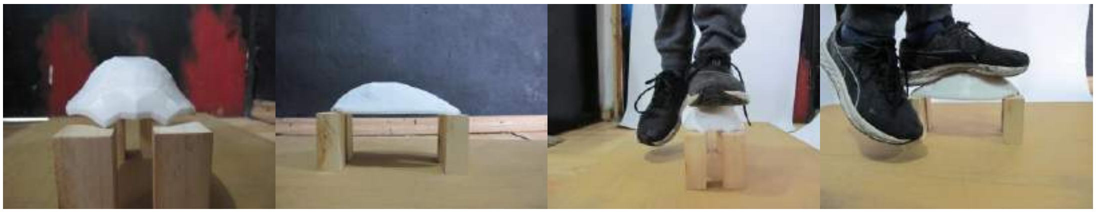


Figure 15: Prototype in 3D printing: (a) Front view, (b) Lateral view and ((c) and (d)) Person who climbed on the prototype.

4 VIRTUAL MODELS 5 MM THICK WITH TWO DIFFERENT MATERIALS AND THEIR COMPARISON WITH AN ELLIPSOID.

The virtual models measures 610 mm long X 328.25 mm wide X 129.89 mm high. As an example, we present the study where 700lb of weight (317,515 kg) is applied and four restrictions were placed on the points where the exoskeleton touches the ground.

In the first virtual model, a stainless steel 18/8 sheet was used, with an elastic limit of 36259.4psi and, a density of 0.289018lb/inch³. The model has a mass of 14.2683lb (6.47kg) calculating a maximum of the efforts of 62.4psi. The results show that the displacement of the model goes from zero to 0.0169548 inches (0.43053mm) (Fig.16 (a)).

In the second virtual model, an ABS plastic was used, with an elastic limit of 2900.75psi and, a density of 0.0382949lb/inch³. The model has a mass of 1.89054lb (0.8575kg) calculating a maximum of the efforts of 62.4psi. The results show that the displacement of the model goes from zero to 1.45214 inches (36.884356mm) (Fig.16 (b)).

The deformation in both cases is in the lower lateral parts and in the center. It can be seen in Figure 16(c) that the edges of the structure do not deform.

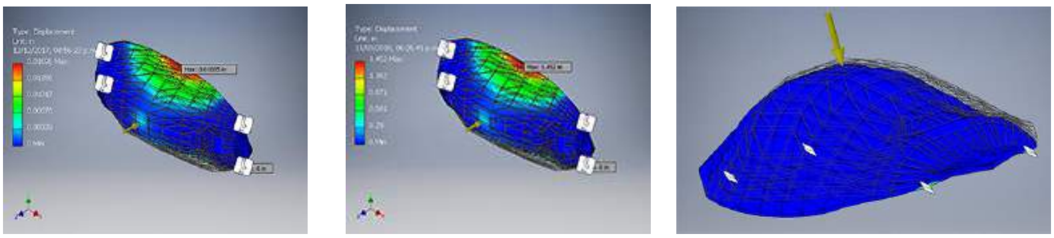


Figure 16: (a) First model displacement, (b) Second model displacement and (c) Deformation.

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 23.2132lb (10.53kg), calculating a maximum of the efforts in the model of 24.9706psi. The displacement of the ellipsoid ranges from zero to 0.007577 inches (0.19245mm) using an 18/8 stainless steel sheet (Fig.17 (a)) and, from zero to 0.669348 inches (17.0014mm) using an ABS plastic (Fig.17 (b)). The deformation is in the lower lateral parts of the ellipsoid. It can be seen in Figure 17(c) that the edges of the structure are deformed.

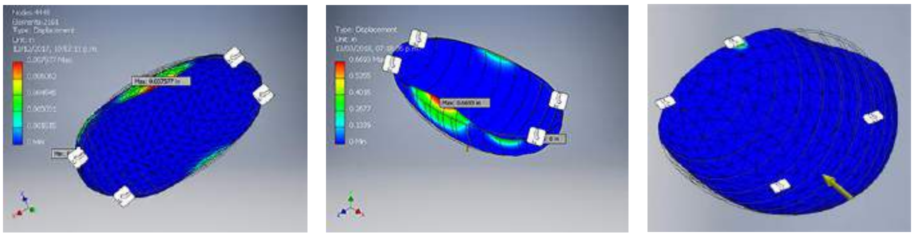


Figure 17: Ellipsoid (a) Displacement stainless steel, (b) Displacement ABS plastic and (b) Deformation.

5 VIRTUAL MODELS 15 MM THICK.

The 15mm thick virtual model is formed by two equal pieces and an intermediate structure, where each piece measures 5 mm thick (Fig.18). The model measures 610 mm long X 328.25 mm wide X 129.89 mm high, the filling was 100% and has 1,777,474.7205mm³ of volume. As an example, we present the study where 700lb of weight (317,515 kg) is applied and four restrictions were placed on the points where the exoskeleton touches the ground.

Figure 18: 15mm thick virtual model.

An ABS plastic was used, with an elastic limit of 2900.75psi and, a density of 0.0382949lb/inch³. The model has a mass of 4.15378lb (1.88kg) calculating a maximum of the efforts of 51.5013psi. The results show that the displacement of the model goes from zero to 0.2325 inches (1.93mm) (Fig.19 (a)). The deformation is from the lower lateral parts of the model to the center. It can be seen in Figure 19 (b) where the edges of the structure do not deform.

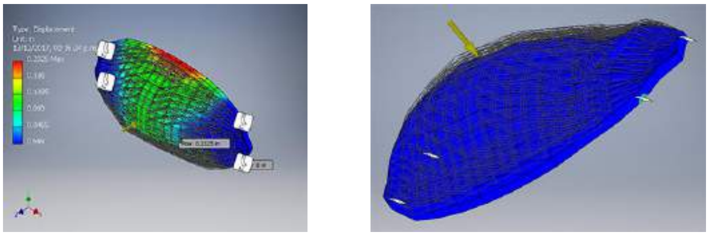


Figure 19: 15mm virtual model (a) Displacement and (b) Deformation.

6 RESULTS.

In the first physical test of the cardboard model, the results show us that the displacement of the model in the center is similar to the displacement of the virtual models although it moves outwards in the lateral parts (Fig.20 (a). In the second physical test, the model does not return to its original shape when the weight is removed due to the malleability of the cardboard. (Fig.20 (b)).

Figure 20: (a) First physical test and (b) Second physical test where the cardboard model after removing the weight is observed.

In the two virtual models of the exoskeleton of the cochineal simulating a canoe of ABS plastic, the first model that measures 610mm long X 328.25 mm wide X 129.89 mm high, with a thickness of 15mm. And, the second model of the canoe that measures 1200mm long X 645.73mm wide X 282.42mm high, with a thickness of 30mm. The results show us that according to the weight the model has a lateral displacement inwards (Fig.21 and Fig. 22) and in the center (Fig. 23 and 24).

Canoe 610mm long	
Weight (kg)	ABS
22.67	0.649
45.35	1.301
65	1.866
80	2.297
120	3.444
158.75	4.561

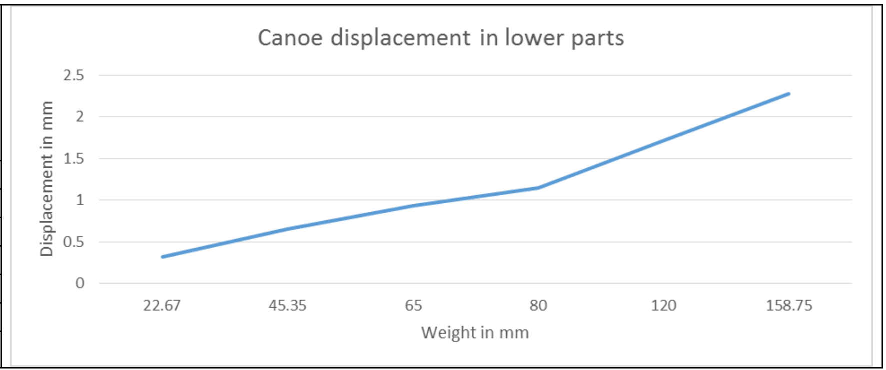


Figure 21: Lateral displacement inward canoe 610mm.

Canoe 1200mm long	
Weight (kg)	ABS
22.67	0.324
45.35	0.650
65	0.932
80	1.148
120	1.723
158.75	2.280

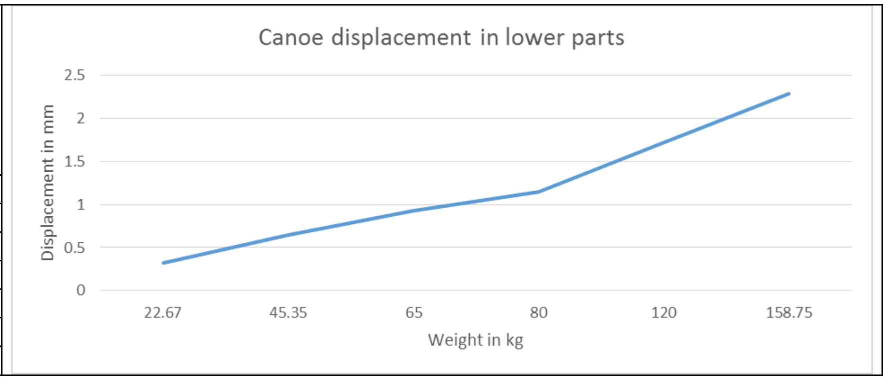


Figure 22: Lateral displacement inward canoe 1200mm.

Canoe 610mm long	
Weight (kg)	ABS
22.67	0.057
45.35	0.116
65	0.167
80	0.206
120	0.309
158.75	0.411

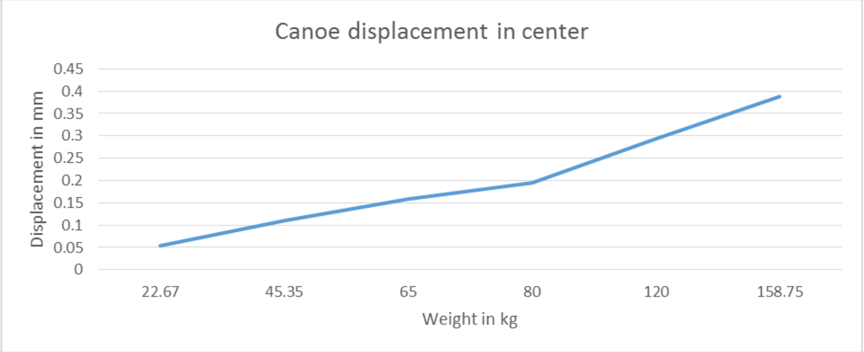


Figure 23: Central displacement canoe 610mm.

Canoe 1200mm long	
Weight (kg)	ABS
22.67	0.028
45.35	0.058
65	0.083
80	0.103
120	0.154
158.75	0.203

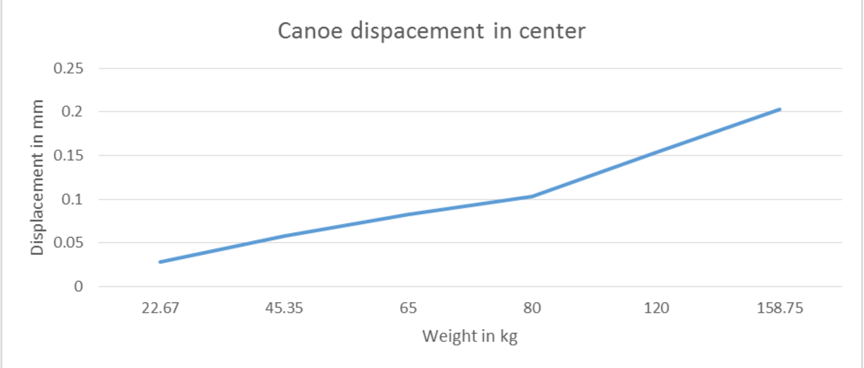


Figure 24: Central displacement canoe 1200mm.

In Tab.3 and Fig. 25, the comparison of the numerical values given in mm of the displacement in center of the cochineal exoskeleton as a canoe of 610mm and 1200mm long respectively can be seen.

Canoe		
Weight (kg)	610mm	1200mm
22.67	0.057	0.028
45.35	0.116	0.058
65	0.167	0.083
80	0.206	0.103
120	0.309	0.154
158.75	0.411	0.203

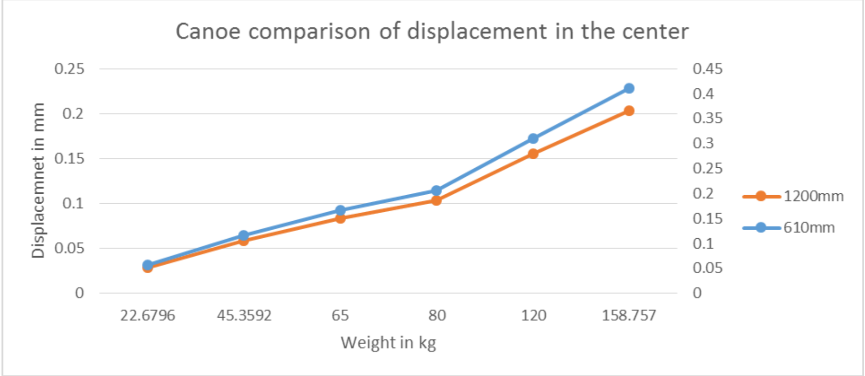


Table 3 and **Figure 25**: Comparison canoe 610mm and canoe 1200mm.

The results show us that the displacement curve both in the center and laterally of the canoe model, are similar and significant with ABS plastic, what varies are the numerical values. We give the example of the weight of an obese person (350lb) ((Fig. 26) and (Tab. 10)):

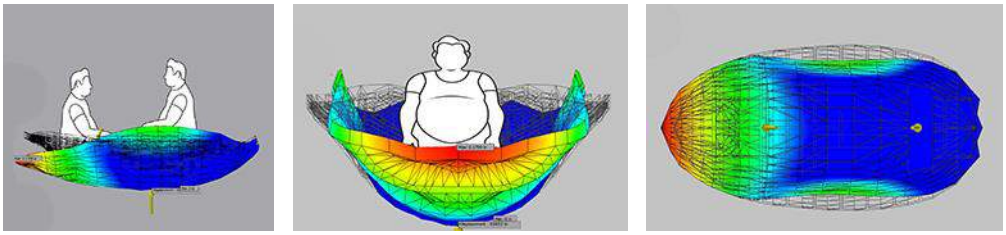


Figure 26: Displacement of the canoe with the weight of an obese person of 350lb each (158.757 kg).

	ABS material	
	Displacement in the lower parts	
Weight	15mm thick	30mm thick
158.757kg	4.569mm	2.278mm
	Displacement in center	
	0.411mm	0.203mm

Table 10: Displacement of the cochineal exoskeleton with the obese person.

This tells us that if the length, width, thickness are larger, the canoe could support a greater weight.

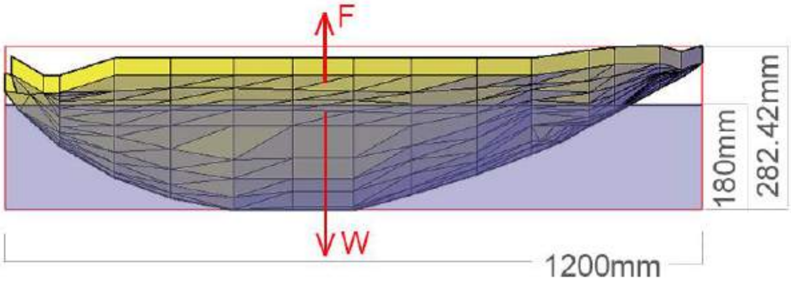


Figure 27: Flotation analysis.

In the flotation analysis of the cochineal exoskeleton measuring 1200mm long X 282.42mm high X 645.73mm wide, with a thickness of 30mm of ABS plastic (Fig. 27), the results show us that the buoyancy force is 122.62N (Fig. 27). The maximum height of the water is 180mm before the canoe sinks with a volume of 0.0125m³.

Cochineal center parts		
Weight (kg)	Stainless steel	ABS
22.67	0.006	0.525
45.35	0.012	1.054
65	0.017	1.511
80	0.021	1.859
120	0.031	2.788
158.75	0.043	3.688

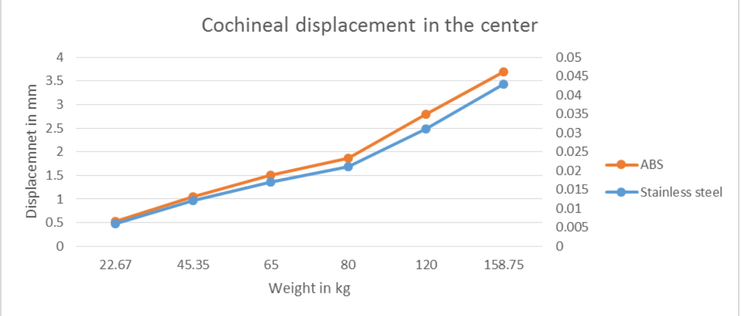


Table 4 and **Figure 28**: First comparison.

In the tables and the graphs Tab.4 and Fig. 28, Tab.5 and Fig. 29 and Tab.6, Fig. 30 and, Tab.7, Fig. 31, the comparison of the numerical values given in mm of the displacement of the cochineal exoskeleton and ellipsoid 5mm thick according to the materials can be seen.

In the virtual models of the cochineal exoskeleton 5mm thick, the same weights were used: 22.67, 45.35, 65, 80, 120, 158.75 kg and the same materials: the 18/8 stainless steel sheet and the plastic ABS to perform the stress analysis.

Cochineal lower lateral parts		
Weight (kg)	Stainless steel	ABS
22.67	0.030	2.634
45.35	0.061	5.269
65	0.088	7.550
80	0.108	9.293
120	0.156	13.940
158.75	0.215	18.442

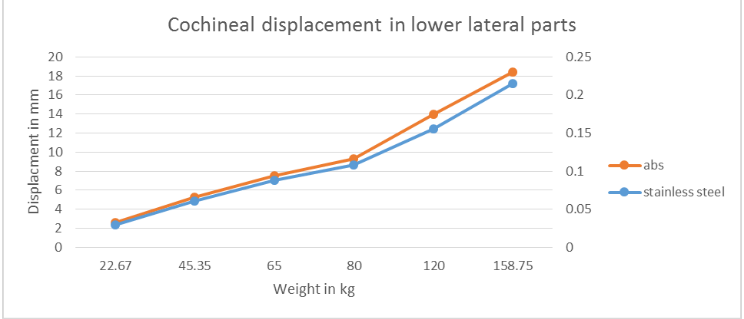


Table 5 and **Figure 29**: Second comparison.

Stainless steel		
Weight (kg)	Cochineal	Ellipsoid
22.67	0.030	0.013
45.35	0.061	0.027
65	0.088	0.039
80	0.108	0.048
120	0.156	0.072
158.75	0.215	0.096

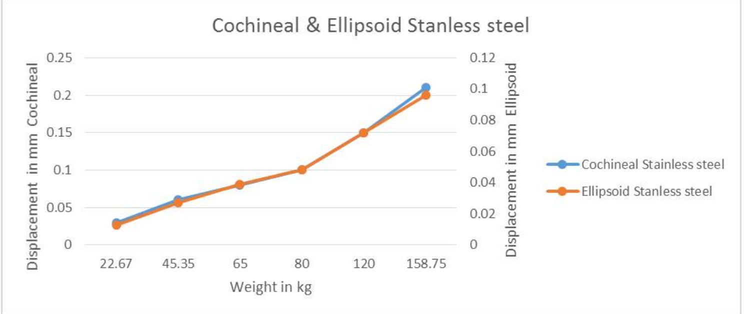


Table 6 and **Figure 30**: Third comparison.

ABS		
Weight (kg)	Cochineal	Ellipsoid
22.67	2.634	1.214
45.35	5.269	2.428
65	7.550	3.480
80	9.293	4.283
120	13.940	6.425
158.75	18.442	8.500

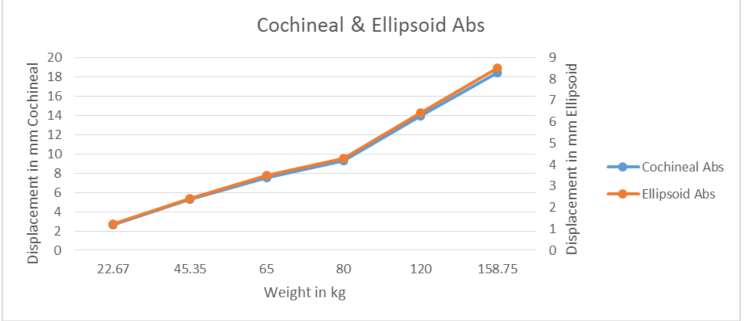


Table 7 and **Figure 31**: Fourth comparison.

In the table and the graph Tab.8 and Fig. 32 and Tab.9 and Fig. 33, the values can be seen in mm of the displacement of the virtual model of the cochineal exoskeleton 15 mm thick and, the comparison between the thicknesses 5mm and 15m with the ABS material.

Cochineal 15mm thick	
Weight (kg)	ABS
22.67	0.421
45.35	0.843
65	1.209
80	1.488
120	2.232
158.75	2.953

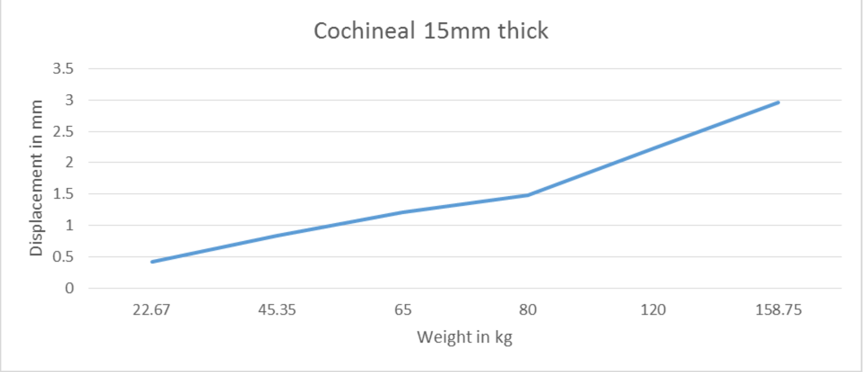


Table 8 and **Figure 32**: Cochineal 15mm thick.

Cochineal ABS material		
Weight (kg)	5mm thick	15mm thick
22.67	2.634	0.421
45.35	5.269	0.843
65	7.550	1.209
80	9.293	1.488
120	13.940	2.232
158.75	18.442	2.953

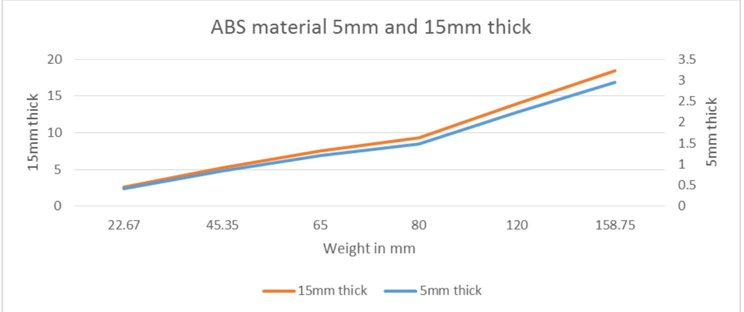


Table 9 and **Figure 33**: Comparison 5mm and 15 mm thick.

The results show that both stainless steel and ABS plastic can be used to make the model of a canoe with the shape of the cochineal exoskeleton since, in both materials, the displacement both in the center and in the lateral parts is significant.

7 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, therefore, 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.

8 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.34 (a)) as a backpack (Fig.34 (b)), or a structure of a building. (Fig.34 (c)).

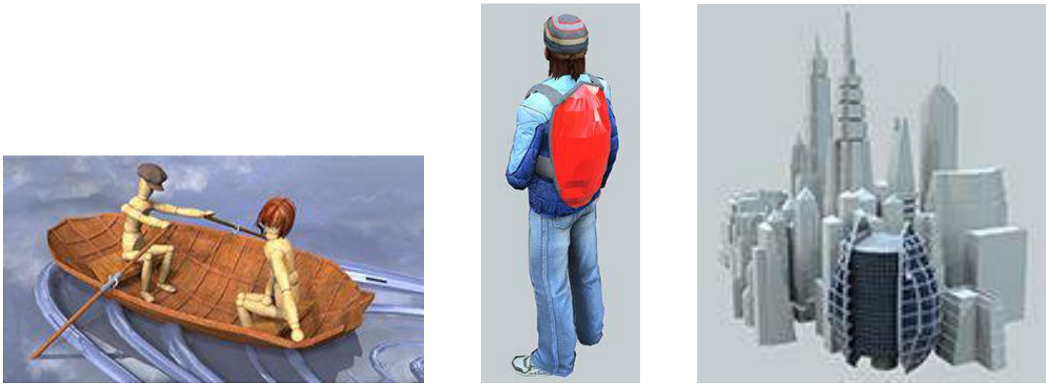


Figure 34: (a) Canoe, (b) Backpack and (c) Building.

Dina Rochman, http://orcid.org/0000-0001-8902-3513
América Sánchez, http://orcid.org/0000-0003-0406-4127
Enrique García, https://orcid.org/0000-0003-0144-9881
Alfredo Almaraz, https://orcid.org/0000-0002-8553-9181

REFERENCES:

[1] Adriaenssens, S.; Block, P.; Veenendaal, D.; Williams, Ch.: Shell Structures for Architects. Form finding and optimization, Routledge, Taylos and Francis, New York, 2014.
[2] Carlo, P.: Leonardo the machines, Giunti Editore, Florence, Itali, 1999.
[3] Moores, T.; Canoecraft. An illustrated guide to fine woodstrip construction, Firefly Books, Canada, 2000.
[4] Rochman, D.: Prototyping the complex biological form of the beetle Deltochilum Lobipes via 2D geometric morphometrics landmarks and descriptive geometry for 3D printing, Computer- Aided Design & Applications, 14(1), 2017, 107-116. https://doi.org/10.1080/16864360.2016.1199761
[5] Rohlf, F. J.: TpsDig, version 2.12, Stony Brooks Departament of Ecology and Evolution, State University of e work at Stony Brooks (2008). http://life.bio.sunysb.edu/morph/
[6] Rohlf, F. J.: Geometric morphometrics simplified: Trends In Ecology and Evolution, USA, http://dx.doi.org/10.1016/j.tree.2004.08.005
[7] Zelditch, M.; Swiderski, D. L.; Sheets, H. D.; Fink, W.: Geometric Morphometrics for Biologist: A Primer, Elsevier Academic Press, USA, 2004.