3D Printing as a Design Tool for Wearables: Case Study of a Printed Glove

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Abstract. In the research work herein described, the body is analyzed from the perspective of the integration of mechanical and electronic resources, both seen as communicative systems. In this sense, the body becomes a project design for both fashion design and engineering, and therefore requires technical specificities of these wearable devices attached to them. Specifically, this paper described the development of the prototype of a glove, produced with 3D printing technology (FDM). The glove is the first step in the development of prostheses that are integrated into garments. In this work, the 3D printing method, its limits and capabilities are evaluated, a draw printing materials are studied concerning print quality and user comfort. As a conclusion, we pointed out the need for a constant search for flexible filaments more appropriate for garments, especially with regard to movements of opening and closing of the hands. We also confirmed the effectiveness of the 3D printing technique as a tool for Designers to quickly and inexpensively visualize the initial shape of their products and thus be able to make changes in a more appropriate way.

Keywords: 3D printing, Design, Wearables.

1 Introduction

In an analysis of the garments developed by the engineer and artist Flavio de Carvalho, we identify the evolutionist thought of Charles Darwin that clarifies the associations of biology to reflections on the evolution of the garments [1]. As well as being based on the theory of the utopian body of Michel Foucault, Carvalho thought of the garments as a blossoming of utopias, ghosts or body desires, projecting them to another space, garment as prosthesis [2]. This discussion makes it possible to think about the technological body, in which its traditional limits are questioned. It is not just a garment, but also an extension, prostheses that penetrate and line the human body through the biotechnological sciences.

Coexisting with the concept described, advances in miniaturization of electronic devices have generated a growing interest in Wearable Technologies. It is a fact that wearable systems are non-invasive devices that allow clinicians to monitor individuals for long periods of time [3]. This happens because the contemporary body admits the projection of these tools both internally and close to the skin. This is a path that theorists call confirmation of self-regulatory systems [4].

These considerations, added to the advances of the Additive Manufacturing (AM), provide a conceptual extension of 3D printing, resulting in processes with potential to offer new, advanced products related to wearables. However, addressing the issue of these new products to be worn by humans, requires parameterizing the body as support in many dimensions: shapes, sizes, thermophysiological comfort, psychological comfort, etc. Whether it is following its forms, or building new volumes, clothing necessarily presents itself aggregated to body culture [4].

Therefore, based on the assumption that garments are prosthetics of the body, and motivated by the demand of wearable devices with monitoring functionalities, we have chosen for the execution of the 3D printing tests, the modeling of a medical glove. In addition, it has been chosen because it is a garment that integrates – coats - the part of the body referring to the upper limb, the forearm and the hand, and therefore, its specific movements require great flexibility of the material. In recent studies, we have identified the patent of two gloves: a glove with compass and thermometer (CN201088158 Y) [5], and in 2017, the medical glove to prevent infection, with bacteria thermometer (CN106983498 A) [6].

2 Materials and Methods

2.1 3D printing

3D printing is a form of AM technology, in which products or prototypes are constructed by depositing materials, layer by layer, through a series of transverse slices.

Today, more than 100 different types of 3D printers are available on the market, many of which are desktop printers, featuring relatively low and affordable prices. There are also industrial-scale 3D printers with higher prices, however, capable of processing a wide range of materials on a larger scale. In the same way, several techniques are used by these printers. We opted for the Fused Deposition Modeling technique (FDM), because this is one of the most used AM techniques in garments [8].It consists in the use of a thermoplastic filament, which is introduced into an extrusion head, and is heated to a semi-liquid state, before being extruded and deposited in thin layers by the nozzle [9]. Since we assume the choice of flexible thermoplastic printing material, it is, therefore, a suggested technique for its use.

In order to be able to choose the most suitable filament for the glove, the two most important parameters are high resistance to bacteria and high flexibility. The glove should make possible the following movements: flexion and extension; adduction and abduction; internal and external rotation; and circumference. In our search, we found a flexible thermoplastic elastomeric filament (TPE), based on polyurethane and other additives: *Filaflex Original 82A,* from the Spanish company *Recreus*. Table1 presents the physical properties of the filament as well as the printing properties provided by the manufacturer.

Table 1. Printing and Properties of Filaflex Original 82A. Source: *Recreus*.

Physical Properties	Typical Value	Test Method
Density	1,14 g/cm³	ISO 1183-1-A
Hardness Shore A	82	ISO 7619-1
Elongation at break	665%	ISO 37
Tensile strength	42 Mpa	ISO 37
Abrasion loss	23mm³	ISO 4649-A
Flammability rating	HB	UL 94
Printing Properties	**Value**	
Printing Temperatures	225-235 ºC	
Printing Speed	20-40 mm/s	
Hot-Bed temperature	0 ºC	
Optimal layer height	0,2mm	
Minimal Nozzle diameter	0,3MM (0,4mm or higher recommended)	
Retraction parameters	3,5-6,5 mm (speed 20-120 mm/s)	

The printer used was the UP Plus 2, 3DP-14-4A, from UP! For initial printing tests, we searched for models that were similar to a glove. On the *Open Bionics* website, we found a one-hand file that was suggested for printing on flexible materials ("*New flexy hand for filaflex"). F*rom this file only the thumb was printed, with three different filaments: acrylonitrile butadiene styrene *(*ABS), polylactic acid (PLA), and TPE. These experiments were designed to explore the skills of the printer and the resulting properties of the models. For this purpose, we used the following recommended temperatures: For ABS, the extruder temperature was 240°C and the bed temperature 110°C; for PLA, the extruder temperature was 195°C, and the bed temperature 60°C. To print TPE, the extruder temperature was set to 230°C, the bed was not heated.

The results printing with the flexible filament on our desktop printer were not satisfactory, as will be explained later. We verified that the adversity resulted from the specificity of the filament. Using this filament required setting more printing parameters than the UP software allows. Thus, it was necessary to use another printer. The company *Xpim* in the city of Braga/Portugal had experience with flexible filaments, and they were able to print in larger sizes (it was possible to print the whole glove). A POM printer was used for the final prototype. Table 2 details its technical specifications. In this course, it was also necessary to change the type of the flexible filament. Although we did the initial tests with Filaflex, the prototype was printed with Ninjaflex Cheetah, as this is the flexible filament normally used by *Xpim*. This material has a shore hardness scale of 85, suitable for flexible materials.

Table 2. Specifications used in the final prototype and the print parameters.

POM Printer Technical Specifications		Printing Parameters	
Dimensions	95x95x170 cm	Diameter of the filament	2,95mm
Print volume	70x60x60 cm	Print runtime	10 hours
Resolutions	100 - 900 µ	Print temperature	230ºC
Extrusion ºC	Up to 350ºC	Bed temperature	45ºC
Bed temperature	Up to 120ºC	Print speed	50mm/s
Energy consumption	240 V, 9A, 50-60Hz	Layer height	0,25mm
		Percentage of compactness	100%

The software used for slicing was Cura, as it allows a more detailed configuration of the printing parameters. The bed was prepared with Kapton Polyimide tape and water-soluble PVA support material was used.

2.2 Modeling

The proposed three-dimensional model for the respective study is a glove. Measurements of a male arm were made using a measuring tape. The resulting values are: forearm width (35,5cm); wrist width (21cm); length between wrist and end of the middle finger (19cm); length of the forearm to end of the middle finger (35cm). Based on these measures, we started modeling using the *SolidWorks*3D Computer Aided Design (CAD) software. Due to the characteristics of the three-dimensional model, we observed that it would be more appropriate to change the modeling process for software that has a cognitive feature similar to the *moulage* process. In Fashion Design, *moulage* is a three-dimensional modeling technique of clothing in which the fabric is molded, pinched, scratched and cut straight onto a mannequin [7].In this sense, we found the sculpt feature in *Fusion 360* software, and we opted for this simple and intuitive functionality.

In the sequence, with the same method of the *moulage* - in which modeling is done on a mannequin of the human body - we searched on the website cgtrader.com, for the base of a male arm with extension *Object File Wavefront 3D* (OBJ). From then on, we molded the glove with the pre-established measures. Subsequently, we defined the thickness of the model (2mm).Fig. 1 presents the rendered 3D model of the glove.

Fig.1. Rendered glove.

3 Results

As far as the initial tests with the three filaments (ABS, PLA and Filaflex) are concerned, satisfactory prints were achieved with the first two. However, being rigid materials, they did not meet the comfort requirements for a wearable part.

In the first printing test with the Filaflex filament, we followed the parameters provided by the supplier. However, the model showed some discontinuities in parts of the print. In addition, the matte transparent filament turned glossy when printed, which is indicative of problems with temperature.

In the second printing attempt with Filaflex we changed to the black filament. Extrusion temperature was to 265°C, because we noticed that the printer always printed below the temperature set. We observed that, regarding color, the same issue occurred: the black matte filaments became glossy as they went through the extrusion process. Still, print quality was better, but we noticed that the filaments were not bonding to each other. They were forming a kind of a lace (Fig. 2). New attempts provided the same unsatisfactory results.

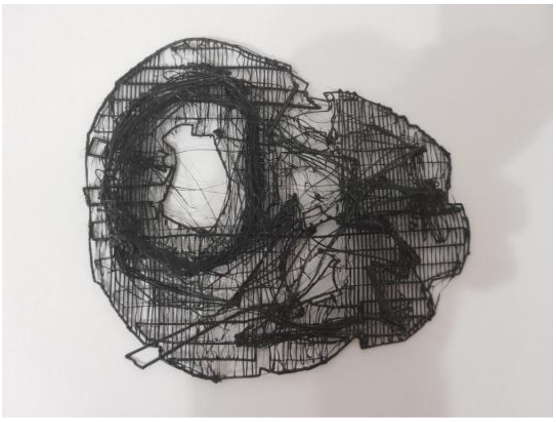

Fig.2. Glove print test

The next step was searching for the causes of these problems, namely identifying if it was the 3D model, the slicing process or the print parameters.

In this sense, the first change was the choice of the printer. We found at *Xpim* a way to test the print of the prototype again. *Xpim* printed the modelled glove with NinjaFlex flexible filament twice.

In the first attempt, the result was not satisfactory at the fingers, because their interior was filled by strings of filament. This happened because, when travelling from one side of the perimeter to the other, the nozzle was not able to stop the filament flow, leaving remains of fused filament behind. To solve this problem the initial speed of 50 mm/s was reduced to 60% at the fingers.

In the next attempt, the interior of the fingers was not filled anymore, but small voids appeared at the perimeter. This meant that the nozzle was not able to produce filament quickly enough when it reached the perimeter of the finger. Reducing the "retraction" parameter allowed mitigating this problem, and a satisfactory result was obtained (Fig.3).

Fig.3. Result of the glove, dressed on one arm.

4 Discussion

The prototype presented, a glove, acts as a garment, so it is a direct extension of the surface of the body. In this perspective, with regard to the adopted modeling methodology, in which there is a correspondence of the concepts of *moulage* in the 3D modeling of the piece, we observe that the anatomy of the glove fulfills the dressing requirement. In this sense, the choice of Fusion 360 software was successful.

Regarding the filaments, it was possible to use the ABS and PLA filaments following the specifications of the suppliers regarding temperature and printing speed. They also were easier to handle, adjusting very few parameters, and in fact have good print quality even using a desktop printer.

However, Filaflex flexible filament requires a greater specificity of parameters, and a slower printing speed (the slower, in this case, the better the quality). Printing results with this filament have confirmed that we still need to experience 3D printing speeds and feeds according to the specificity of each material and the printer model used. Although there are indications from manufacturers, these standards are not adequately addressed, which proves to be an area of constant research [10].

With Ninjaflex, the best result within the given time frame could be achieved. However, its flexibility does not meet the comfort requirement that a garment demands, nor does it possess the necessary breathability. The rotational movement of the pulses is maintained, however, the flexibility of the resulting surface is not sufficient to perform the movement of opening and closing the hand.

5 Conclusions

The observations made in this work were only possible due to the prototyping of the piece by the 3D technique, which proved feasible as to the exploratory character that the design creation process demands. To this extent, this study also intends to provide insights into the fabrication of garment pieces as prostheses using AM.

Regarding the design of the glove, the analysis of the model used shows that further study and modeling of the arm shape is necessary. For future work, in order to integrate the garment into the prosthesis, it is necessary to improve design and aesthetics of the proposed object to make it functional and based on ergonomic concepts. Is also important to carry on searching for and studying flexible materials that allow comfort and the necessary movements of the users.

As an initial study, we perceive as positive the findings made in relation to choosing of the *Fusion 360*modeling software, as a correlation to the garment *moulage* technique. This also narrows the relationship between fashion and AM, and confirms 3D printing as a design tool.

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