Development of low cost customized hand prostheses by additive manufacturing

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ABSTRACT: The main goal of this work was to develop a low cost, simple, functional and ergonomic hand prosthesis. The design and constructive solutions developed, successfully respond to the barriers imposed by the natural complexity of the human hand, resulting in a product where the ergonomic design is intimately linked to the function and shape of the prosthesis through a structural and mechanical design very close to the natural anatomy of the hand.

In this publication the development and production by additive manufacturing (AM) of a low cost mechanical prosthesis for the trans-radial level amputation of the upper limb, is described. The prosthesis has a very low cost production and can quickly reach people all around the world through AM, which is an emerging technology already available everywhere, namely low cost printers.

This work emerged from the e-NABLE project that aims to design and manufacture prosthetic hands in polymeric materials through AM, tailored to meet user's specific needs. Thus, a prosthesis was created which resembles the human hand, with a direct relation between body and prosthesis, regarding proportions, shapes, and movements. This innovative product is done using techniques and constructive solutions regarding the 3D printing with polymers. The movements are achieved by the use of wires.

The dissemination of this project is very important because it could reach younger creatives available to help people in any part around the world who need a prosthesis but cannot afford high cost prostheses available on the market.

Keywords: Design; Mechanical Prostheses; Additive Manufacturing; Low Cost; Transradial Amputation

1. STATE OF THE ART

The absence of hands has a great impact on human life, due to the loose of a working tool, image and personality development, interpersonal relationships, sexual identity, skills, self-expression, psychological reaction to this adversity of each individual, among others factors.

Therefore, the development of low cost prostheses is a social concern, in order to improve quality of life of the amputee and especially to reach those who can't have access to this product due to low financial condition.

Nowadays there are many types of prostheses available on the market, ranging from the simples ones, with only aesthetic function, to mechanical or bionic ones. Despite all actual technology progress, prices are still very high, easily reaching thousands of euros, making them unavailable for a wide range of population.

The hand as part of the human body is studied in three aspects; osteology, arthrology and myology. All of them are essential to understand bones, joints and muscles that, together, define the hand functionality [1]. The development of hand prosthesis is vital to improve the living conditions of people who do not have this part of the body. In a hand prosthesis project it is necessary to take into account all aspects related to the hand anatomy and type of amputation in order to obtain a prosthetic hand with aspect and functionality similar to the human one.

Amputation can have two origins: congenital deficiency, when someone is born without a limb and traumatic amputation derived of a surgical operation for removing a member or part of it, due to an accident or illness.

Upper limb amputations have various levels, depending on the removal degree or members absence. Figure 1 shows some amputation levels and the functional joint available to forward movement to the prosthesis [2].

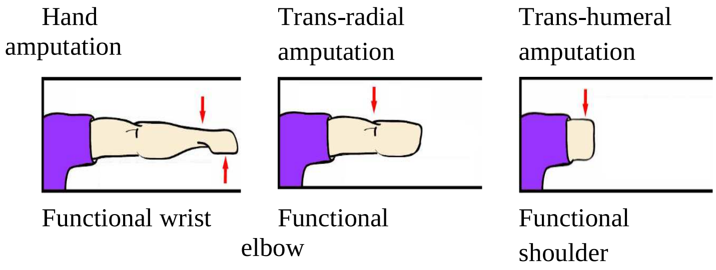


Figure 1. Amputation levels showing the available functional joint [2].

Since ancient times there are references to the existence of prostheses designed to replace missing parts of the human body. Between 218-201 BC a hand of steel was made to General Marcus Sergius, who lost a hand in the Second Punic War. In the Middle Age, Ambroise Paré, a great master of surgery, with a great drawing ability and aesthetic sense developed a large number of metal prostheses. In the nineteenth century, several prosthetic solutions, created by Peter Baliff and Robert Norman, driven by belts are reported [3]. Robert Norman designed a hinged hand made from whalebone, shown in Figure 2, which can be considered as the prosthesis that generated the current concept of low cost customized prostheses presented in this study.

Figure 2. Hinged hand made in whalebone, driven by belts, designed by Robert Norman [3].

Nowadays, there are many types of prostheses available on the market as a result of research and development work of multidisciplinary teams, ranging from the simples ones with only aesthetic function, usually made with silicone to mimic the skin (Fig. 3a), to bionic prostheses, which are much more sophisticated and with functionality closer to the human hand (Fig. 3b). However, all of them are very costly, with prices of up to tens of thousands of euros, turning them inaccessible to the majority of the population [4].

a) b)

Figure 3. a) Silicone prosthesis; b) Bionic prosthesis [4].

A more economical mechanical prosthesis (at a cost of about 600 €) and used for some amputees at the level of trans-radial amputation, comprises a mechanism allowing the hand closure and opening through the movement of a functional joint (blades movement or elbow bending) through a steel cable connected to a hook. For a more pleasant appearance, over the hook (Fig. 4a) is placed a PVC glove (Fig. 4b), and finally a silicone glove as a cosmetic coating (Fig. 4c). Its connection to the amputated limb is accomplished through a component that is customized according to each user, which engages the highlighted part in Figure 4 a).

a) b) c)

Figure 4. Mechanical prosthesis; a) Hook; b) PVC glove; c) Silicone glove [5].

In 2013, Ivan Owen developed his first metal prosthesis. Then using 3D printing he made a lighter, durable and functional prosthesis (Fig. 5). Subsequently, he decided to place the files in an open-source database, allowing everyone to print his prosthesis, using 3D printing, anywhere in the world. This work originated the e-NABLE project [2] which nowadays has a worldwide community of about 7,000 volunteers (teachers, students, engineers, scientists, doctors, designers and artists, among others) and has already provided about 2,000 low cost upper limb prostheses to users in 45 countries. This project aims to design and manufacture prosthetic hands in polymeric materials through AM technology – low cost 3D printing, tailored to meet user's specific needs, especially in under developed countries. This project turns the cost and production time much more reduced than in conventional prostheses. Besides that, adaptions are possible, at a reduced price, to follow child growth.

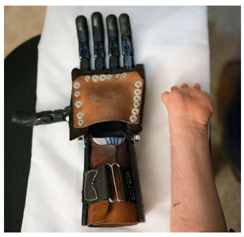
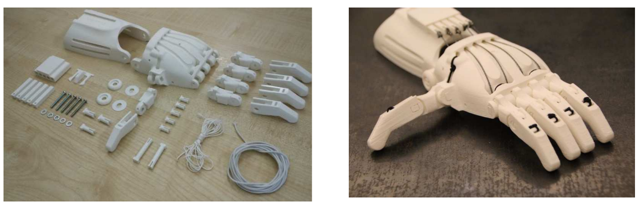


Figure 5. First metal prosthesis designed by Ivan Owen [2].

Despite all the existing technological progress, the lack of sensory function, not achieved in any available prosthesis, turns out to be the major factor for user rejection of prostheses use. Therefore, the development of a customized low cost hand prosthesis that allow performing simple actions like holding a cup will provide its user with a better quality of life, even if its appearance is that of a "plastic hand".

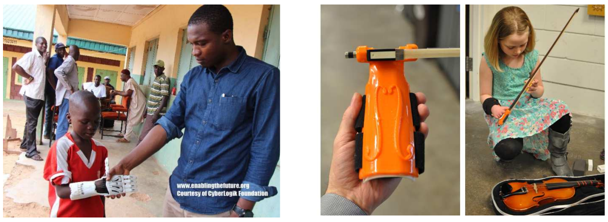
These prostheses work by bending and extension of the wrist. The functional joints are achieved through small springs and wires that join the different parts and that with the rotation of the wrist provide a closing movement of the prosthetic fingers. Figure 6 shows all the parts needed to assemble a hand available through the e-NABLE project (a) and presents a complete Raptor Hand prosthesis (b).



a) b)

Figure 6. a) 3D printed parts and other components necessary to assemble a low cost prosthesis (e-NABLE project) concept; b) The Raptor Hand prosthesis [2].

In Figure 7 one can see two examples of prostheses created under the e-NABLE project tailored to meet specific needs of some children.



a) b)

Figure 7. Examples of prostheses; a) Musa, an African child that was only 4 years old when felt into a kitchen fire. He lost his right hand due to severe burns and an infection. Through the e-NABLE project he got a hand prosthesis; b) Child and its prosthesis adapted to play violin, designed by the e-NABLE project [2].

3D printing is the production of objects, almost unrestricted in shape, by adding successive layers of a material [6, 7]. In all AM (3D printing) processes the construction by layers produces a surface roughness, called staircase effect, which is related with the layer thickness. In order to soften this shortcoming, there are some surface treatment solutions, such as polishing, painting, application of acetone or other specific products for this purpose [8]. The XTC product, from ON-Smoth Company is economical, smoothes the staircase effect and can be applied onto various types of surfaces such as plastic, paper, foam, cardboard, ABS or PLA. After this stage, parts can be painted or coated. The final aspect is a glossy surface as the one shown in Figure 7 b) prosthesis.

The most common AM process currently available is the Fused Deposition Modeling (FDM), launched in 1991 by Stratasys Inc, USA. This process consists in extruding a filament, usually plastic, through a heated nozzle which is fed by a reel (Fig. 8).

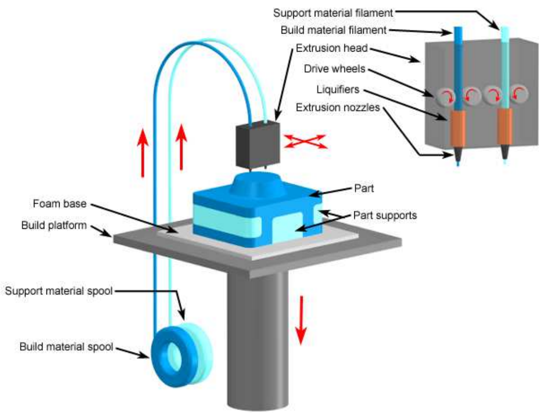


Figure 8. Schematic representation of FDM process [9].

Typically, these machines have two extrusion heads, one for the construction material and other to the support material [8]. The simplicity of construction and operation of this process led to a significant growth of equipments sold by many companies. Since the FDM patent was dropped the open source equipment emerged with an exponential growth as many users (designers, engineers, students and others), called “makers”, build their own customized equipments [10].

The Raptor Hand prosthesis (Figure 6 b) was the first one produced by the e-NABLE project. Despite all the innovation, it features some functional, constructive and even ergonomic problems, considering also that its aesthetic aspect is not the most appealing one. Currently, the prosthetics hands provided by the e-NABLE project have some limitations and conceptual problems: can only be applied if the person has a functional wrist or elbow, to be able to close and open the prosthesis; all fingers have the same size, which does not reflect a real hand; existence of some little dissimulated hinges, wires and rubber bands visible and unprotected; the elastics placement method and its durability; tightening of the prosthesis on the arm; restricted movements; and movement of the thumb very different from reality, among others [2].

Thus, this work aims to contribute to the study and research of possible solutions to solve or at least mitigate these problems through the use of different materials and constructive solutions adapted to each amputation, always with the following main concerns: simplicity, low cost and the possibility of being made in any 3D printer.

2 PRODUCT DEVELOPMENT

2.1 Introduction

In order to obtain a real case of a Portuguese child who needed a prosthesis and was available to participate in the e-NABLE project, some contacts were made with the amputee's services of several hospitals in the north of the country. None suitable case in terms of age and level of amputation was found. Therefore, considering an orthopedic doctor suggestion, it was decided to develop a prosthesis based on the same design concepts of e-NABLE but to join a pre-existing metal part, shown in the Figure 4 a), that many amputees use to be able to fix the hook also shown in the same figure. This way they can perform some movements of their daily life, such as dressing, eating, cooking, among others. The main idea is to replace the hook with a prosthesis, with dimensions and shape similar to the human hand, to produce movements of locking and fixing, and a flexible cosmetic glove that may be placed over it. The prosthesis must be linked to an aluminum standard piece shown in Figure 4 a). The manufacturing technology should be low cost 3D printing and the accessories used to link the various parts (screws, bolts, rubber bands, springs and wires) must be cheap, simple and easy to buy.

The prosthesis development process is divided into three phases. The first phase concerns the anthropometric and anatomical hand study, the second phase is the functional study of the prosthesis and finally the third phase, is the modeling, manufacturing and assembly of the final product.

2.2 Product definition

The developed product consists of a mechanical prosthesis that is activated by the movement of opening the shoulder blades or the rotation of the elbow, which causes the traction of a wire (effect similar to that of the bicycle brake). It is a light and low cost product due to its 3D printing production method [5].

Its connection to the amputated limb is made through a costumized component that is defined by an orthopedic doctor (yellow part, Figure 9). Between the prosthesis and the component produced with the support of the orthopedist, there is a metallic part that allows the joining of the two (gray part, Figure 9). Subsequently, the prosthesis is coated by a silicone cosmetic glove, which mimics the human hand, disguising the robotic aspect of it.

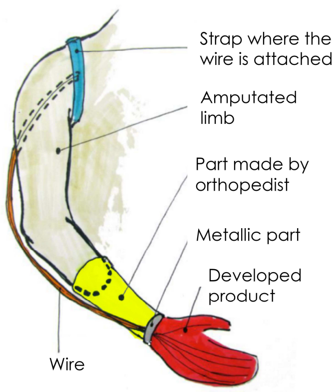


Figure 9. Connection of the product developed to the amputated limb.

In contrast to existing mechanical prostheses, the prosthesis developed in this study allows two types of grip, cylindrical and spherical, allowing the user greater freedom and easiness in daily activities.

The two modes of grip are capable to be achieved through a mechanism present in the thumb, allowing the finger to acquire two distinct positions. This is placed in the desired position by the aid of the other hand. In the case of a bi-amputee, this positioning is done with the aid of the leg.

It also has flexible filament parts in the palm and fingertips, which concede a greater grip in grabing objects. The wires and springs applied are placed in a way to be hidden, not interfering with the aesthetics of the product. On the other hand, components such as screws, bolts, springs, bearings, etc., are all in stainless materials. Finally, it was intended that the design of the prosthesis be anatomically realistic, as translated through the design presented.

2.3 First phase - *Anthropometric and anatomic hand study*

To the modeling process, is fundamental to understand the hands functioning and know its dimensions. This phase is divided in two parts: in the first, measurements are taken, as well as proportions of the wrist, fingers and hand central part - anthropometry -, and the second one, is the understanding of joints functioning and hand architecture - anatomy.

To obtain the dimensions needed for modeling, a hand plaster model of an adult man with a maximum length of about 210 mm was produced, using the same techniques used in orthodontics or sculpture. A mixture of water and alginate resulting in a paste which is then applied on the workpiece, from which one wants to obtain the mold. After drying, the workpiece is taken out, and a plaster slurry is poured into the mold. Subsequently, the plaster hand was demolded to give a faithful reproduction of the desired object, as can be seen in Figure 10. Over this model, a color scheme was made and lines were drawn to indicate the different parts of the hand and the areas where the fingers stretch and fold, to facilitate measurements and allow the use of true dimensions in this study. Thus, it is possible, on further work to make 3D models of smaller or larger dimensions, by grading.

Figure 10. Plaster model of a real hand.

Regarding the anatomy, the following points must be considered: the fundamental movements for the prosthesis functioning are the closing and opening of the hand. The articulation which allows folding and stretching the five fingers is a hinged joint, similar to a hinge. The connection between the thumb and hand main body is implemented through a saddle joint similar to a “cardan”.

The joints between the distal and medium phalanx (fingertip) of index, middle, ringer and little fingers were excluded because they are not relevant for the hand functioning. A single piece was designed to reproduce this part of the finger, with an angle of 20°. However, between the middle and proximal phalanges (which joins the fingers to the hand main body), between the proximal phalanx and the metacarpal articulation, a 90° rotation must be considered. On thumb, among distal and proximal phalanxes as well as the proximal phalanx and metacarpal there is also a 90° rotation. It was also considered important to incorporate more than one hold mode by the thumb with a rotation close to 54°, which promotes two different closing modes, as can be seen in Figure 11.

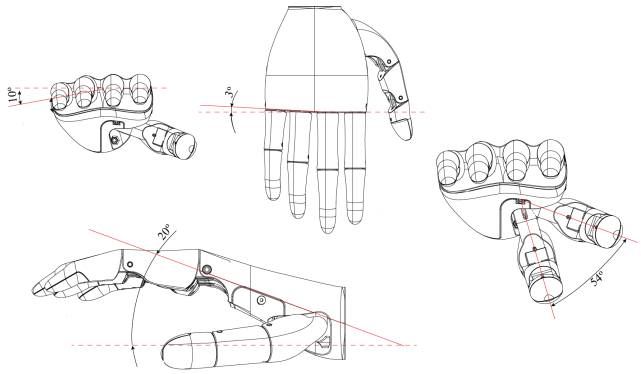


Figure 11. 2D hand modeling with angles among the different parts in accordance with the plaster model and real human hand.

The hand has a few more aspects to consider in terms of form. Ringer and little fingers, make an angle of 10° horizontally and 3° vertically. Finally, hand junction with the wrist makes an angle of 20°, to put it in its functional position. These aspects must be taken into account during project and modeling and are summarized in Figure 11.

2.4 Second phase - Functional prosthesis study

2.4.1 Joint system design for stretching and bending the fingers

The reference prosthesis (Raptor Hand 2) has mechanical solutions to this articulation that in terms of aesthetic and functional point of view are not the most efficient: the elastics lose their elasticity in a short time and the hinges are often loosened in its axis. The objective is to develop a joint system considering the following assumptions: mandatory flexion to 90°, allowing the total fingers closure; blocking the rotation movement at the top, preventing hyperextension; hidden the components that produce the stresses; extension strength by a flexible hinge; flexion strength by a wire/spring.

Facing the restrictions and constraints specified, some solutions were studied. In the first one, hinge is 3D printed on flexible filament using it as an elastic. After construction and assembly, this concept was discarded because the movement produced by this solution is not smooth and precise, which is critical to the prosthesis proper functioning.

Another solution is based on assumptions identical to the first one but using orthodontic elastics for the application of extension stress and a Teflon tube as the axis of the hinge, in order to reduce friction. This solution also has problems: the support that ties the elastic is quite small and brittle, break easily and there is not enough space to accommodate all the components inside.

The final concept is presented in Figure 12, and differs from the foregoing in some aspects. The extension stress is performed by a torsion spring and uses a brass pipe as a hinge axis, to avoid deformation by the force applied by the spring.

a) b) c)

Figure 12. Final concept of hinge joint design for the closing movement of fingers: a) External appearance; b) Brass tube and spring; c) Front view of the joint.

2.4.2. Thumb rotation mechanism

The thumb finger is the most complex and difficult to understand in terms of the movements. Since the objective will be to do more than one type of grip, the thumb may not always be in the same position, and must be able to perform a rotation (see Figure 11). After several iterations, the final design is presented in Figure 13 that has the rotation mechanism inside the hand and is patent pending. The actuation is performed manually by the user other hand, similar to what happens nowadays in bionic prostheses on the market.

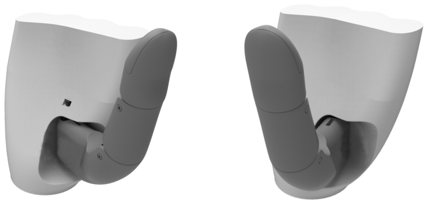


Figure 13. Final concept for thumb movement - two positions.

2.4.3 Flexion stress: spring connected to amputee functional joint

The mechanical system is composed by wires, springs and hinges. The opening and closing of the prosthesis by the user is achieved through the movement of the elbow or shoulder blades. This locking is due to the existing wire in the bottom of the prosthesis which is connected to the elbow or the shoulder blade by means of a guide tube in a similar way to the wires changes and brakes of bicycles.

According to mathematical equation that defines torque, B = Fxd, being F the stress and d the distance between the rotation axis and the wire/spring, it is found that greater the distance between the shaft and the thread, lower the force needed for closing the prosthesis. Thus, the string is placed as far as possible from the shaft, allowing the user to use less force to close the prosthesis (Figure 14).

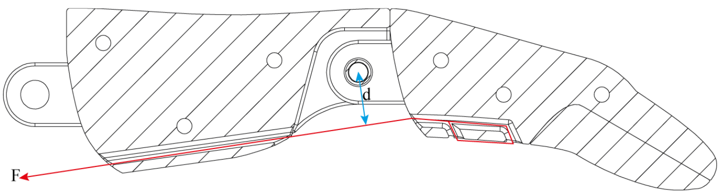


Figure 14. Cross section of a finger indicating the string path.

The basic requirements for the choice of wire which produces the bending stress were: greatly reduced elasticity level, ensuring a good response in tension during stress application and wear resistance. Initially, a nylon spring was tested from which was obtained a good response in terms of mechanical properties but low wear resistance. So, a kevlar string was selected, consisting of 8 filaments crossed with a thickness of 0.2 mm, able to withstand tensile forces up to 130N.

2.4.4 Extension stress

The force which counteracts the hand locking is accomplished by a torsion spring. After several studies and tests it was found that the most suitable spring is made of hardened stainless steel wire with 1 mm in diameter.

2.5 Third phase - Modeling, manufacture and assembly of the final product

The modeling of the final product integrates the constructive solutions described in the second phase, considering the dimensions and functional concerns studied in phase 1 and seeking the low cost production process based on AM.

Due to the necessity of creating space for crossing the fingers wires, which converge to a single wire, the main frame is composed by two parts: the main structure produced in solid filament and a lid in flexible filament. The path of the strings was designed so that they are all connected in the center of the main body through tunnels in order to be joined in a single wire. This main wire will connect to the elbow or the shoulder, which are the functional linkage of the amputee, allowing hand closing by force "F" (Figure 15).

The main structure of the prosthesis (main hand body) is designed in order to be printed vertically as shown in Figure 16, without the use of supports. The highlighted areas indicate some of these situations. Because of their rounded shapes, fingers had to be split in two halfs, allowing to print them without supports (Figure 16).

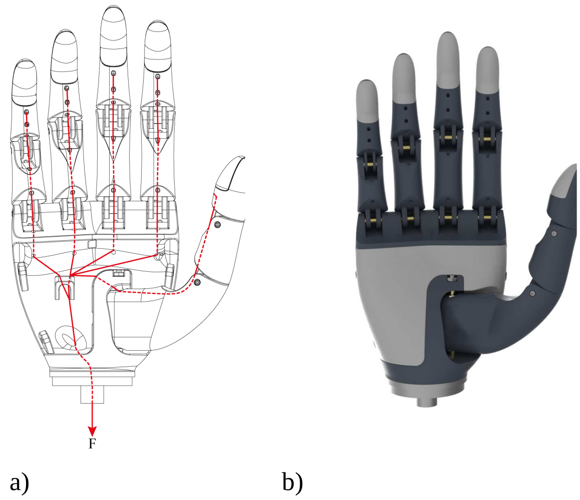


Figure 15. Prosthesis; a) 2D modeling of a prosthesis with the strings configuration; b) Hand 3D modeling.

The first cut was made in the center of the finger, also sectioning the existing tunnel for string path, which causes a problem: during the pull, the string enters in the groove resulting from the union of the two parts and can break. Using the cut shown in Figure 16 this problem was overcomed. The two parts are then glued with cyanoacrylate. The use of flexible filament for the construction of specific areas of the prosthesis, such as the hand palm and fingertip (Figs 15 b) and 16 b) gives a greater adhesion and adaptability to objects during handling.

A personal printing system based on FDM process (designed and assembled by the first author of this paper), with maximum construction dimensions of 300x300 mm was used to print the parts. For fingers and main structure of the prosthesis a PLA filament was selected and for the palm and fingertips TPE (thermoplastic elastomer) with a polyurethane base and some additives (Filaflex).

a) b)

Figure 16. Prosthesis hand; a) 3D printing position of the main prosthesis body to avoid the use of supports; b) finger parts.

2.6 Production of prototypes by AM

In parallel with the modeling, test prints of all parts were carried out in order to understand their functionality and the capacity to answer effectively to their purpose. The production of the prototypes was carried out using a low-cost 3D printing machine derived from the Prusa i3 Hephestos model of the BQ brand.

In order to obtain a product or prototype, it is necessary to go through the 3D CAD model transformation process, which is organized in four main stages: first the desired 3D CAD object is modeled; then it is transformed into a ".stl" file that converts the surfaces of the geometry into triangles; later, it is introduced in a software that finally translates it into a ".gcode" file. In this step the surfaces forming the volumetry are converted into layers and, if necessary, the supports are formed. The generation of supports occurs when a part has a protrusion, as exemplified by the images in figure 17. Finally, it is printed and, if necessary, surface finishing [6].

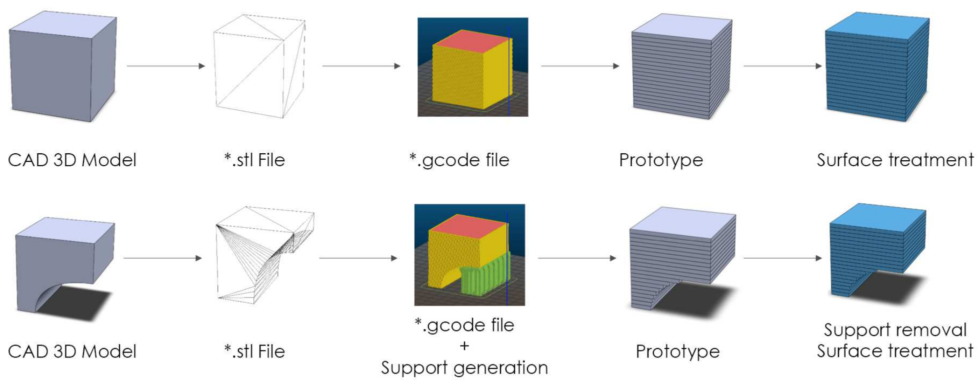


Figure 17. Process of converting a CAD file into a prototype.

As previously mentioned, several steps are required to make a three-dimensional impression. After obtaining the ".stl" file of the part to be printed (from the modeling), it is necessary to set the desired print settings. It is in this step that all the parameters are defined, such as layer thickness, extrusion temperatures and type of filling, among others.

The print settings are very important and are done when generating the ".gcode" file. The values to be set for the parameters vary depending on the type of filament and the desired quality level for the printing. In particular, layer height and velocity are essential parameters for defining the quality and detail of the printed part.

The layer height should be about 80% of the nozzle diameter of the extruder, which means that an extruder with a nozzle having a diameter of 0.3 mm is used, the layer height should be 0.24 mm. Depending on the quality and detail required for the part, the value of this parameter can vary between 0.05 and 0.3 mm. Knowing that the smaller the height of the printing layer, the greater the detail and the better the quality that can be obtained, and taking into account that the prosthesis requires a reasonable level of detail, a value of 0.15 mm layer was selected.

It becomes clear that the lower the print layer height, the longer it takes, as there is a need to print more layers.

Within the speed parameter, as an important parameter to define print quality, there are several values to be established, such as: exterior and interior perimeters, bridges, supports, filling, moving, etc. These speeds change depending on the material, the type of part to be printed and the quality required.

In this case, for a high-quality impression and considering the available printing system, an overall value of 45 mm/s was defined for the PLA filament (polylactic acid) and 30 mm/s for the TPE filament (thermoplastic elastomer). Due to the tensile properties of the TPE and to ensure a good print and to prevent the fillet from jumping out of the pulley which guides it to the extrusion head, it is advisable that the speed does not exceed 30 mm/s.

In the first layer all speeds earlier referred should have a reduction of up to 50%, to assure a good deposition and the correct adhesion to the printing table (bed). The extrusion flux of material in this first layer should be higher; 150% and 100% for the following layers.

The filling is the parameter that sets the print density inside the piece and can vary between 0% (hollow) to 100% (solid piece). Combined with this property is the pattern of filling, which may have different forms. There are parallel or perpendicular patterns, hexagonal, circular, concentric, and others. In this case it was used a hexagonal pattern and a filling of 20%, giving the printed piece good quality and adequate mechanical properties, in terms of strength and rigidity.

The vertical shells parameter sets the thickness of the perimeters or walls in each layer. Establishes the contour of the model, and from it dimension depends the strength of the piece. To ensure a good adhesion between layers and part resistance, in our case it was used a value of 3 mm.

The horizontal shells parameter sets the height of the solid layer on the top and bottom faces. It confers rigidity to the model with respect to the upper and lower faces. A value of 3 mm per face was established. If it is necessary to increase the stiffness, this value can be increased, as well as the previous parameter.

Another parameter to take into account is the extrusion temperature. The working temperatures for the PLA range from 190°C to 210°C, while for TPE is 210°C to 230°C. These values may differ from one supplier to another, so it is of utmost interest to consult the technical data sheet for each filament.

Finally, the temperature of the warm bed is important so that a good adhesion of the impression is assured. For the printing of PLA and TPE, the heated bed can be kept off or at a temperature of approximately 50°C, while for ABS a temperature of 90°C is always required.

In relation to the filament there are two possible diameters: 1.75 mm and 3 mm. The diameter of the selected filament must always be inserted in the ".gcode" file. For the manufacture of the fingers and main structure of the prosthesis, a 1.75 mm PLA filament was used and for the palm and fingertips, 1.75 mm TPE.

Once the configuration of all parameters has been established, the ".stl" file is imported, the orientation and position of the part in the printing table is defined and the ".gcode" file is exported [10].

It should be noted that, for the test prints, some values of the applied printing parameters were lower than those previously mentioned, since there was no need for impressions with high strength and rigidity, since they are experimental, from the point of view of functionality.

2.7 Results and discussion

After obtaining the 3D CAD model of the prosthesis, a total model of the hand was constructed and tested in terms of usability. A severe wear was identified in the wire, and after several traction movements, it began to cut the polymer. In order to solve this problem, ceramic guides (common in the textile industry for the passage of the wires) were placed in the mouths of the tunnels, preventing this wear.

According to medical opinion, it was still necessary that the joints present between the medial phalanges and the proximal phalanges, second articulation (Figure 18, detail C), close before the joints present between the proximal phalanges and the metacarpus, first articulation (Figure 18, detail B), in order to facilitate the grasping of the objects and to make the prosthesis closure as real as possible.

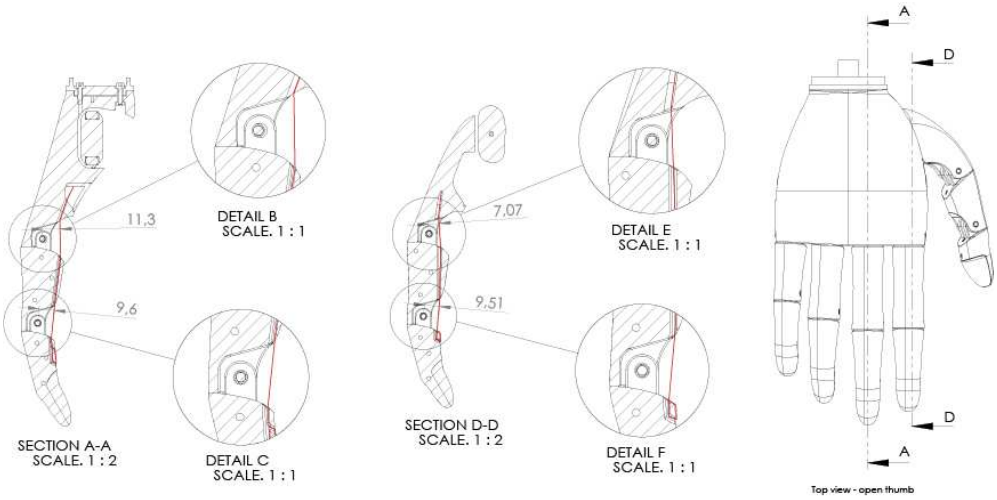


Figure 18. Distances (mm) between the axis of rotation and the wire.

To do this, the distance between the axis and the yarn of the first joint must be less than the distance between the yarn and the axis of the second joint, so that greater torque is exerted on the first joint and less torque on the second joint [5]. Figure 19 shows the final prototype of the prosthesis.

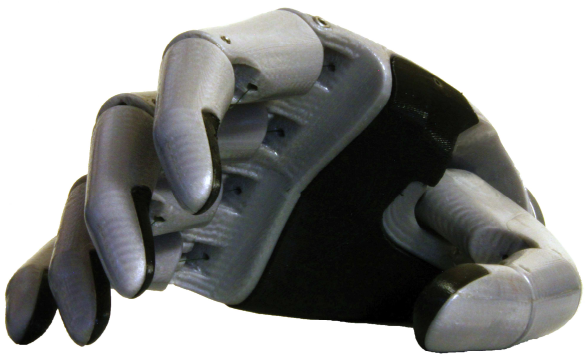


Figure 19. Final prosthesis in PLA and TPE.

3. CONCLUSIONS

The objective of this work was successfully completed, since this project culminates in obtaining a first prototype of a prosthesis for the level of transradial, transhumeral, and scapulo-maxillary amputation of the upper limb. After completion of a final prototype and evaluation of all costs, it is concluded that it is possible to produce a low-cost prosthesis through additive manufacturing. However, given the implicit complexity of this product, it is essential to reflect on a series of procedures to be adopted later, in order to improve its effectiveness.

It is considered that the important issue of product accessibility has been assured since the cost of producing the prosthesis will be very low.

The objective of simplicity of the constructive composition is also met, which ensures that this product is capable of proper maintenance and ensures ease of assembly and dismantling.

It should also be noted that this prosthesis fits within the stipulated weight parameters, and has a weight of approximately 200 g.

The effort made around the idea of implementing two types of thumb grip resulted in a simple and essentially functional mechanism, providing a greater range of movements.

In this way, the product presented tries to be a small contribution to the design and progress of mechanical prostheses, thus improving the quality of life of all those who are or may be affected by the amputation of an upper limb.

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