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Design and fabrication of a low-cost fused deposition modeling 3D printer

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Abstract

The increasing consumption of parts made under additive manufacturing techniques has driven a great diversity of machines that employ this principle. This article shows the design and fabrication of a wire feed machine that can be built with a minimum cost and accessible to any student, home or research group that requires it. The step by step design and selection of components easily available in the market and self-made is presented. As a result we obtain a robust equipment with a working area of 20*20*42 cm open source.

Keywords: 3D printing, low cost, fused deposition.

I. INTRODUCTION

Three-dimensional printing, or more formally additive manufacturing [1], is the process where a variety of technologies convert data from a three-dimensional (3D) model generated in a computer-aided design (CAD) system into physical models, the data is transformed into a series of two-dimensional (2D) cross-sections of a given thickness that are sequentially deposited one on top of the other by a printer to form a three-dimensional physical model [2].

Additive manufacturing was initially used in prototyping and simulation, since 2000 it has been used in the production of finished products and has gained popularity for its flexibility and the customized service it provides [3]. Consumers can obtain products tailored to their needs and suppliers can create customized parts or produce on a unit scale [1]. The use of this technology finds application in many areas such as the manufacture of artificial limbs, lenses and optical elements, sensors, clothing, footwear [1], textile engineering [4] and even education [5].

There are several methods that allow the additive production of 3D shapes, including stereography, lithography, fused deposition modeling (MDF) [4] or laser sintering modeling [2]. The MDF technique is based on the resistive heating of filaments in an extruder nozzle. The molten material is deposited on the printing platform layer by layer and then hardened there [6]. Various materials can be used by MDF printers, for example, acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) [7], polyamide, polycarbonate, polyethylene, polypropylene or wax [8]. Although the diffusion for products derived from this technology remains limited compared to other conventional processes, additive manufacturing shows a positive growth trend [9]. This trend is favored by the diffusion of cheaper technologies such as MDF, which makes it the most interesting method for small companies as it allows taking advantage of this technology without large investments [4].

Currently, the need for rapid prototyping equipment has encouraged different researchers to manufacture low-cost 3D printers. In 2015, it was demonstrated that it is possible to design and build a 3D printer using free software for prototyping and building inexpensive plastic parts [5]. In the same year, they fabricated and implemented a 3D printer under the scheme of a parallel Delta robot and managed to decrease the printing time without losing quality [10]. On the other hand, Kun [11] reconstructed by reverse engineering a 3D printer using the MDF technique, and from his findings he started the design of his own printer with the aim of perfecting the system. Eventually, the RepRap project began when Adrian Bowyer published the designs of his 3D printer parts and encouraged others to improve them and publish improved versions. Bowyer's ultimate goal was to develop a 3D printer that would be self-replicating and low cost, it is said that from that point a true 3D printer revolution began [12].

Based on the above, the design and manufacture of a low-cost MDF 3D printer was proposed. As a basis, the design of the Maker Z18 machine was used, the only professional printer that the University of Pamplona has and which has shown good performance in its service.

II. METHODOLOGY

To carry out the construction of the 3D printer, first the design and assembly of the components was carried out with the help of CAD software. The size and proper location of each part was verified (Figure 1). Subsequently, the materials required for the mechanical system and the electrical system were selected (Table 1). In addition, the manufacturing processes required for the fabrication of the elements were established. Finally, the assembly and tuning of the printer was carried out.

a. Design of the 3D printer by fused deposition modeling:

The design stage started with the sketch of part 1, the structure served as a support to assemble all the components that allow the kinematic link of the 3D printer. Figure 2 shows the main dimensions of the structure.

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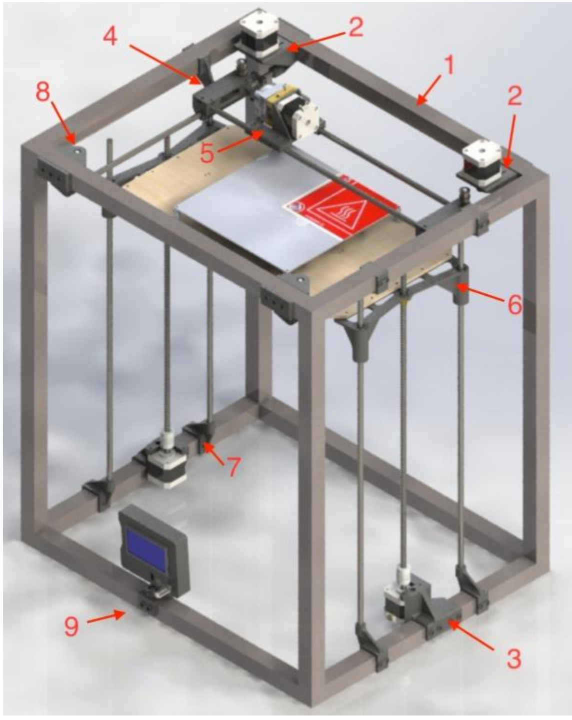

Fig. 1. CAD design and parts of the low-cost fused deposition 3D printer

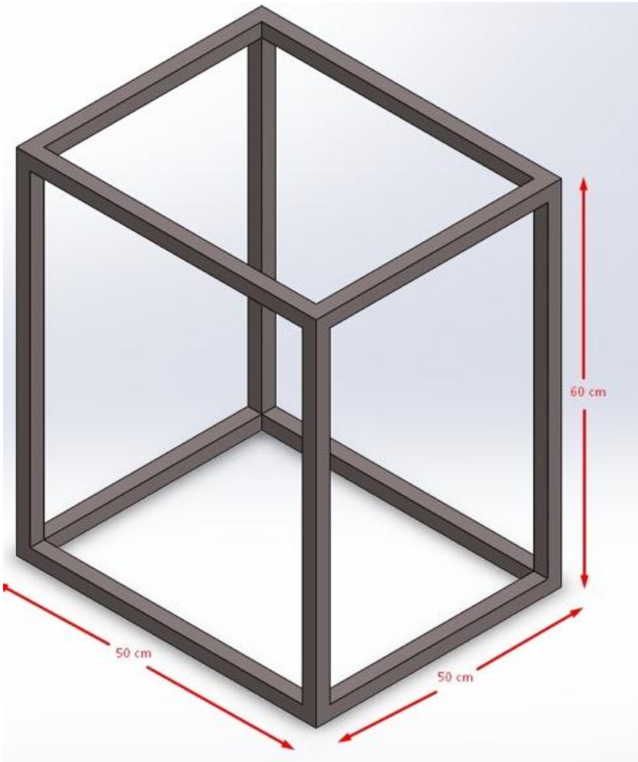

Fig. 2. Design of part 1 (structure) of the low-cost fused deposition 3D printer.

Table 1. Materials and quantity of parts for the manufacturing process.

Piece	Quantity	Name
1	1	Structure
2	2	X-axis and Y-axis motor mount
3	2	Z-axis motor mount
4	2	Y-axis slide
5	1	X-axis slide
6	2	Z-axis slide
7	8	Z-axis guide
8	2	Y-axis guide
9	1	LCD Support

Next, the supports for the motors (parts 2 and 3) were designed. These components were adapted to fit the profile used for part 1. It is important to mention that the dimensions of the parts depended on the profile selected for this purpose. Figure 3 shows the motor support for the X-axis and Y-axis (part 2). These supports contain 3 main parts: firstly, the area where the motor is located and secured; secondly, the cavity that allows the part to fit into the rectangular profile and finally a cylindrical support where two smooth 5/16 inch stainless steel rods are fastened and on which the Y-axis carriage moves (part 4).

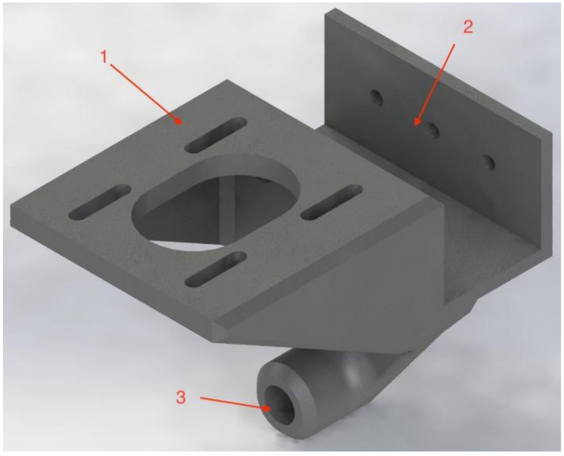

Fig. 3. Design of part 2 (X-axis and Y-axis motor support) of the 3D printer.

The Y-axis carriage (Figure 4) has the function of transmitting motion in the Y-axis. In addition, it has two cavities that house 5/16 inch stainless steel smooth rods on which the X-axis carriage moves.

Fig.4. Design of part 4 (Y axis carriage) of the 3D printer.

The X axis carriage (part 5), in addition to transmitting the movement in the X axis, has the main function of supporting the end effector of the 3D printer (Figure 5). Taking into account that this element is responsible for depositing the material and also for moving along the X axis and Y axis, this piece must support the weight of the motor and the *Hotend* and additionally must withstand the efforts generated when making rapid changes of direction.

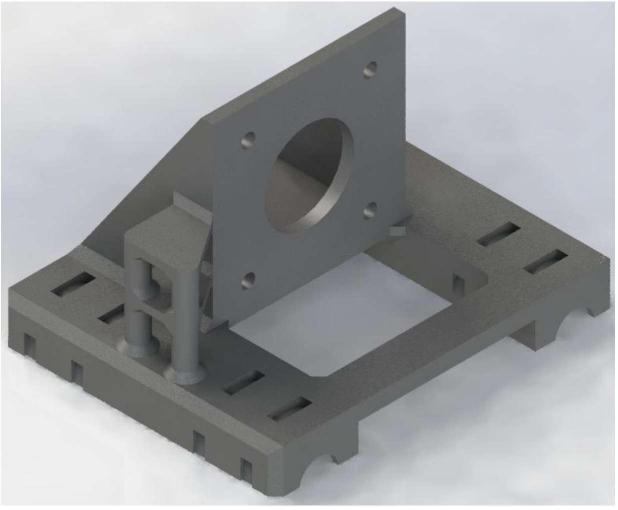

Fig. 5. Design of part 5 (X axis carriage) of the 3D printer.

The Z-axis carriage has the function of transmitting the movement in the Z-axis, on it rests the platform that holds the hot bed, and the hot bed is the surface where the molten material will be deposited. The carriage has cavities at the ends where smooth 5/16 inch stainless steel rods are housed (Figure 6), to guide the displacement of the platform along the Z-axis, these rods prevent the hot bed from tilting in any way.

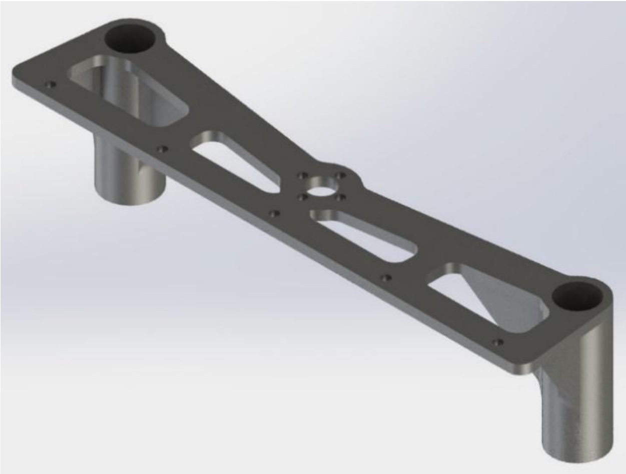

Fig. 6. Design of part 6 (Z-axis carriage) of the low-cost fused deposition 3D printer.

b. Fabrication of the 3D printer by fused deposition:

Fabrication of the structure: for the fabrication of the structure (piece 1), low-cost materials and processes were sought. For this reason, a 1-inch, 16-gauge, square structural steel profile was used. This material is widely used in the construction field and in the metal-mechanic industry in Colombia, so it is easily accessible, its cost is low and it has a good resistance-weight ratio [13]. Four 60 cm sections and eight 50 cm sections were cut. They were then joined by shielded metal arc welding (SMAW), a process used to permanently join metal [14]. The equipment and filler material required for the SMAW welded joints are low cost and at the same time provide high stiffness to the structure. As filler metal, 6013 coated electrode of 3/32 inch diameter with an amperage of 70 A and a voltage of 220 V was applied with a Lincon welding machine.

Manufacture of the supports, carriages and guides : The manufacture of parts 2 to 9 was carried out with the fused deposition modelling technique. For this, a Prusa i3 printer with a printing area of 20x20x15 cm was used. Polylactic acid (PLA) filament with a commercial diameter of 1.75 mm in black was used. The printing parameters used with this material can be seen in Table 2.

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Table 2. Printing parameters for the polylactic acid (PLA) used to manufacture the 3D printer supports, carriages and guides.

Parameter	**Value**	**Unit**
Extrusion temperature	205	°C
Hot bed temperature	70	°C
Layer height	0,2	mm
Internal perimeters	7	UNI
External perimeters	15	UNI
Pattern Type	Straighten 45°.	-
Density	100	%
Print speed	80	mm/s

Electronics selection: there are a significant number of options for the electronics of a 3D printer, in this case the criteria that were taken into account for the selection of these components were the low price and availability in the market. Each component was searched for and ordered from online stores. Figure 7, shows the electronics schematic.

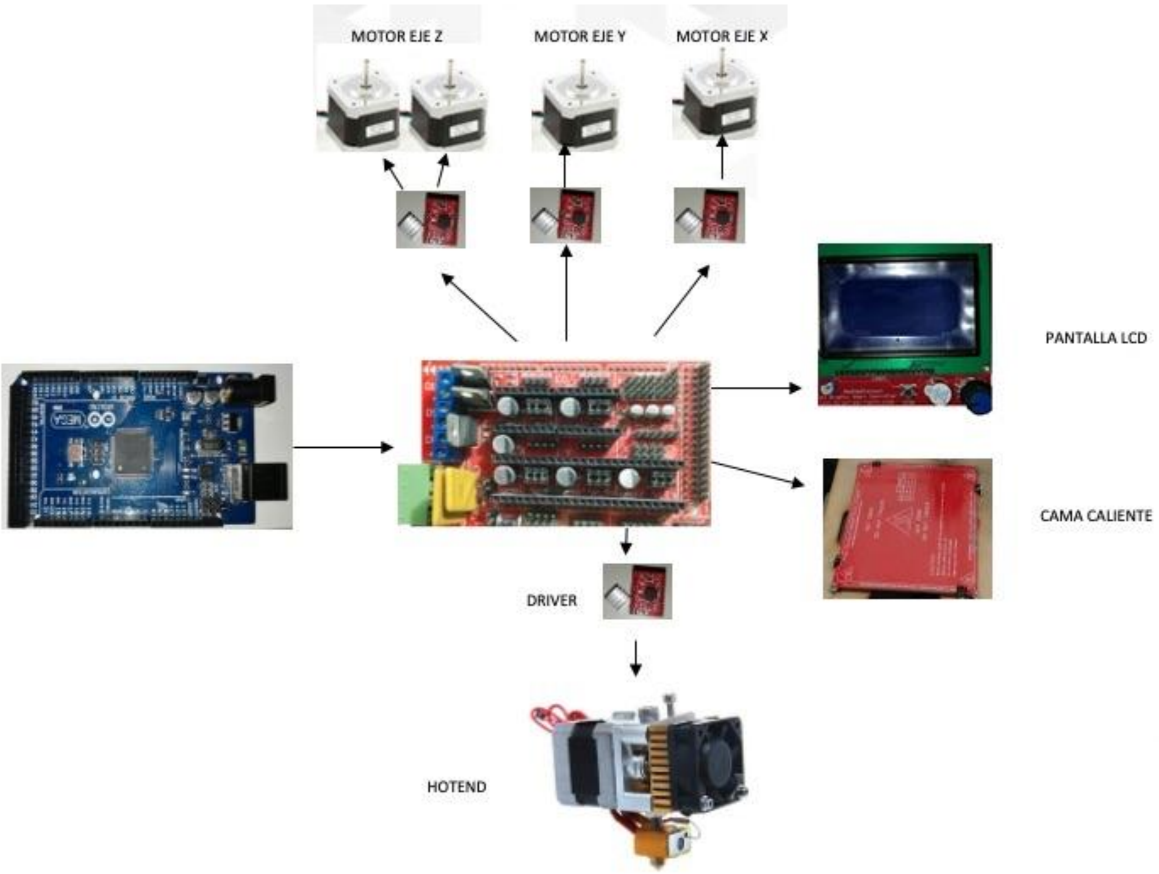

Fig. 7. Electronic schematic used for the fused deposition 3D printer.

An Arduino mega board and a Ramps 1.4 were used. The Ramps card is the element in charge of executing the instructions of the Arduino card and interconnecting all the necessary components to control the printer, giving the stages of power control and protection to avoid overloads or short circuits. NEMA 17 motors were used and a Pololu A4988 Driver was used to control them. For the deposition of the material a hot bed made of bakelite was used together with a mirror to ensure that the deposition surface is as flat as possible. As an end effector a standalone direct extrusion *hotend* was used, which has a mk8 extruder connected to the block and nozzle by means of a throat that is responsible for guiding the filament so that it can be extruded. To control the printing area mechanical limit switches were used. Other elements required for the construction are described in Table 3.

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Table 3. Materials required for the construction of the fused deposition 3D printer.

Quantity	Name	Description
2	50 cm trapezoidal rods	Diameter 8 mm with nut
6	5/16" Stainless Steel Smooth Rods	To guide the X, Y, Z carriages
2	Radial Bearings 624 ZZ	To support the Z-axis trapezoidal rod.
11	8 mm linear bearings	lm8uu for Z axis 4 for X axis 3 and for Y axis 4
2	20 tooth pulley for 5 mm shaft reference gt2.	One for the X-axis motor and one for the Z-axis motor.
2	20 tooth pulley for 8 mm shaft reference gt2.	For Z-axis trapezoidal bars.
1	A 5 to 8 mm flexible coupling	For the Y-axis
8	35 mm M3 screws	To clamp the Y-axis corner pieces
3	Screws m3 35 mm	To fasten motor Y-axis part to the frame
4	Screws m3 12 mm	To clamp the Y-axis motor to the Y-axis motor part
9	15 mm M3 screws	To fasten the limit switch X-axis supports to the structure
8	20 mm M3 screws	For clamping linear bearing housings
8	20 mm M3 screws	To clamp the Y-axis part and clamp the belt
3	35mm M3 screws	To clamp the part Z-axis motor bracket
4	12 mm M3 screws	To fasten the motor to the part Z-axis motor bracket
2	40mm M3 screws	To fasten Z-Axis support Motor to the frame
2	40 mm M3 screws	For clamping Z-axis smooth rod
2	15 mm M3 screws	For fastening the trapezoid nut of the right X-piece
1	40 mm M3 screws	To tension the X-axis belt
2	15 mm M3 screws	For fastening the trapezoid nut of the left X-piece
4	25 mm M3 screws	To attach the motor to the left X-piece
1	35 mm M3 screws	To adjust the height of the left X-piece with the Z-axis limit switch
5	40 mm M3 screws	To attach electronic support to the structure
4	20 mm M3 screws	To fasten the fan to the electronic support piece
2	50 mm M3 screws	To fasten the electronic support cover with the electronic support part
1	40 mm M3 screws	For LCD display bracket
6	15 mm M3 screws	To attach the Arduino mega board with the electronics holder
4	40 mm M3 screws	To attach the extruder bracket to the structure
6	30 mm M3 screws	To fasten the extruders to the extruder support piece
4	70 mm M3 screws	To support the LCD case
4	35 mm M3 screws	For the warm bed
4	20mm and 20 turns springs	To level the hot bed

III. RESULTS

The cost of the 3D printer manufactured in this study was determined to be about $415. Table 4 lists the approximate prices in mid-2021 and the materials used to build the printer.

Table 4. List of materials used in the manufacture and their prices in the Colombian market.

Item	Name	Unit value	Quantity	Total value
1	Structural Steel Pipe (1x1 inch, 16 gauge)	32.000	2	64.000
2	NEMA 17 motor	62.000	5	310.000
3	Electronics kit (Arduino mega, Ramps, LCD, 4 drivers)	175.000	1	175.000
4	Extruder MK8	135.000	1	135.000
5	GT2 6 mm strap(meter)	6.000		30.000
6	Bearing 624zz	2.700	16	43.200
7	Linear Bearing	5.000	12	60.000
8	Toothed pulley	8.00 0	2	16.000
9	Elastic coupling	6.000	2	12.000
10	4-line wiring	94.900	1	94.900
11	Stainless Steel Bar 5/16 in.	15.000	5	75.000
12	Base spring	1.000	4	4.000
13	Screws	50.000	1	50.000
14	Trapezoidal rod 8 mm	38.000	2	76.000
15	End of stroke	5.000	6	30.000
16	Warm bed 20x20 cm	56.000	1	56.000
17	ATX power supply	20.000	1	20.000
18	NTC 100k sensor	3.700	1	3.700
19	Hot bed mirror	10.000	1	10.000
20	Plastic straps	8.000	1	8.000
21	Plastic spiral for cable covering	21.000	1	21.000
22	PLA Material	90.000	1	90.000
23	Manufacture of 3D parts	100.000	1	100.000
24	Additional Expenses	200.000	1	200.000
Total				1`682.000

The cost of materials is in Colombian currency, to make the conversion to dollars the following current equivalence is used: 1 dollar = 3900 Colombian pesos October 2021.

Unlike most Cartesian open source 3D printers, the 3D printer design implemented in this study (Figure 8) allows the hotbed to only move in the Z-axis and the lighter *Hotend to* move in the X-axis and Y-axis.

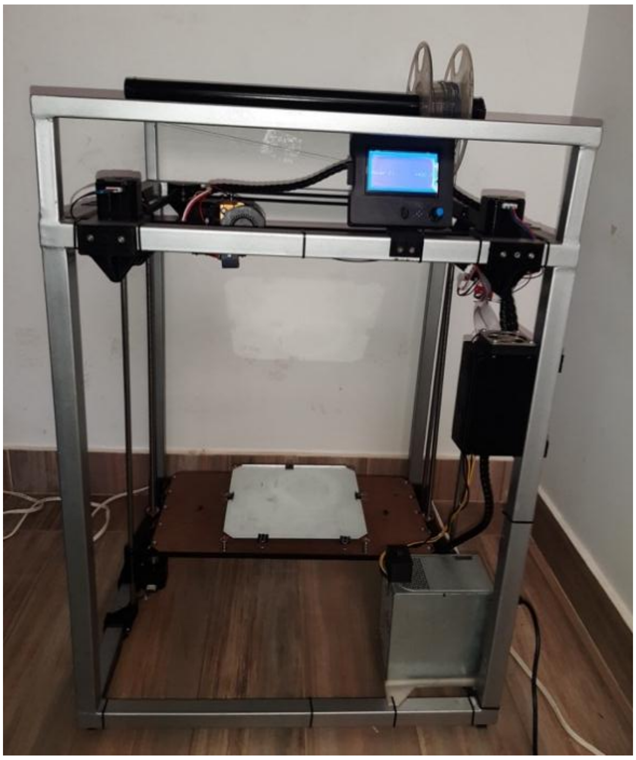

Figure 8. Overview of the Fused Deposition Modeling 3D Printer

The size of the frame (part 1) allowed for a Z-axis print area of 42 cm in height (Figure 9a), resulting in a print volume of 20328 cm3. Although a 22x22 cm hot bed was used for this case (Figure 9b), beds of up to 30x30 cm can be installed, which could increase the print volume up to 37800 cm3. Figure 10 shows the final prototype designed and built.

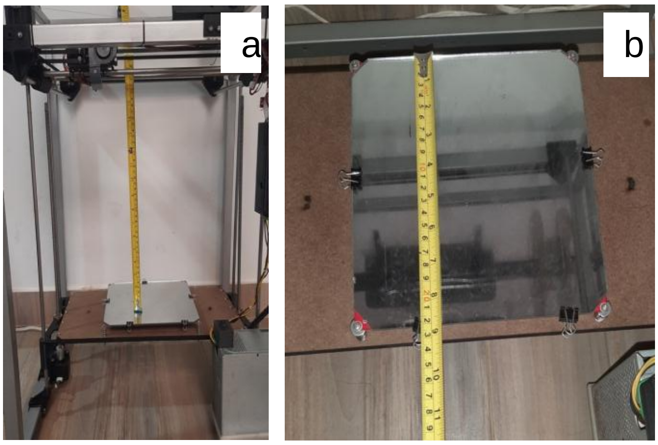

Figure 9. Printing area and volume: (a) printing volume obtained and (b) area of the 22x22 cm hot bed.

Figure 10. Final prototype.

IV. CONCLUSION

The cost value of the 3D printer designed and manufactured in this study represents a low value, considering that the cost of professional 3D printers in the market is around 11 thousand dollars.

The manufacture of the supports, carriages and guides using the MDF technique offered advantages in the cost of raw material and the low energy consumption of the equipment, so the parts obtained were more economical. In addition, PLA has good tensile strength, flexural strength, stiffness and is a biodegradable material, which makes the design of our printer more environmentally friendly.

The change in design implemented in this printer, together with the high rigidity and strength of the metal structure joined by welded joints, allows faster movements without vibration. This represents a significant advantage in terms of speed and print quality.

The size of the metal structure allows an increase of 46% in the printing volume, from 20328 cm3 to 37800 cm3.

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