

Development And Manufacture Of A Mechanical Hand Prosthesis Using 3d Printing With Pla And Tpu Filaments

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ABSTRACT

3D printing technology revolutionises the manufacture of mechanical hand prostheses, offering accessible and personalised solutions for people with upper limb amputations. This article analyzes how the use of materials such as polylactic acid (PLA) allows the production of lightweight, biocompatible and low-cost devices, which overcome economic and logistical barriers. The World Health Organization estimates that 300 million people require prosthetics or rehabilitation. However, high costs, ranging from \$5,000 to \$50,000, and poor infrastructure in developing countries, such as Ecuador, where more than 200,000 people need prosthetics, limit access to these devices. 3D printing, using the fused deposition modeling (FDM) technique, facilitates the rapid creation of transradial prostheses, functional fingers, and orthotics. Free software, such as Blender, SketchUp or SolidWorks, and in our case Fusion 360 allow you to design 3D models adapted to the needs of each user. Tools like Cura turn these designs into understandable codes for 3D printers. Computational simulation optimizes design by evaluating the performance and durability of prostheses before they are manufactured, ensuring functionality and ergonomics. The article highlights the use of the ELEGOO Neptune 4 Plus printer, which offers accuracy, speed and affordable costs of \$2.50 per 100 grams of material. This approach combines low cost, customization, and high performance, which improves the quality of life for users, especially in regions with limited resources. Initiatives such as donations from the Ministry of Health of Ecuador, which has delivered 11000 prostheses since 2017, and the work of foundations such as ROMP reinforce the importance of these innovative solutions to meet the demand for prosthetics.

Keywords: Accessible, PLA, TPU, Filaments

I.INTRODUCTION

Currently, the World Health Organization (WHO) estimates that approximately 0.5% of the world's population needs a prosthesis, orthosis or physical rehabilitation, which means that around 300 million people (Valero et al., 2019). This need is particularly critical in developing countries where working conditions and accidents increase the demand for prosthetics for those who have been seriously injured. There is a high demand for prostheses in the market, however, access to a quality one goes hand in hand with limited resources or other factors such as: (Demeco et al., 2023)

High cost. - The price of a prosthetic hand can range from \$5000 to \$50000, making them out of reach for many people. (Gomis López et al., 2013)

Lack of infrastructure. - In many developing countries, the lack of specialized centres and people distracts people who need prosthetics. Industrial innovation. (Kumar et al., 2023)

Geographical inequality. - People who live in difficult fields or places face great obstacles in obtaining appropriate prostheses. (Merizalde et al., 2023)

However, the needs for prostheses in a local or national context according to statistical data report that:

People with disabilities. - according to the Ministry of Public Health, there are more than 480000 people with disabilities in Ecuador. (Alejandra et al., 2024)

False needs. - More than 200000 people need a prosthesis from this group to improve their quality of life. (Camila et al., 2024)

Limited focus. - Despite the high demand, many people face difficulties in accessing prosthetics due to financial and logistical factors. For example, more than 15000 people cannot access a prosthesis in Ecuador due to its costs of \$8000. (The Universe, 2024)

In response to the lack of access to these prostheses, certain solutions have been given to the problems.

Image 1: Prostheses with 3D printing



Source: Authors

National production. - The country has implemented programs to produce approximately 300 months of prostheses using advanced technologies such as the CAD-CAM system, which allows for faster and more personalized production. (Acosta Calvo, 2021)

Donations from the Ministry of Health. - Since 2017, the Ministry of Public Health has donated 11,000 prosthetics to benefit people with limited resources (Cotopaxi Tech, 2022).

Foundations and organizations. - devices such as the ROMP Foundation have delivered only 239 prostheses in 2023 and are currently providing care to more than 600 patients expanding their work in several provinces through mobile clinics (Mas Solano, 2024).

Mechanical hand prostheses have emerged as fundamental solutions to improve the quality of life of people with upper limb amputations. These prosthetics, designed for the basic functions of the human hand, allow users to regain a certain degree of autonomy and take up daily activities (Reinoso Salazar & Villa Samaniego, 2023). Despite this, the production of available and functional prostheses remains a technical and financial issue. 3D printing with a wide wire (polylactic acid) has become a promising technology to overcome these barriers due to its ability to produce customized, light, and low-cost units. (Méndez Castillo, 2022). (Santiago Tunja Peñaloza Tutor & Carlos Moya Jiménez, 2025) In (Bennis, 2023) his research topic, he mentions that the development of 3D printing has transformed prosthetic design and production, allowing it to adapt to the specific needs of each user. A broad filament from permanent sources, such as cornstarch, is distinguished by its own light impression, biological compatibility, and reduced costs. (p. 11).

"These features make it an ideal way to develop mechanical prosthetics, especially in a low-income or low-user setting, requiring temporary devices before a permanent solution." (Arenas et al., 2023)

Despite advances, the design and functionality of mechanical prosthetic hands present significant challenges. Aspects such as ergonomic design, ability to move, and durability of the material need to be considered. In this context, computational simulation plays a crucial role, making it possible to analyse and optimise the performance of prostheses before they are physically manufactured. Through motion simulations and stress analysis, it is possible to identify critical areas and improve the design to ensure its functionality. (Sánchez Véliz et al., 2024)

(Serna Edgar, 2017) he mentions in his book that there are currently several companies dedicated to the design of free software for good quality 3D modeling; the wide variety of software such as; Blender, Sketchup, OpenSCAD, SolidWorks, Autocad among others, allows the user to choose the program at their convenience and thus start creating a digital design. On the other hand, the design of a 3D model requires a conversion from an STL format to a gcode language understandable by the 3D printer to carry out the printing process; For this step, software such as; Slic3r or Ultimaker's Cure. (Autodesk, 2025) (Ultimaker, 2025)

Definition and particularities of the implementation of 3D printing in limb prostheses

3D-Printed prosthetics are artificial devices designed to replace the body's limb or part of three-dimensional (3D) printing technology using plastic materials in the form of filament, this type of prosthesis consists of a layer of FDM (Fused Deposition Modeling) technology, which allows you to adjust, low cost and fast production. (Almeida Pozo, 2021)

Common applications in the manufacture of prosthetic limbs

Prosthesis of the hand (transradial)

Functional fingers

Splashes and orthoses (immobilization support)

Cosmetic prosthesis (for non-functional visual replacement)

Functional adjustments (e.g., grippers or gripping tools)

Prosthesis development using 3D printers

From the background reviewed, we enter a dilemma that many people do not have a prosthesis mainly due to cost, which is why the manufacture of such a prosthesis in PLA and TPU filament is developed (Zumba-Novay & Merizalde-Salas, 2023).

Image 2: CAD design software

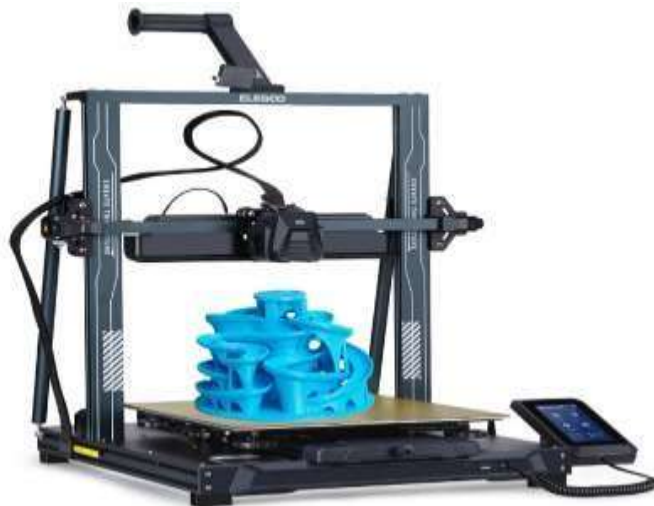


Source: (Velasco, 2022)

3D printer selection (ELEGOO Neptune 4 plus)

The 3D printer used is considered high performance which will provide us with speed, precision, versatility, adaptability and mainly affordable printing costs of approximately \$2.50 per 100 grams. (Díaz, 2023)

Image 3: ELEGOO Neptune 4 Plus 3D Printer



Source: (Díaz, 2023)

Table 1: Printer Specifications (ELEGOO Neptune 4 Plus)

Print volume	320x320x385 mm
Recommended print speed	250 mm/s

Processor	64-bit, quad-core 1.5 GHz ARM.
Compatible filaments	PLA, TPU, PETG, ABS, ASA, Nylon
File Transfer	WiFi, Wi-Fi, USB
Power	400 W

Print Specifications

Table 2: Printing Specifications

Finger and palm print with filament	PLA marca SUNLU
Color	Blue Gray
Diameter	1.75mm
Density	1.22 g/cm ³
Wedding temperature	215°C
Bed temperature	65°C
Layer Height	0.6mm

Filaments that can be used for denture printing

PETG. - This filament combines the advantages of PLA and ABS, providing better mechanical strength, flexibility and excellent bonding between layers, it also shows greater resistance to moisture and some chemicals. It is a safe alternative for external prostheses that need durability without sacrificing ease of printing (Velasco et al., 2022a). Unlike PETG, ABS, which is characterized by its hardness and resistance to shocks, is used in prostheses that require more functionality or in mechanical components, although it demands closed printers and good ventilation due to the vapors that are released during its printing process. (Velasco et al., 2022)

ASA. - It is an advanced version of ABS, it maintains its mechanical characteristics, but provides better protection against UV radiation and weather conditions, making it perfect for prostheses or objects that will be used outdoors or under sunlight. (Briceño-Martínez et al., 2019)

Nylon. - On the other hand, Nylon is one of the most resistant and durable materials; although it is flexible, its robustness makes it an ideal choice for moving components, gears or prostheses that must withstand significant mechanical loads. Despite this, its printing process is more complicated, as it needs high temperatures and special care with humidity, since it has the tendency to absorb water from the environment. (Lee et al., 2022)

PLA. - (polylactic acid) stands out as one of the most widely used materials due to its simple printing, low price, and biodegradable nature. However, its limited ability to withstand high temperatures and mechanical pressures makes it a suitable choice only for prostheses that are aesthetic, illustrative or temporary. (Guzmán et al., 2022)

TPU. - (thermoplastic polyurethane) is a filament that is characterized by its flexibility and elasticity, being ideal for creating components that need shock absorption or that will be in direct contact with the skin, such as pads, adapters or protective covers. (Urcuango Conumba, 2023)

Advantages of 3D denture printing

3D printing has revolutionized the production not only of prostheses, but rather it gives the advantage of designing, customizing or in turn downloading any desired shape from

software, in turn it is a technology that in this case study decreases prices significantly being accessible to populations with fewer resources or in turn provides more options for people who have difficulties of this type. (Guzmán Anrango & Valenzuela Maila, 2023) One of the most important features is customization. 3D printing facilitates the creation of prostheses that perfectly fit the dimensions, requirements and anatomy of each person, which increases comfort, functionality and integration with the body. (Siegel et al., 2024) Additionally, the digital method allows for quick modifications to the design before proceeding with printing, which is especially useful for growing pediatric patients or those with non-standard amputations.

Another considerable advantage is its low cost compared to prostheses made using traditional methods. Thanks to the availability of inexpensive materials such as PLA, PETG or TPU, and the use of printers that are inexpensive, it is possible to manufacture functional devices at a fraction of the price of a conventional prosthesis. This makes it easier for a greater number of people, mainly in low-income communities or in developing countries, to access solutions that improve their mobility. (Rossi & Chown, 2025) (Marcillo Parrales et al., 2021)

Speed in production is also a highlight. While traditional dentures may take weeks or months to be ready, a 3D printed denture can be designed and printed in just a few days. This speed allows you to deal with medical emergencies or carry out continuous tests without long waits. (Gorman et al., 2021) (Tao et al., 2019)

In addition, 3D printing drives innovation and local development, as teams of designers, doctors, and engineers can collaborate directly to constantly improve devices, experiment with new shapes, and adapt to specific conditions. This also promotes education and community involvement, empowering new designers, technicians and educational institutions. Haga clic o pulse aquí para escribir texto.

Image 4: 3D printed prosthetic hand



Source: Authors

3D printing of prostheses provides benefits such as customization, cost reduction, reduced manufacturing times and greater accessibility, becoming a powerful tool to change the lives of people with amputations or physical disabilities. (Diment et al., 2017) This article analyzes morphometric variables, such as palm circumference, width and length of the dominant hand, subsequently carrying out a statistical study based on these factors, from which approximate measurements have been obtained for the development, modeling and manufacture using the ELEGOO Neptune 4 Plus printer using PLA and TPU filaments. which were selected due to their low cost, versatility and easy acquisition in the market.

II. METHODOLOGY

The study took an experimental approach focused on the development, modeling, and fabrication of a mechanical prosthetic hand, using 3D printing with PLA filament. The research was divided into three stages; computational design, additive manufacturing and functional validation. The preliminary validation was carried out first with a standard anatomical model and then with an adult volunteer who did not present pathologies in the upper extremity. (Pérez Mora, 2023). Inclusion criteria: People over 18 years of age. Have no musculoskeletal conditions in the dominant upper extremity. Exclusion criteria: Having amputations that make it difficult for the prosthesis to adapt mechanically. Suffering from neuromuscular diseases or disorders that prevent functional interaction with mechanical devices.

The 3D design of the prosthesis was carried out in Autodesk Fusion 360, applying principles of biomechanics and anthropometry. The manufacture was made with an Elegoo Neptune Plus printer, using PLA filament and 1.75 mm TPU. (Mohammadi et al., 2020)

The printing parameters were set as follows; layer height of 0.2 mm, an infill of 25%, extrusion temperature at 200°C and bed temperature at 60°C. The assembly included additional components such as nylon laces, elastic bands, M3 screws, nuts and springs. For the surface finish, hand tools such as files, sandpaper, and precision scalpels were employed. (Gorman et al., 2021)

The functionality of the prosthesis was assessed by grasp tests with everyday objects such as cups, pencils, spheres and bottles. The ability of the fingers to open and close was measured using a mechanical thread traction system. Likewise, the total weight of the device, the manufacturing time, the volume of material used and the cost per unit were recorded. (Olivia Silvia D.J, 2012) .

The data obtained were analyzed using descriptive statistics, applying measures of central tendency (mean, median, mode) and dispersion (standard deviation, variance and interquartile range) to a set of key variables, including anthropometric dimensions of the hand such as palmar circumference, metacarpal width and total length. These variables were fundamental to evaluate the ergonomic fit of the design, as they directly influence the physical interaction with the prototype. Variables related to mechanical performance (such as structural rigidity and flexibility of printed material), manufacturing efficiency (print time, material consumption, and dimensional accuracy), and practical functionality (comfort of use, stress response, and anatomical adaptability) were even analyzed.

By researching, developing, and manufacturing a mechanical prosthetic hand that is functional, ergonomic, and affordable, using PLA and TPU filament 3D printing technology. The aim is to offer an accessible and customisable solution for people who have suffered an amputation in the distal part of an upper limb for those over 18 years of age as we have mentioned above.

Image 5: Hand average calculator.



Source: (Sullivan,2023)

Note. - The measurements of the hand were compared with the averages given by the Medical News Today calculator.

The study ensures that it can be fully replicated by offering open access to CAD files, print parameters, and assembly protocols in a well-documented digital repository, such as GitHub or Zenodo. The experimental conditions and technical specifications are described in great detail to ensure that other research groups can reproduce the results.

III. RESULTS

In the apparatus of results, we try to write all the statistical data such as the mean, median, mode, range, standard deviation, among others, mainly of the important measurements of the palm of the dominant or right hand, in this case we will have a number of 50 samples of both the length, width and circumference which have been obtained mainly from scientific articles dedicated to the manufacture and design of prosthetic hands and in our case specifically for adults over 18 years of age. The statistical calculation of these is important for an estimate of the dimensions to carry out 3D printing.

Table 3. Palm length measurements

Long	$x - u$	$(x - u)^2$
188,14	-2,61	6,80
186,72	-4,03	16,22
187,03	-3,72	13,82
194,24	3,49	12,19
193,44	2,69	7,25
193,97	3,22	10,38
185,97	-4,78	22,83
195,56	4,81	23,16
188,76	-1,99	3,95
188,59	-2,16	4,66
195,31	4,56	20,81
193,20	2,45	6,01
188,26	-2,49	6,19
187,41	-3,34	11,14

192,78	2,03	4,13
193,88	3,13	9,81
195,17	4,42	19,55
194,26	3,51	12,33
189,62	-1,13	1,27
190,83	0,08	0,01
194,44	3,69	13,63
187,51	-3,24	10,48
193,41	2,66	7,09
188,73	-2,02	4,07
190,42	-0,33	0,11
195,38	4,63	21,46
194,69	3,94	15,54
194,65	3,90	15,23
190,26	-0,49	0,24
191,78	1,03	1,07
187,51	-3,24	10,48
187,41	-3,34	11,14
192,41	1,66	2,76
189,53	-1,22	1,48
188,27	-2,48	6,14
186,15	-4,60	21,14
189,59	-1,16	1,34
192,03	1,28	1,64
186,26	-4,49	20,14
187,16	-3,59	12,87
194,19	3,44	11,85
185,93	-4,82	23,21
193,63	2,88	8,31
190,15	-0,60	0,36
194,47	3,72	13,85
187,29	-3,46	11,96
187,42	-3,33	11,08
191,48	0,73	0,54
189,70	-1,05	1,10
192,41	1,66	2,76

Table 4: Palm circumference measurements

Circumference	$x - u$	$(x - u)^2$
47,53	0,33	0,11
46,53	-0,67	0,46
45,74	-1,46	2,15

49,34	2,14	4,56
48,48	1,28	1,63
44,47	-2,73	7,48
48,95	1,75	3,05
50,53	3,33	11,06
51,20	4,00	15,96
47,52	0,32	0,10
50,38	3,18	10,08
51,01	3,81	14,48
48,87	1,67	2,77
50,65	3,45	11,87
46,81	-0,39	0,16
46,22	-0,98	0,97
50,98	3,78	14,25
47,28	0,08	0,01
48,75	1,55	2,39
51,89	4,69	21,95
45,78	-1,42	2,03
42,61	-4,59	21,11
42,13	-5,07	25,75
45,42	-1,78	3,19
48,18	0,98	0,95
43,16	-4,04	16,36
46,50	-0,70	0,50
44,96	-2,24	5,04
49,50	2,30	5,27
51,09	3,89	15,09
42,05	-5,15	26,57
46,16	-1,04	1,09
42,44	-4,76	22,70
49,01	1,81	3,26
45,07	-2,13	4,56
48,54	1,34	1,78
50,88	3,68	13,51
47,78	0,58	0,33
51,19	3,99	15,88
50,95	3,75	14,03
42,49	-4,71	22,23
42,84	-4,36	19,05
45,61	-1,59	2,54
46,38	-0,82	0,68
46,68	-0,52	0,28
43,63	-3,57	12,78
50,88	3,68	13,51

42,46	-4,74	22,51
42,42	-4,78	22,89
50,32	3,12	9,70

Table 5: Palm width measurements

Width	$x - u$	$(x - u)^2$
108,24	-0,85	0,72
113,93	4,84	23,46
111,24	2,15	4,64
111,85	2,76	7,64
106,26	-2,83	7,99
109,79	0,70	0,50
109,74	0,65	0,43
108,97	-0,12	0,01
108,42	-0,67	0,44
104,61	-4,48	20,04
112,09	3,00	9,02
105,24	-3,85	14,79
110,52	1,43	2,06
106,59	-2,50	6,23
107,78	-1,31	1,71
107,27	-1,82	3,30
109,80	0,71	0,51
108,38	-0,71	0,50
107,37	-1,72	2,95
110,80	1,71	2,94
105,19	-3,90	15,18
111,89	2,80	7,86
104,97	-4,12	16,94
113,41	4,32	18,70
108,55	-0,54	0,29
108,32	-0,77	0,59
109,89	0,80	0,65
109,64	0,55	0,31
105,13	-3,96	15,65
113,78	4,69	22,03
106,29	-2,80	7,82
108,80	-0,29	0,08
109,91	0,82	0,68
108,45	-0,64	0,40
108,47	-0,62	0,38
106,60	-2,49	6,18
107,45	-1,64	2,68

110,61	1,52	2,32
114,50	5,41	29,31
106,70	-2,39	5,69
110,23	1,14	1,31
106,25	-2,84	8,04
108,86	-0,23	0,05
106,87	-2,22	4,91
108,47	-0,62	0,38
113,19	4,10	16,84
112,55	3,46	12,00
113,51	4,42	19,57
112,19	3,10	9,63
104,75	-4,34	18,80

Note. - $\sum (x - \bar{x})^2$ where x is the actual measure minus the arithmetic mean, which are used to find the standard deviation and other variables. $x - \bar{x}$

Central Trend Measures

We will include the measurements of the parts of the right dominant hand such as the length, width and circumference of the palm, as well as the measurements of the index fingers, wrist perimeters, among others.

Arithmetic Mean - The mean or also known as the arithmetic average is the sum of all the measures divided by the amount of data added. (Quevedo, 2011)

Formula

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \text{ (ecuación 1) [31]}$$

In this case we will take into account the measurements of the circumference to show in the presentation.

Table 6: Palm length center trend measurements

N. DATA	50
MEDIA	190,75
MEDIUM	190,34
FASHION	187,41

Table 7: Palm width center trend measurements

N. DATA	50
MEDIA	109,09
MEDIUM	108,68
FASHION	108,47

Table 8: Measurements of central tendency of the circumference of the palm of the hand

N. DATA	50
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MEDIA	47,20
MEDIUM	47,40
FASHION	50,88

Mode. - The mode of a distribution is defined as the value of the variable that is repeated the most. (Quevedo, 2011)

Median. - The median is defined as the value that is in the central position, as long as the data is ordered from highest to lowest. In the event of: (Pereira-González & Basantes-Andrade, 2023)

- If there is an odd amount of data → the median is the value of the medium.
- On the contrary, if there is an even amount → the two central values are averaged.

$$\text{Mediana(impar)} = x_{\frac{n+1}{2}} \quad (\text{ecuación 2}) [29]$$

$$\text{Mediana (par)} = \frac{x_{\frac{n}{2}} + x_{\frac{n+1}{2}}}{2} \quad (\text{ecuación 3}) [29]$$

Mean Axis. - It is the imaginary or real line that divides a set of data into two symmetrical parts, generally related to the median. (Salazar et al., 2018)

For example, in the box and whiskers diagram it is the line that crosses the center depending on the value of the median.

Mid-Range. - Indicates the point that is right in the middle between the lowest and highest value of the data set, divided by two. (Sifuentes et al., 2008)

$$\text{Rango medio} = \frac{x_i + x_f}{2} \quad (\text{ecuación 4}) [35]$$

Frequency measurements

Absolute Frequency

It is the number of times a specific value is repeated within a dataset. It is the most basic way of counting how common a piece of data is within a sample or population. This value has no units and is represented by the letter f . It helps to identify which values are most frequent, allowing information to be organized more clearly. (Salazar et al., 2018) f

Formula

$$f_i = \text{número de veces que aparece el dato } x_i \quad (\text{ecuación 4}) [35]$$

Cumulative absolute frequency

It is the progressive sum of absolute frequencies. It allows you to know how much data there is from the first value to a specific value within the distribution. This type of frequency is very useful for constructing graphs such as the warhead, and for interpreting how many values are below or equal to a certain point. (Almeida Pozo, 2021)

$$F_i = f_1 + f_2 + \dots + f_i = \sum_{j=1}^i f_j \quad (\text{ecuación 5}) [3]$$

Relative frequency

It is the quotient between the absolute frequency of a value and the total data. It represents the proportion or percentage that each value represents with respect to the

total. It is used to compare values in different data sets, as it allows the information to be standardized. It is expressed as a decimal fraction or percentage. (Pereira-González & Basantes-Andrade, 2023)

$$r_i = \frac{f_i}{n} \text{ (ecuación 6) [29]}$$

Graphical Representations of Frequency

They are visual tools that allow the frequency distribution to be clearly and quickly represented. They help identify patterns, most common values, and trends.

Most common types:

1. **Table of frequencies.** - Sorts the data with their respective frequencies.
2. **Bar Chart.** - Displays the absolute frequency of each value as a vertical bar.
3. **Histogram** - Similar to a bar graph, but used for continuous data.
4. **Pie chart (pie).** - Ideal for representing relative frequencies as percentages.
5. **Frequency polygon.** - Joins the midpoints of the bars.
6. **Warhead** - Represents the cumulative frequency, showing how the data accumulates.

Figure 6: Histogram and frequency polygon of palm circumference measurements
Source: Authors

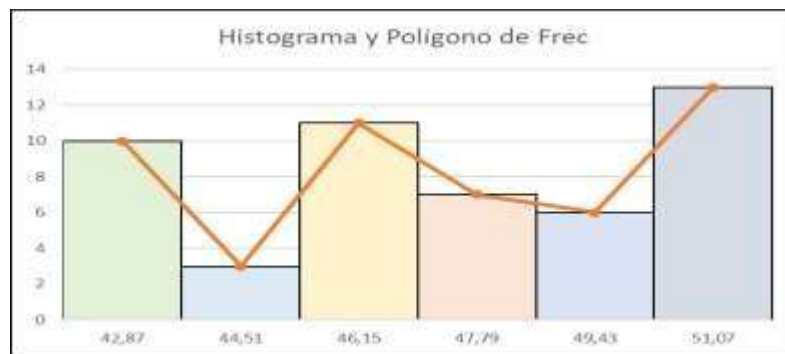
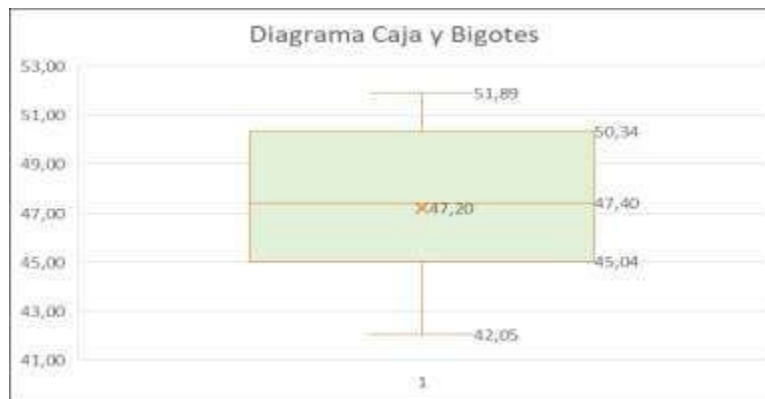


Image 7: Pastel diagram of the palm circumference measurements
Source: Authors



Image 8: Box and whiskers diagram of palm circumference measurements
Source: Authors



Dispersion measures

Dispersion measures are statistical instruments that show how far apart the data are from each other and in relation to a central value such as the average. They make it easier to understand the variation or uniformity of a data set. (Mayorga-Ponce et al., 2021)

Range

It represents a way of measuring variability that reflects the distance between the highest and lowest number in a data set. It indicates the degree of dispersion of the data within a given range. (Cuellar et al., 2021)

$$\text{Rango} = \text{valor máximo} - \text{valor mínimo} \text{ (ecuación 7) [20]}$$

Variance

It's a way of measuring how scattered the data is relative to the average. As the variance increases, so does the dispersion of the data. (Mayorga-Ponce et al., 2021)

For a population:

$$\sigma^2 = \frac{\sum (x_i - \mu)^2}{N} \text{ (ecuación 8) [24]}$$

For a sample:

$$s^2 = \frac{\sum (x_i - \bar{x})^2}{n - 1} \text{ (ecuación 9) [24]}$$

Where:

x_i - each value of the set

μ - Average population

$\bar{x}$ - sample mean

N - total number of data in the population

n - total number of data in the sample

Standard deviation

It is a way of quantifying the dispersion that shows, on average, how far the data is separated from the mean. It is obtained by calculating the square root of variance and is presented in the same units as the data, which makes it more understandable. (Mayorga-Ponce et al., 2021)

For a population

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \text{ (ecuación 10) [24]}$$

For a sample

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n - 1}} \quad (\text{ecuación 11}) [24]$$

Coefficient of variation

It is an indicator of relative dispersion that shows how much the standard deviation represents in relation to the mean, and is expressed as a percentage. It is used to compare variability between different data sets, even if they have different units or scales. (Mayorga-Ponce et al., 2021)

$$CV = \left(\frac{\text{Desviación estándar}}{\text{Media}} \right) \times 100\% \quad (\text{ecuación 12}) [24]$$

3D printing results

Image 9: Prototype of the hand in 3D printing
Source: Authors

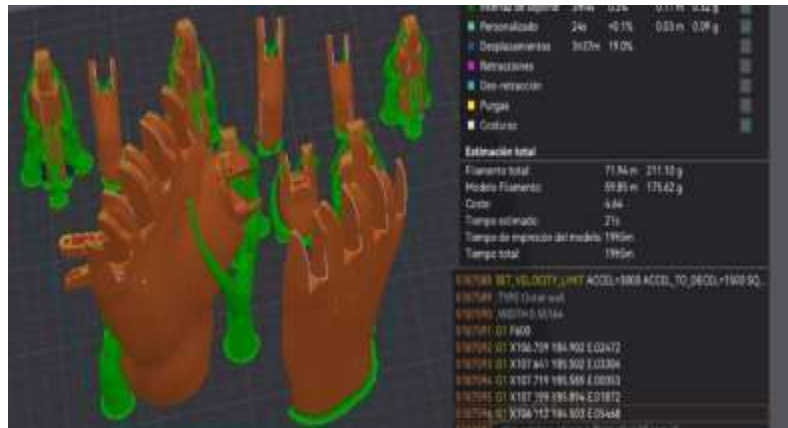


Image 10: Hand holding a thermos flask
Source: Authors



Image 11: Hand holding a
Source: Authors

**Table 9: Print Results**

Total filament used	71.94m 211.10g
Filament model	59.85 m 175.62g
Cost	\$4.64
Estimated time	21s
Model print time	19h 5min
Total Time	19h 5min

IV. DISCUSSION AND ANALYSIS

Interpretation of Results

The estimated weight of the printed prosthesis is 212g excluding the electronic elements. PLA is preferred as a manufacturing material because it is versatile and has an affordable price in the national market of approximately 22 US dollars per 1kg of material, additionally it is combined with TPU filament which has been chosen due to the elasticity properties that the material presents, which helps the correct functioning of the hinges manufactured with it.

Comparison with Conventional Prostheses

The estimated price for printing without any markup, as well as based on the printing time and the amount of material used is \$4.64. It should be noted that with a future study, myoelectric sensors can be implemented, which would shoot up the sale price exponentially. The price of a prosthesis with similar characteristics with the implementation of these sensors is around \$20000 according to (Fang et al., 2020). Now in comparison to its weight the manufactured prosthesis has 212 g which makes it an accessory that causes less fatigue to the user due to the weight of the material, compared to metal or aluminum based prostheses that weigh between 600g and 1500g respectively (Miranda, 2021) .

Limitations of the Study

Difficulty. - The use of supports is mandatory for specific parts of the parts that have overhangs, which compromises the surface finish of these parts in the areas of contact with the supports. Regarding the limitations of measurement, there are none since manual prostheses do not have very long dimensions.

Recommendations and Future Work

One of the main items to investigate in the future is the greater flexibility that can be granted to certain filaments for 3D printing, these characteristics will improve comfort in the field of limb flexibility for each user, as well as maintaining an approximate of the initial costs without skyrocketing prices.

It is recommended that these prostheses be validated prior to use with tests assimilative to a real environment such as blows, cracks, exposure to high or low temperatures before being delivered to their wearers or in turn if serial manufacturing is desired before delivering a whole batch. On the other hand, as mentioned above, PLA is a material that is used for provisional or trial time prostheses, for their longer duration there should be alloys since it is a fairly good and accessible material.

Consistency with the Objectives of the Study

Finally, it was possible to complete the manufacture of the prosthesis with PLA and TPU filaments, which as a main objective has been to lower the cost of the manual prosthesis, thus being more accessible to people with fewer economic resources or in turn, to everything that wants and needs to try new alternatives with different materials. as well as mostly comfortable and versatile.

V. CONCLUSIONS

3D printing technology, which uses filaments such as PLA and TPU, represents a significant advance in the manufacture of mechanical prosthetic hands, as it allows the production of customized, lightweight and low-cost devices. This approach not only reduces the economic barriers that limit access to traditional prosthetics, but also offers solutions that can be tailored to the specific needs of each user, especially in regions with limited resources. The combination of accessible design tools, such as Fusion 360, and the efficiency of printers such as the ELEGOO Neptune 4 Plus, makes it possible to create functional prostheses in a short time, improving the quality of life for amputees. The study demonstrates that the methodology based on computational design, additive manufacturing and functionality testing guarantees the technical feasibility and replicability of the prosthetic manufacturing process. Validation through grip tests and analysis of parameters such as weight, durability and ergonomics confirm that these devices meet the basic requirements for everyday use. Similarly, the availability of detailed CAD files and protocols in open repositories facilitates the adoption of this technology in other contexts, promoting local innovation and collaboration between healthcare professionals, engineers, and designers. Thus, 3D printing is consolidating itself as a sustainable and scalable alternative to meet the growing global demand for prostheses.

VIII. BIBLIOGRAPHY

1. Acosta Calvo, S. L. (2021). Design and manufacture of a mechanical hand prosthesis. <http://rein.umcc.cu/handle/123456789/1861>
2. Alejandra, D., Espinoza, A., Gissele, E., & Romero, A. (2024). POLYTECHNIC SCHOOL OF CHIMBORAZO "PLANNING AND CONTROL SYSTEM FOR THE.
3. Almeida Pozo, L. C. (2021). Mechanical design of 24 prototypes of scalable hand prostheses for children aged 6 to 12 using CAD software.
4. Arenas, R. D. M., Cerna, A. N. F., Ramos, M. R. M., Serón, G. I. E., La Chira Loli, M. B., & Leon, G. H. C. (2023). Virtual education as a science: trends in computer tools. <https://doi.org/10.31219/OSF.IO/EJBQK>
5. Autodesk. (2025). Autodesk Fusion | Cloud-based CAD, CAM, CAE and 3D PCB Software | Autodesk. <https://www.autodesk.com/es/products/fusion-360/overview>

6. Bennis, M. (2023). Opportunities of additive manufacturing in orthosis production. <https://upcommons.upc.edu/handle/2117/395143>
7. Briceño-Martínez, B. J., Llanes-Cedeño, E. A., Rocha-Hoyos, J. C., Chamba, E., Cuasapud, D., Cárdenaz-Yáñez, A., Briceño-Martínez, B. J., Llanes-Cedeño, E. A., Rocha-Hoyos, J. C., Chamba, E., Cuasapud, D., & Cárdenaz-Yáñez, A. (2019). 3D Printing Technologies: FDM and Polyjet Evaluations in Automotive Auto Parts Manufacturing. *UTE Approach*, 10(3), 13–29. <https://doi.org/10.29019/ENFOQUEUTE.V10N3.414>
8. Camila, A., Velasquez, P., Vera, A. S., Presidente, L., Rolando, E., Briceño, P., Omar, D., & Carranza, P. (2024). Design and construction of myoelectric prostheses with 3D printing to compensate for lost functionality in adults due to transradial amputation. <http://tesis.usat.edu.pe/handle/20.500.12423/7478>
9. Cotopaxi tech. (2022). Vista de Vol. 2 Núm. 2 (2022): Cotopaxi Tech. <https://ojs.isuc.edu.ec/index.php/cotopaxitech/issue/view/3/4>
10. Cuellar, J. S., Plettenburg, D., Zadpoor, A. A., Breedveld, P., & Smit, G. (2021). Design of a 3D-printed hand prosthesis featuring articulated bio-inspired fingers. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 235(3), 336–345.
11. Díaz Guilcamaigua, M. I. (2023). Construction and evaluation of optimal parameters for the 3D printing of a mechanical prosthetic hand and wrist: machining of parts with polymers. <http://bibdigital.epn.edu.ec/handle/15000/24875>
12. Diment, L. E., Thompson, M. S., & Bergmann, J. H. M. (2017). Three-dimensional printed upper-limb prostheses lack randomised controlled trials: A systematic review. *Prosthetics and Orthotics International*, 42(1), 7. <https://doi.org/10.1177/0309364617704803>
13. Design and manufacture of ultralight exoskeletons. (n.d.). Retrieved June 4, 2025, from <https://rinfi.fi.mdp.edu.ar/handle/123456789/505>
14. The universe. (2024). "There are patients who wait five or ten years", the complex process to get a prosthesis in Ecuador | Ecuador | News | The Universe. <https://www.eluniverso.com/noticias/ecuador/acceso-protesis-ecuador-personas-con-discapacidad>
15. Fang, L., Yan, Y., Agarwal, O., Kang, S. H., Yao, S., & Seppala, J. E. (2020). Effects of Environmental Temperature and Humidity on the Geometry and Strength of Polycarbonate Specimens Prepared by Fused Filament Fabrication. *Materials* 2020, Vol. 13, Page 4414, 13(19), 4414. <https://doi.org/10.3390/MA13194414>
16. Gomis López, J. M., Jiménez Zarco, A. I., & Luis Tomás, M. (2013). The State of the World's Children 2013: Children with disabilities. <https://repositorio.minedu.gob.pe/handle/20.500.12799/1818>
17. Gorman, N., Feng, J., & Marin Pareja, S. Y. (2021). Enhancing Prosthetic Hand Functionality with Elastic 3D-Printed Thermoplastic Polyurethane. *Lecture Notes in Networks and Systems*, 263, 183–190. https://doi.org/10.1007/978-3-030-80744-3_23
18. Guzmán, A. G., Cortés, G., Cortés, C., Cuatzo Itzcua, M., Antonio, G., & Flores, B. (2022). Design and construction of an extruder to obtain recycled PLA filament. *Difu100ci@, Journal of Scientific Dissemination, Engineering and Technologies*, 16(3), 126–131. <http://difu100cia.uaz.edu.mx/index.php/difuciencia/article/view/252>
19. Guzmán Anrango, D. V., & Valenzuela Maila, W. A. (2023). Design and assembly of a low-cost filament inkjet 3D printer. <https://repositorio.utn.edu.ec/handle/123456789/15044>
20. Julián Manuel Valero González Directors Dr. Ana Alejandra Laborda Soriano Pedro José Satústegui Dordá, A. (2019). Master's Thesis Systematization of recycled prostheses. <http://zagan.unizar.es>

21. Lee, M. Y., Lee, S. H., Leigh, J. H., Nam, H. S., Hwang, E. Y., Lee, J. Y., Han, S., & Lee, G. (2022). Functional improvement by body-powered 3D-printed prosthesis in patients with finger amputation: Two case reports. *Medicine*, 101(25), e29182.
<https://doi.org/10.1097/MD.00000000000029182>
22. Marcillo Parrales, K. G., Mero Lino, E. A., & Ortíz Hernández, M. M. (2021). 3D printing as a development axis in Industry 4.0. *Scientific Series of the University of Computer Sciences*, ISSN-e 2306-2495, Vol. 14, No. 4, 2021 (Issue dedicated to: : April), pp. 151-160, 14(4), 151–160.
<https://dialnet.unirioja.es/servlet/articulo?codigo=8590504&info=resumen&idoma=SPA>
23. Mas Solano, C. (2024). TOPOLOGICAL ANALYSIS AND OPTIMIZATION OF BIOMECHANICAL ELEMENTS.
<https://repositorio.comillas.edu/xmlui/handle/11531/83504>
24. Mayorga-Ponce, R. B., Reyes-Torres, S. B., Baltazar-Téllez, R. M., & Martínez-Alamilla, A. (2021). Dispersion Measures. *Education and Health Scientific Bulletin Institute of Health Sciences Autonomous University of the State of Hidalgo*, 9(18), 77–79.
<https://doi.org/10.29057/ICSA.V9I18.7115>
25. Méndez Castillo, J. A. (2022). Dynamics of the medical, industrial and financial complex in physical rehabilitation in the General Social Security System in health (1993-2015): The case of hearing aids. 1.
<https://dialnet.unirioja.es/servlet/tesis?codigo=329400&info=resumen&idioma=ENG>
26. Miranda, C. (2021). Design and manufacture of ultra-lightweight exoskeletons.
<http://rinfi.fi.mdp.edu.ar/xmlui/handle/123456789/505>
27. Mohammadi, A., Lavranos, J., Zhou, H., Mutlu, R., Alici, G., Tan, Y., Choong, P., & Oetomo, D. (2020). A practical 3D-printed soft robotic prosthetic hand with multi-articulating capabilities. *Plos One*, 15(5), e0232766–e0232766.
<https://doi.org/10.1371/JOURNAL.PONE.0232766>
28. [28] Olivia Silvia D.J. (2012). NATIONAL UNIVERSITY OF CÓRDOBA-FACULTY OF ARCHITECTURE, URBANISM AND DESIGN-2012 THE TEACHING OF DESIGN AND THE ROLE OF THE INDUSTRIAL PRODUCT AS A COMPONENT OF CULTURAL HERITAGE. Articulation Strategies between the Project Area and the Social Sciences Area.
29. Pereira-González, L. M., & Basantes-Andrade, A. (2023). Probability and statistics. UTN Publishing.
30. Pérez Mora, S. R. (2023). Design and construction of a biomechanical prototype arm-hand by means of a muscle sensor.
<https://repositorio.uisek.edu.ec/handle/123456789/4978>
31. Quevedo, F. (2011). Measures of central tendency and dispersion. *Medwave*, 11(03).
<https://doi.org/10.5867/MEDWAVE.2011.03.4934>
32. Reinoso Salazar, S. K., & Villa Samaniego, C. D. (2023). Design and construction of a prototype of a prosthesis for transhumeral amputation of two degrees of freedom by voice control and activation by ALEXA. Polytechnic High School of Chimborazo.
<https://dspace.esPOCH.edu.ec/handle/123456789/22180>
33. Rial Boubeta, Antonio., & Varela Mallou, J. (2008). Practical statistics for research in health sciences: exercises solved with G-Stat. 1–344.
https://books.google.com/books/about/Estad%C3%ADstica_pr%C3%A1ctica_para_la_investiga.html?hl=es&id=5KdXV7lxHIEC
34. Rossi, R., & Chown, G. (2025). Hand function and quality of life with a 3D-printed prosthesis: A case report. *Journal of Hand Therapy*.
<https://doi.org/10.1016/J.JHT.2024.12.004>,

35. [35] Salazar, C., Castillo, S. del, & others. (2018). Basic Fundamentals of Statistics. Unidentified publisher.
36. Sánchez Véliz, M. J., Jara Cadena, M. S., & ESPOL. IFMCP. (2024). Design of arm prostheses based on the classification of myoelectric signals using artificial intelligence. <http://www.dspace.espol.edu.ec/handle/123456789/65661>
37. Santiago Tunja Peñaloza Tutor, E., & Carlos Moya Jiménez, R. (2025). Development of hand prostheses manufactured using 3D printing technology for workers with finger amputations due to occupational accidents. <https://repositorio.uta.edu.ec/handle/123456789/43631>
38. Serna Edgar. (2017). DEVELOPMENT AND INNOVATION IN ENGINEERING Editorial IAI. <http://fundacioniai.org>
39. R., Harwood, J. K., Lau, A. C., Brenneis, D. J. A., Dawson, M. R., Pilarski, P. M., & Schofield, J. S. (2024). A performance evaluation of commercially available and 3D-printable prosthetic hands: a comparison using the anthropomorphic hand assessment protocol. *BMC Biomedical Engineering* 2024 6:1, 6(1), 1-14. <https://doi.org/10.1186/S42490-024-00086-W>
40. Sifuentes, N., Violeta, A., & Ponce, M. (2008). Applied inferential statistics. Universidad Nacional Mayor de San Marcos. Lima, Peru.
41. Average hand size: adults, children, and relationship to height. (n.d.). Retrieved June 4, 2025, from <https://www.medicalnewstoday.com/articles/average-hand-size>
42. Tao, Y., Shao, J., Li, P., & Shi, S. Q. (2019). Application of a thermoplastic polyurethane/polylactic acid composite filament for 3D-printed personalized orthosis. *Materiali in Tehnologije*, 53(1), 71-76. <https://doi.org/10.17222/MIT.2018.180>
43. Ultimaker. (2025). UltiMaker: Professional 3D printers that empower innovation. <https://ultimaker.com/es/>
44. Urcuango Conumba, M. V. (2023). Evaluation of the additive manufacturing process by means of 3D printing of the mechanical parts of a prototype of a human artificial heart in TPU and PLA filament for mold making: 3D printing of polymers. <http://bibdigital.epn.edu.ec/handle/15000/24345>
45. Velasco, M. A., Quevedo, Y. N., & Bonilla, C. A. (2022). Topic A1 Materials: Additive manufacturing Determination of mechanical properties at tension and compression of PETG processed by fused filament manufacturing.
46. Zumba-Novay, E., & Merizalde-Salas, A. (2023). Optimization of the manufacturing process by 3D printing of the glass lift handle in Chevrolet Aveo Family. *Revista Repique*, 5(1), 2550-6676. <https://doi.org/10.31876/REPIQUE.V5I1.204>
47. Demeco, A., Foresti, R., Frizziero, A., Daracchi, N., Renzi, F., Rovellini, M., Salerno, A., Martini, C., Pelizzari, L., & Costantino, C. (2023). The Upper Limb Orthosis in the Rehabilitation of Stroke Patients: The Role of 3D Printing. *Bioengineering*, 10(11), 1256. <https://doi.org/10.3390/BIOENGINEERING10111256>
48. Kumar, M., Krishnanand, Varshney, A., & Taufik, M. (2023). Hand prosthetics fabrication using additive manufacturing. *Materials Today: Proceedings*. <https://doi.org/10.1016/J.MATPR.2023.06.396>
49. Medical new today. (2019). Average hand size: adults, children, and relationship to height. https://www-medicalnewstoday-com.translate.google/articles/average-hand-size?_x_tr_sl=en&_x_tr_tl=es&_x_tr_hl=es&_x_tr_pto=tc
50. Merizalde-Salas, A., Zumba-Novay, E., & Peralta-Zurita, D. B. (2023). Alternative Material for the plastic injection molding of the Kia Rio's ventilation grille. *Interdisciplinary Scientific Journal Research and Knowledge*, 13(1), 1390-8146. http://revistasdigitales.utelvt.edu.ec/revista/index.php/investigacion_y_saberes/article/view/197/249