Introduction:
In this work, we present the invention of a prototype whose objective is to delineate the curves of exoskeletons to reproduce their shapes and to produce three-dimensional models to help describe, understand, and predict processes occurring in the natural world. The prototype consists of several pieces: a table to place the exoskeleton, a scantling to hold the saw blades as riels, three prism-shaped bases, and an L-shaped piece that has a pencil point and a pointer (Fig.1).
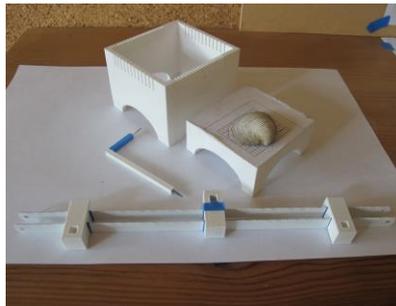
Fig. 1: (a) Scantling, (b) Table, (c) L shaped piece and (d) prism-shaped piece.

It is worth mentioning that this prototype was made during the Covid 19 contingency using the materials we had at home and the 3D printer. Despite the lack of access to other technologies, it was possible to make the 3D prototype, delineate the exoskeleton curves and print the 3D model.

Main Sections:
As mentioned above, the prototype consists of several parts, and each one has a unique function. The scantling is used to hold the saw blades that are the rails. The prism-shaped base is placed on the riels and the L-shaped is inserted into it. This L-shaped piece has a pointer that is used to locate the points of any curved shape and a pencil point that is used to trace the points marked with the pointer on a sheet of paper.

After modeling the parts of the prototype, they were 3D printing. As it can be seen in Figure 2, it was necessary to use adhesive tape in certain pieces to adjust the tolerances, and in addition, two prisms equal to the central prism were printed to place them at a distance of the saw blades to balance the weight.
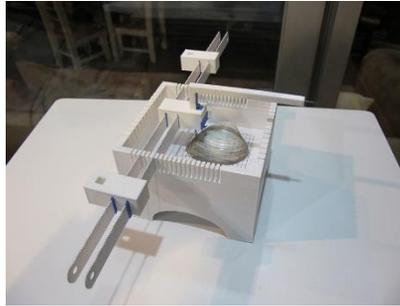
Fig. 2: 3D printing of the complete prototype.

Based on Gaspard Monge's representation method, in the prototype, the table or base is the horizontal plane, the vertical plane is the paper where the projections are marked, and the L-shaped piece represents the projection lines of the "z" and "y" axes of the orthogonal projection

How does the prototype work?
The base or table where the exoskeleton is placed is inside the scantling. The scantling has multiple slots on all sides so that the saw blades can be placed parallel to the axes of the grid to find the projection of the points in both in the transverse or longitudinal direction.

The central prism on the saw blades rails has a hole where the L-shaped piece inserted. It has, enough tolerance to allow the L piece move up or down when the saw blades move to the right or to the left.

When the pointer is over the exoskeleton, the projection of the point in space can be drawn on the sheet of paper with the point pencil. It can be seen in Figure 3 that the sheet of paper is in an upright position glued to a wooden base.

Once all the projections of the points in space of the first axis of the grid are traced on the sheet of paper, the saw blades can be moved to the next slot of the scantling to draw, on the same sheet of paper the projections of the points in space of the second axis of the grid. The same procedure is followed until the last axis of the grid is traced.
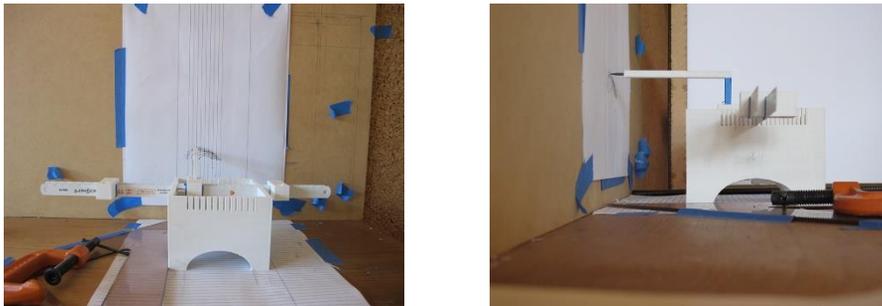

Fig. 3: Drawing the projections of the points in space of the curves of the exoskeleton on a sheet paper.

To corroborate that the prototype works, we tasted it using the valve of a white clam (Spisula solida). This mollusk belongs to the *Mactridae* family, of the genus *Bivalvia*. The valve used measured 44 mm in length and 51.41 mm in height.

Pelecipods or bivalves have an external shell made up of two valves (bivalves). The shell, and therefore each valve, grows from an upper vertex called the umbo, with concentric growth rings forming around it.

To find morphological measurements of the length, height, and thickness of seashells, biologists use the malachometer. A malachometer is an instrument used for fieldwork with readings up to 20 cm (Fig.4 (a and b)),

Fig. 4: (a) Morphological measurements of a seashell and (b) Malachometer.

Sometimes the shells need to be cut their largest diameter with a diamond-edged cutter to be able to see the growth rings or lines and determine their age.

With our prototype, the valve curves can be delimited so that the growth ring or lines can be observed on a sheet of paper without any damage to the shell.

Methodology:
The methodology that was carried out for the analysis of the shape of the valve was the following: first, a plaster model was carried out, to avoid damaging the valve (Fig. 5) and to mark lines in both transversal and longitudinal directions to form a grid. A 3D impression of a box was filled with Play-Doh modeling compound (Fig. 6), the shell was pressed on it which due to its smooth consistency allowed the valve shape to be correctly casted with plaster.
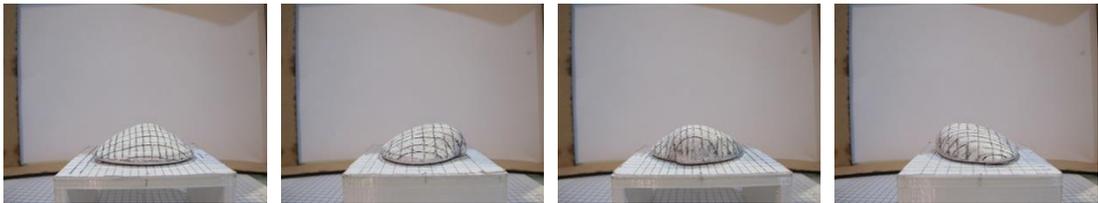

Fig. 5: Four views of the plaster cast with grid.

Fig. 6: Mold and emptied of plaster.

Once the grid was defined in the plaster model, the prototype was modeled and printed according to the grid of the plaster piece and the original valve was used to trace its curves using the methodology describe above. (Fig. 7). The sheets of paper were then scanned to find the numerical values of each of the points of the curves in the tpsDig computer program. The curves were drawn in a vector program (Fig. 8). We ended up modeling and printing the shell. (Fig.9 and 10).
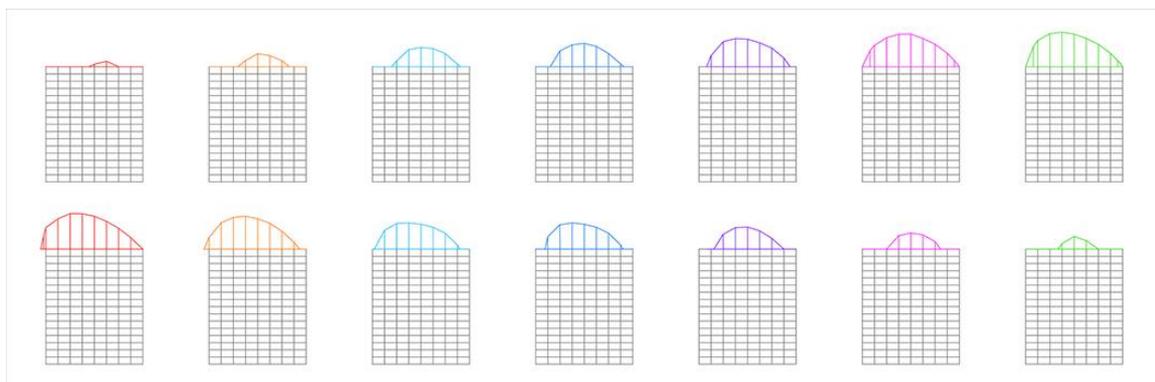
Fig. 7: Valve curves on the sheet of paper.

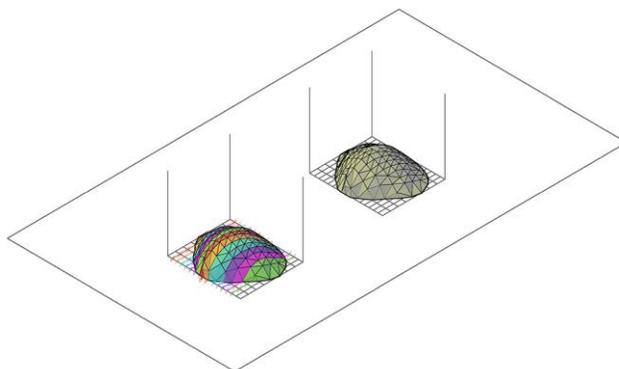Fig. 8: Valve curves drawn in a vector program.

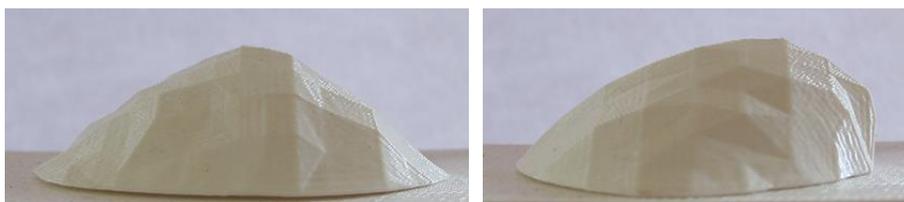Fig. 9: Valve curves modeled in a vector program.

Fig. 10: 3D printing model.

In the comparison between the 3D model and the original valve it can be observed in Figure 11that, the errors in both the shape and the heights are significant. This is due to two factors: the first factor is that the pointer, although it ends in a point, is too wide to mark the points at the end of small-scale exoskeletons. The second factor is that the L-shaped piece sometimes moved from its 90˚ angle.

The prototype can be improved by exchanging the scantling for a structure. This structure would have the slots to place the rails and to place a spring-loaded piece that goes through the L-shaped piece so that it maintains the 90˚ angle and can go up and down.

Fig. 11: Comparison between the model and the valve.

Conclusions:
We have presented a prototype based on Gaspard Monge's geometric representation system. With this prototype, exoskeletons curves are delineated in two-dimensional space to produce three-dimensional models.

The prototype function test was carried out with a white clam since mollusks constitute the largest phylum of invertebrates after arthropods. Some 100,000 current species have been described and 35,000 fossil species are known, proving their long geological history.

This prototype and the three-dimensional physical models generated in this work would be useful in biodiversity research, both for current specimens and specimens archived in museums.

References:
[1]   Echabazal, O.: Age, growth and mortality of *Spondylus crassisquama*, Lamarck, 1819, in ojo de liebre lagoon, Baja California Sur, México, Master's Thesis, Instituto Politécnico Nacional Interdisciplinary Center of marine sciences, 2018Bates, J.; Ding, M.-S.; Park, J.: A Study on Rapid Prototyping Techniques, TR UMCP-97-003, University of Massachusetts, Boston, MA, 1997, http://www.um.edu/~bates.html.
[2]   Fururity, https://www.futurity.org/shells-3d-imaging-biodiversity-2107392/, 3D imaging reveals hidden history in old shells
[3]   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
[4]   Rohlf, F. J.: Geometric morphometrics simplified: Trends In Ecology and Evolution, USA, https://doi.org/10.1016/j.tree.2004.08.005
[5]   Schreck, K.: Monge´s Legacy of descriptive and differential geometry, Docent Press, Boston, Massachusetts, USA, 2016.
[6]   http://nes.pe/tag/malacometro.