

Design of a Prototype to Delineate the Curves of Exoskeletons to Produce Three-dimensional Models

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Abstract. This document describes the design, construction, and functionality of a prototype, of which the objective is to delineate the curves of exoskeletons to produce three-dimensional physical models. To make the prototype, we used Gaspard Monge's geometric representation system. The prototype includes a 3D printing, a table to place the exoskeleton, a scantling to hold saw blades that function as rails, three prism-shaped bases, and an L-shaped piece to hold in place a pencil point and a pointer. With our method, we can create a documentary collection of the periodic growth of the exoskeleton; since we have the numerical values of the "X" and "Y" coordinates and the geometric contour of the curves to make mathematical comparisons and 3D printing of the exoskeletons structure.

Keywords: Gaspard Monge's representation method, 3D Prototype, 3D model.

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1 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 a three-dimensional physical model 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 rails, three prism-shaped bases, and an L-shaped piece to place on the ends a pencil point and a pointer in 3D impression (Figure 1).

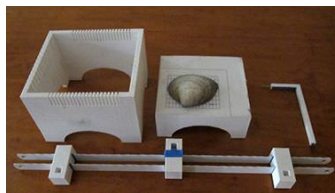


Figure 1: Scantling, Table, L shaped piece, prism-shaped piece and saw blades.

To corroborate that the prototype works, we tested 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.

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

Its curved exterior surfaces have geometric patterns and textures that are central objects of study in applied and computational harmonic analysis. (Tingram Gaos, et al. 2019) [2].

In 1923 Frank W. Weymouth carried out the first study of the periodicity of growth ring formation in bivalves. In the article, Periodicity of internal growth ring deposition in the Pismo clam (*Tivela stultorum*) from Playa San Ramon, BC, Mexico [5], the authors propose the mark-recapture method to analyze the growth structures of the shells.

This method consists of collecting the valves periodically to mark them with an electric drill (Moto-Tool Dremel 270) and then carry out the analysis of the growth structures of the shells. These marks are covered with an epoxy resin to reduce erosion when the valves are in the water.

The partially marked valves are embedded in a plaster block, cutting them on their dorso-ventral axis with an electric saw with a diamond disc to observe the rings with a stereoscopic microscope, with reflected and/or transmitted light.

The downside to using a plaster block is that being completely dry, it is very brittle and can break or chip. The advantage of working with a PLA 3D model is that there is no risk of breaking or chipping when cutting it and, we can print as many pieces as we need.

To find morphological measurements of the length, height, and thickness of seashells (Figure 2 (a)), biologists use the malachometer. A malachometer is an instrument used for fieldwork with readings up to 20 cm (Figure 2 (b)) [7].



Figure 2: (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.

Our design, on the other hand, causes no damage to the shell.

It is worth mentioning that this prototype was made during the Covid-19 contingency using the materials we had at home and a 3D printer. Despite the lack of access to other technologies, the 3D printed prototype, and 3D printed physical models were successful.

This article has the following sections: Section 2, talks about the prototype, Section 3, describes the methodology we followed. Section 4 list the results and, finally Section 5 presents

the conclusions. All the figures in this document are original and created by the author that works at the Universidad Autónoma Metropolitana Campus Cuajimalpa in Mexico City.

2 THE PROTOTYPE

In the year 1799, Gaspard Monge (1746-1818) developed a system for the geometric representation of three-dimensional objects by projection on two planes based on a double orthogonal projection, or dihedral system (Figure 3 (a and b)).

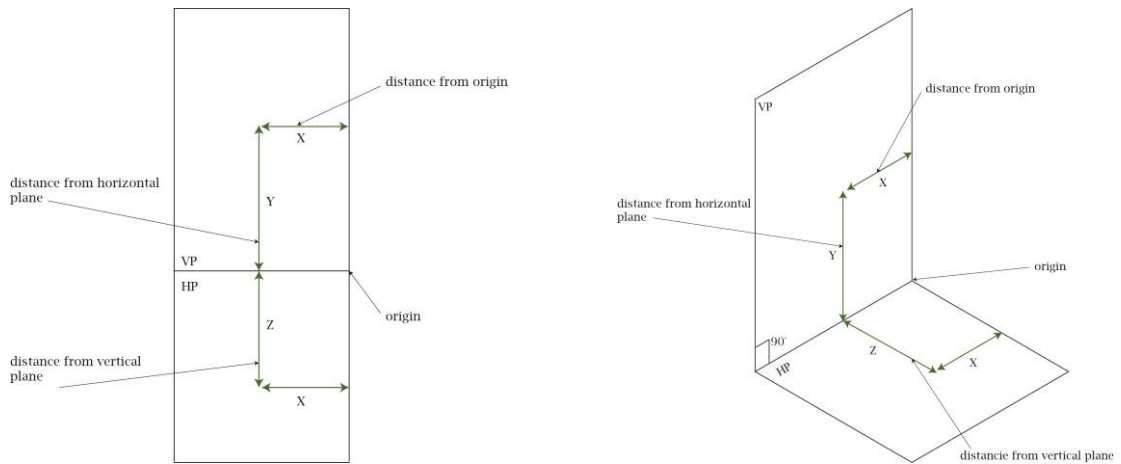


Figure 3. Dihedral system: (a) Orthogonal projection and (b) Isometric projection.

Monge teach a way to determine the forms of objects and to deduce all of the proprieties resulting from their respective position. The first essential principle centered on horizontal and vertical projection. Monge perceived that any point in space could be define by three coordinates determined by the distance of the point to three mutually perpendicular planes (Schreck et al. 2016) [5].

The point, the line, the plane, and the solid are the elements of the dihedral system used. In this research, we worked with the point in space considered in the framework of Euclidean geometry as the fundamental element to find the location of the surfaces in the three axes X, Y and, Z (Figure 4 (a and b)).

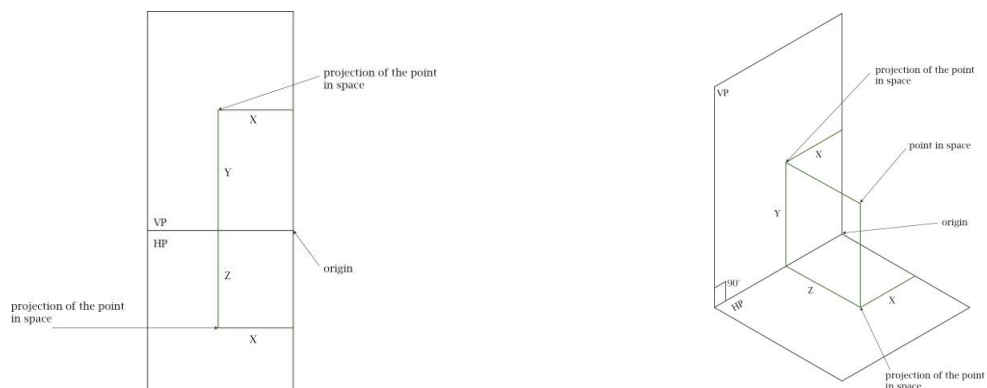


Figure 4: The point in space: (a) Orthogonal projection and (b) Isometric projection.

As we mentioned, the prototype consists of the following parts: a table to place the exoskeleton, a scantling to hold the saw blades as rails, three prism-shaped bases, and an L-shape part to attach a pencil point and pointer (Figure 5 (a, b, c and d)).

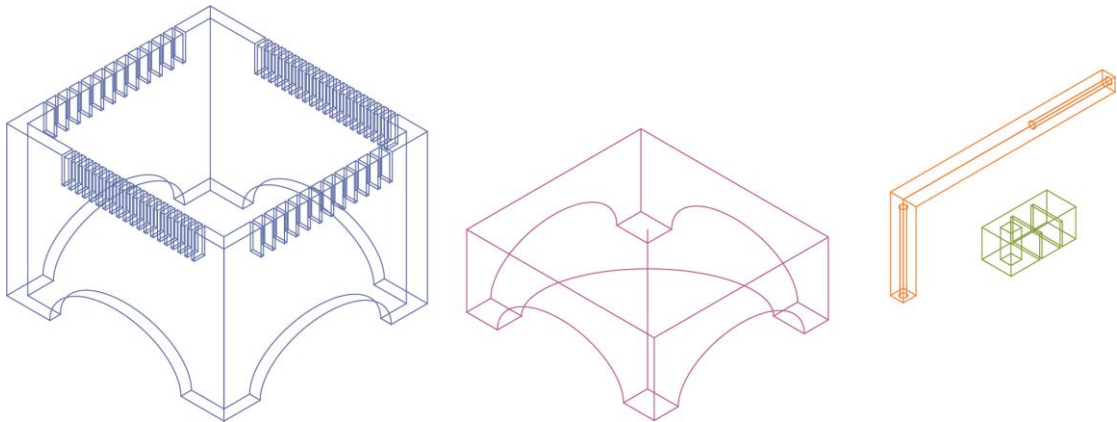


Figure 5: 3D modeling (a) Scantling, (b) Table, (c) L shaped piece and (d) prism-shaped piece.

Each of the parts has a unique function. The scantling is used to hold the saw blades that became the rails. The prism-shaped base is on the rails and the L-shaped is placed inside the prism. This L-shaped part has a pointer to locate the points of the curved shape and a pencil to trace the points located with the pointer on a sheet of paper (Figure 6 (a, b, c and d)).

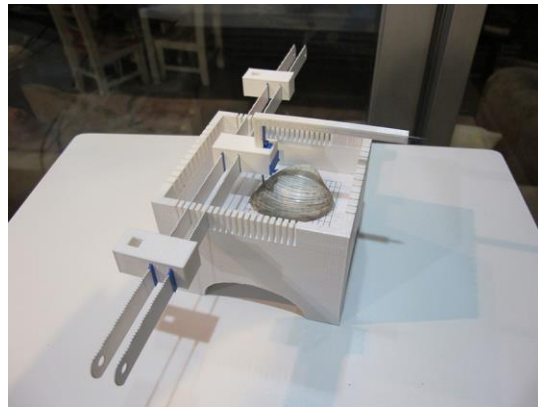


Figure 6: 3D prototype (a) Scantling, (b) Table, (c) L shaped piece, (d) prism-shaped piece and (e) saw lades.

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 (Figure 7 (a, and b)).

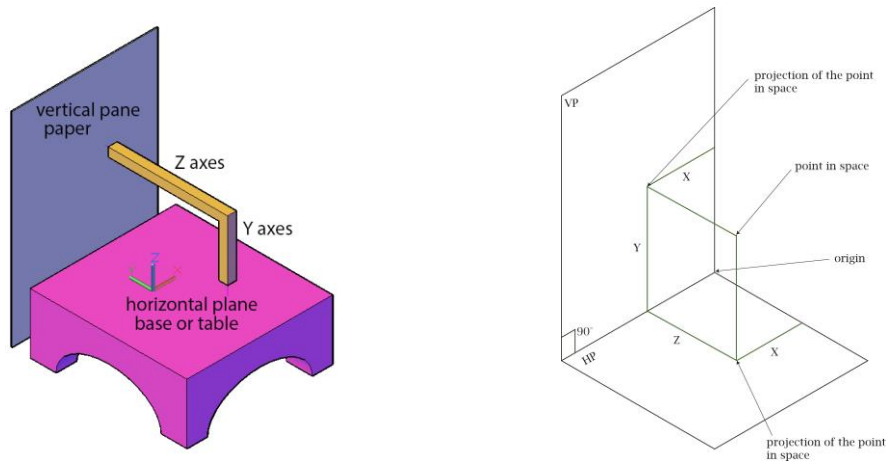


Figure 7: Gaspard Monge's representation method (a) Prototype and (b) Orthogonal projection.

2.1 How does the Prototype Work?

The base or table where we place the exoskeleton is inside the scantling. The scantling has multiple slots on all sides so that the saw blades can be positioned parallel to the axes of the grid to meet the projection of the points both transversely and longitudinally.

The central prism on the saw blades rails has a hole where the L-shaped piece is inserted. It has enough tolerance to allow the L piece to move up or down when the saw blades move to the right or 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 pointed pencil. As it can be seen in Figure 8, the sheet of paper is in an upright position glued to a wooden base.

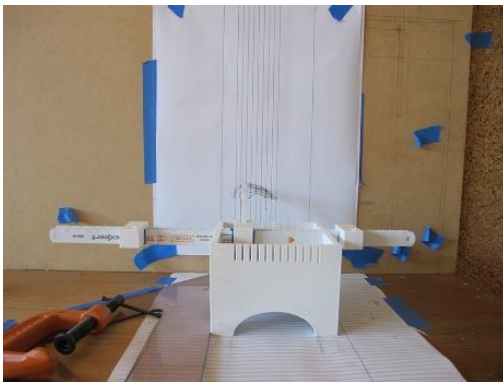


Figure 8: Drawing the projections of the points in space of the curves of the exoskeleton on a sheet paper.

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 line of the grid.

3 METHODOLOGY

The methodology we carried out to analyze the valve shape is as follows: first, we traced the valve contour on the sheet of paper to wrap it in a rectangle and define the grid. Then, we divided the long side of the rectangle into sixteen parts, and the narrow side into eight parts (Figure 9 (a), (b) and (c)). If we had used a different shell, the grids to establish the number of points to be recorded would have to be modified.

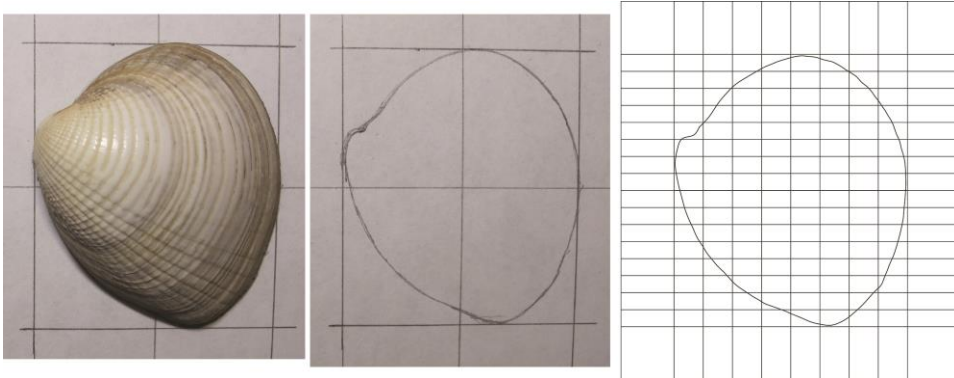


Figure 9: (a) Shell, (b) Contour and (c) Grid.

To avoid damaging the valve, we began with a 3D impression of a box filled with Play-Doh modeling paste, the shell was pressed onto the paste, which due to its smooth consistency allowed the valve shape to be correctly cast with plaster. (Figure 10).



Figure 10: Mold and emptied of plaster.

To draw the grid on the plaster model, we designed a prototype. This prototype consists of three pieces: a table to place the model, a scantling with multiple slots on all sides to hold the saw blade as a rail, and a prism-shaped base with two holes to insert in each of them a pencil lead.

The prism-shaped base is on the rail, the table is inside the scantling, and the scantling holds the saw blade (Figure 11 (b)).

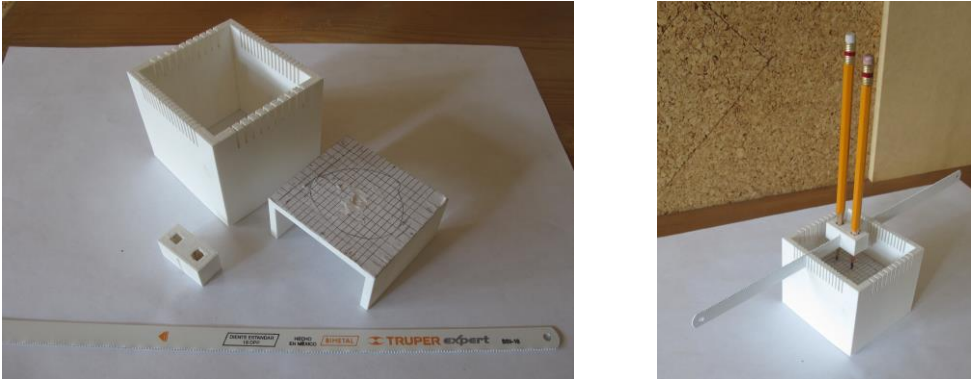


Figure 11: 3D prototype (a) Scatling, (b) Table, (c) prism-shaped piece and (d) Assembly.

As the prism has two holes, two lines are drawn on the plaster with a single movement, one to the right and the other to the left, keeping the distance between the axes from the grid.

Having finished drawing the grid on the plaster model (Figure 12), we made the new prototype described in the first section without modifying the grid.

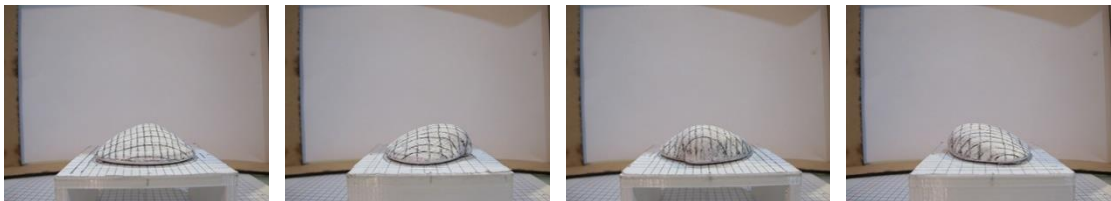


Figure 12: Four views of the plaster cast with grid.

We used the original valve to draw the curves using the procedure described in Section 2.1. (Figure 13). Next, we scanned the sheets of paper to find the numerical values of each of the points of the curve in the tpsDig2 computer program. Then, we drew the curves in a vector program (Fig. 14). We finished by modeling and printing the valve. (Figures 15 and 16).

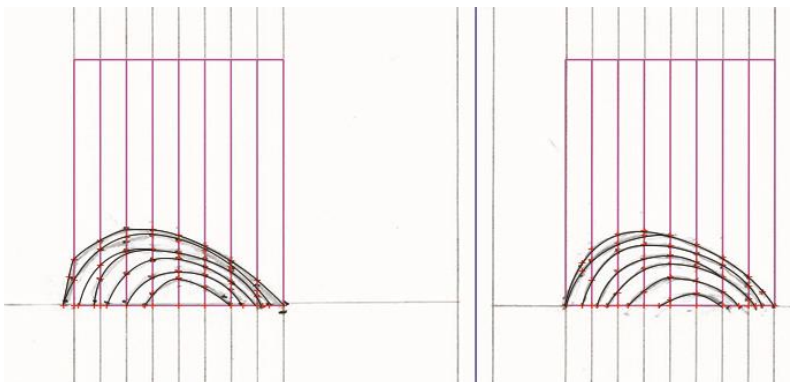


Figure 13: Valve curves on the sheet of paper.

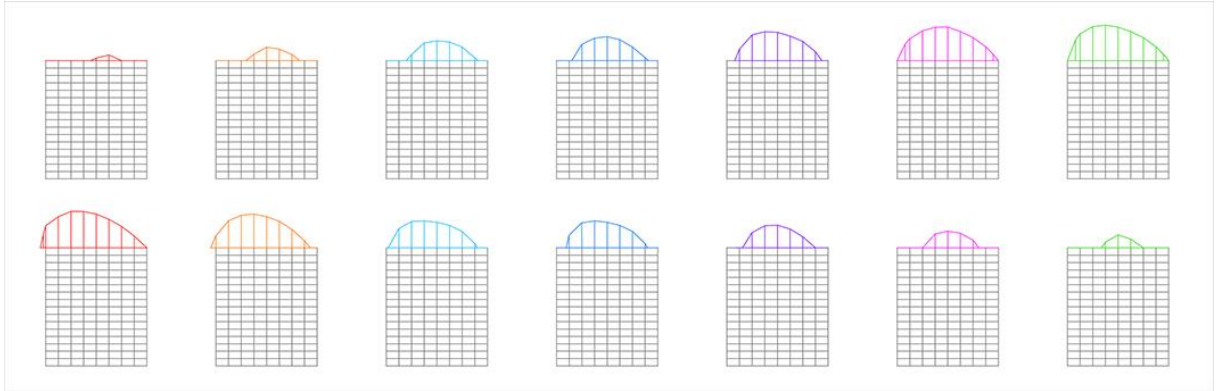


Figure 14: Valve curves drawn in a vector program.

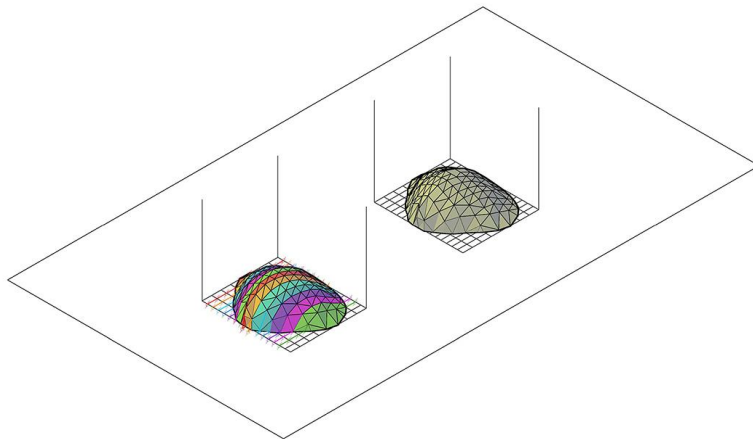


Figure 15: Valve curves modeled in a vector program.

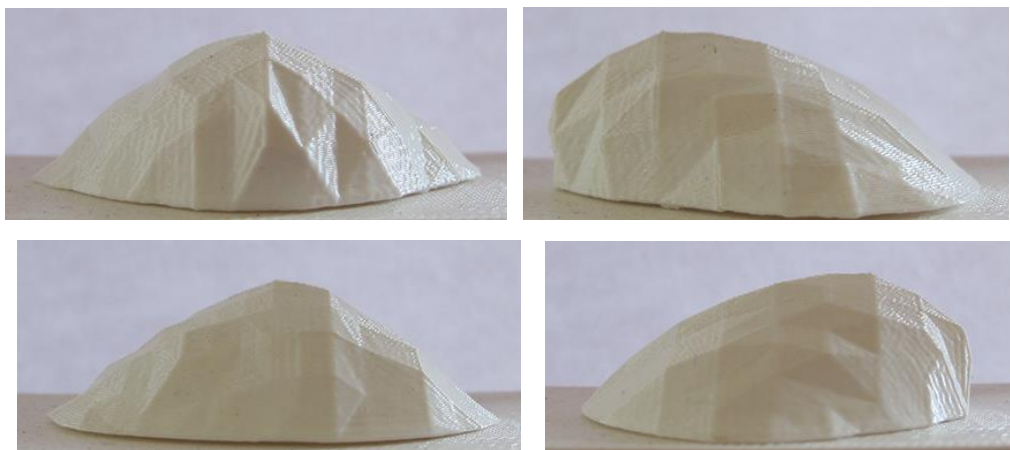


Figure 16: 3D printing model.

4 RESULTS

As already mentioned, Gaspard Monge's geometric representation system is a method of representing the elements of three-dimensional space on a plane, using the orthogonal projection on two planes that intersect perpendicularly. With this system, we can draw imaginary figures and objects. But if we work with biological forms, it would be difficult to reproduce them.

Some techniques used to reproduce three-dimensional objects or biological forms include scanning, digitizing, and photogrammetry. The literature tells us that it is necessary to consider the brightness of the available light, the reflective characteristics of materials and fastening objects so that they do not move, to obtain good results with these three techniques. It is also necessary to rectify the projections of the points and surfaces before modeling the solid.

Since 2015, we have worked on the geometric reproduction of biological forms and created a method that links descriptive geometry and geometric morphometrics [3].

In this method, we use a collection of five photographs to label each morphological point called "Landmarks", in order to define the numerical values of the coordinates "x" and "y" in the Cartesian space. With these coordinates, the geometry of biological forms is created through surfaces, meshes, and solids by finding the coordinates "x", "y", and "z".

Like the previous techniques, this method has several problems. First, because it implies copious manual work and finding the projections of the points in space takes a long time because of the photographic perspective.

Also, the numerical values of the "x", "y", and "z" coordinates of the three projections of the points in space must be corrected so that they coincide in the orthogonal projection. The correction is mathematical.

In the prototype we designed, the projection of the points in space are located directly on the biological forms or exoskeletons.

No mathematical rectification is needed to find the distances "x" and "y" of the projections of the points in space after having obtained the numerical values with the tpsDig2 program since we only use the vertical plane of the orthogonal projection.

In the prototype, the L-shaped piece is key since, as can be seen in Figure 17, its sides represent the projection lines of the "z" and "y" axes of the orthogonal projection.

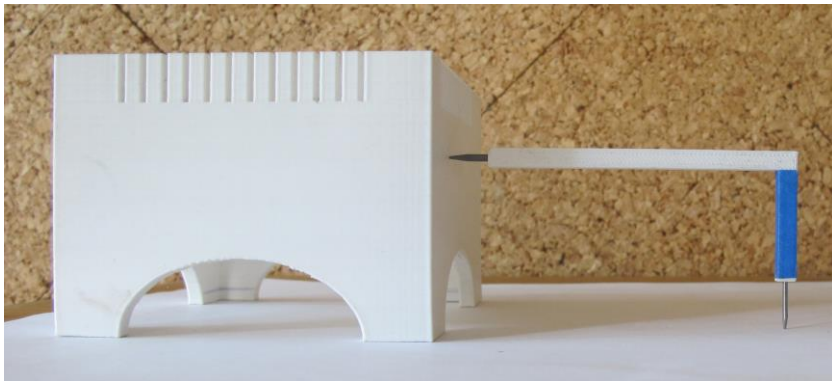


Figure 17: L-shaped piece.

We use the pointer to locate the point in space on the horizontal plane, and we use the tip of the pencil to mark the projection of the point on the vertical plane at the same time.

We tagged 9 points from the grid and 150 points of 14 curves in the vertical plane in the tpsDig2 program. For simplicity, we illustrate the numeral values of grid and solely the points of the curve # 8 of valve in Tab.1 (Figure 18).

The program tpsDig2 creates a text file that contains the numerical values of the coordinates "x" and "y" of each of the points in the vertical plane, considering the origin 0, 0 in the lower left side [5].

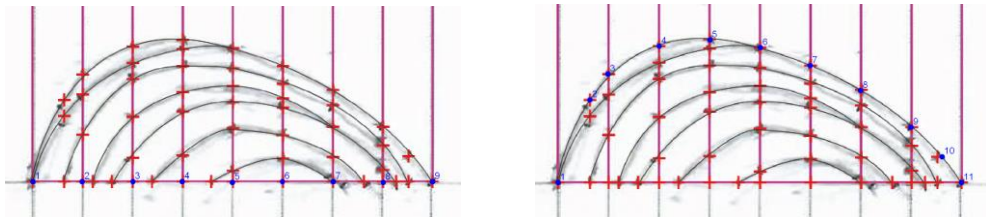


Figure 18: Tagged points (a) From de grid and (b) Curve # 8.

Grid	X	Y	Concatenation	Curve # 8	X	Y	Concatenation
1	1394	199	1394,199	1	1394	199	1394,199
2	1459	199	1459,199	2	1435	305	1435,305
3	1524	199	1524,199	3	1459	338	1459,338
4	1589	199	1589,199	4	1524	374	1524,374
5	1654	199	1654,199	5	1589	382	1589,382
6	1719	199	1719,199	6	1654	372	1654,372
7	1784	199	1784,199	7	1719	349	1719,349
8	1849	199	1849,199	8	1784	318	1784,318
9	1914	199	1914,199	9	1849	270	1849,270
				10	1887	232	1887,232
				11	1914	199	1914,199

Tab. 1: Numerical values of the grid and numerical values for curve # 8.

The numerical values of the concatenation are copied from the Excel file and are pasted into an AutoCAD file and automatically points are traced in space, we scale and rotate the points and curves according the grid (Figure 19).

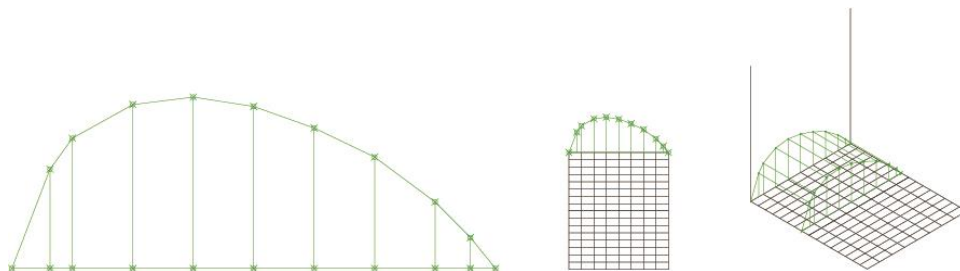


Figure 19: (a) Projection of the points of curve # 8 according to the concatenation and (b and c) Orthogonal projection and isometric projection of the points of curve # 8 scaled and rotated 90°.

When we rotate each of the vertical planes 90° in the right plane and place them on the corresponding line of the grid, each point in the space of the curves is in the three-dimensional space; hence, we can draw the surfaces, perform the modeling and, build the physical model.

In the physical model, we observe the geometry of the structures, the location of lines, points, and planes in space, and we analyze the changes of planes.

If we compare the 3D model and the original valve, the errors we have are where the curve of the valve goes inwards (Figure 20). We can say that 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 in certain parts of small-scale exoskeletons.

The second factor is that the L-shaped piece sometimes moved from its 90° angle. Although we used masking tape in certain parts to adjust the tolerances, and we used to place two prisms equal to the central prism at a distance from the saw blades to balance the weight.

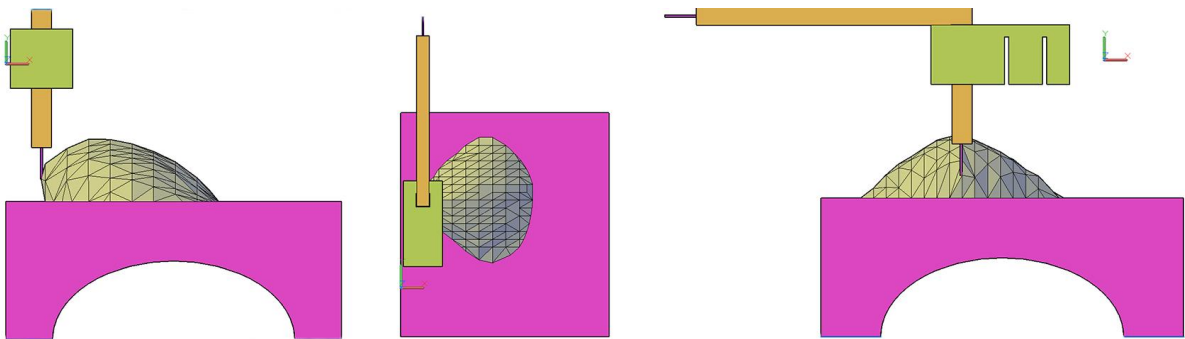


Figure 20: The pointer on the curve (a) Front view, (b) Top view and (c) Left view.

As seen in Figure 21 in the curves that do not go inwards there is no error.

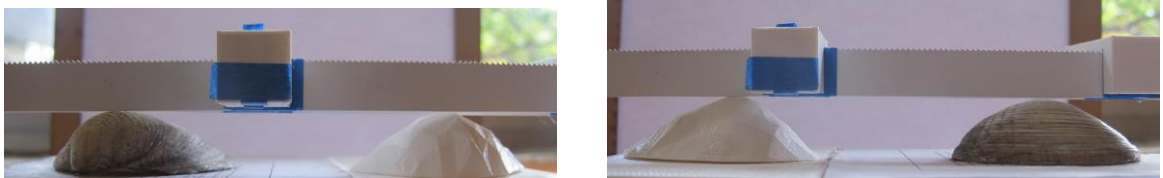


Figure 21: Comparison between the model and the valve.

The prototype would improve by changing the scantling for a structure with the slots to place the rails. We would also add a spring-loaded piece so that the L-shaped piece keeps the 90° angle and can go up and down without any problem. And the width of the pointer should change.

5 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.

We can say that with our method, we can create a documentary collection of the periodic growth of the exoskeleton; since we have the numerical values of the "X" and "Y" coordinates and the geometric contour of the curves to make mathematical comparisons and 3D printing of the exoskeletons structure.

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