Improvement of the Traditional Techniques of Artistic Casting through the Development of Open Source 3D Printing Technologies Based on Digital Ultraviolet Light Processing (DLP)

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Abstract**—**Traditional manufacturing techniques used in artistic contexts compete with highly productive and efficient industrial procedures. The craft techniques and associated business models tend to disappear under the pressure of the appearance of mass-produced products that compete in all niche markets, including those traditionally reserved for the work of art. The surplus value derived from the prestige of the author, the exclusivity of the product or the mastery of the artist, do not seem to be sufficient reasons to preserve this productive model.

The adoption of open source digital manufacturing technologies in small art workshops can favor their permanence by assuming great advantages such as easy accessibility, low cost and free modification, adapting to specific needs of each workshop.

It is possible to use pieces modeled by computer and made with FDM (Fused Deposition Modeling) 3D printers that use PLA (polylactic acid) in the procedures of artistic casting. Models printed by PLA are limited to approximate minimum sizes of 3 cm, and optimal layer height resolution is 0.1 mm. Due to these limitations, it is not the most suitable technology for artistic casting processes of smaller pieces.

An alternative to solve this limitation, are printers from the type (SLS) "selective sintering by laser". And other possibility is a laser hardens, by layers, metal powder and called DMLS (Direct Metal Laser Sintering). However, due to its high cost, it is a technology that is difficult to introduce in small artistic foundries. The DLP (Digital Light Processing) type printers can offer high resolutions for a reasonable cost (around 0.02mm on the Z axis and 0.04mm on the X and Y axes), and can print models with castable resins that allow the subsequent direct artistic casting in precious metals or their adaptation to processes such as electroforming.

In this work the design of a DLP 3D printer is detailed, using backlit LCD screens with ultraviolet light. Its development is totally "open source" and is proposed as a kit made up of electronic components, based on Arduino and easy to access mechanical components in the market. The CAD files of its components can be manufactured in low cost FDM 3D printers. The result is a less than 500 euros, high resolution and open-design with free access that allows not only its manufacture, but also its improvement.

In future works, we intend to carry out different comparative analyzes, which allow us to accurately estimate the print quality, as well as the real cost of the artistic works made with it.

Keywords**—**Artistic casting, electroforming, DLP 3D printer, traditional artistic techniques.

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I. Introduction

TRADITIONAL manufacturing techniques used in artistic contexts and associated business models tend to disappear under the pressure of the appearance of mass-produced products that compete in all niche markets, including those traditionally reserved for the work of art. The processes of artistic casting are techniques that can be improved thanks to the new digital manufacturing technologies. The adoption of open source digital manufacturing technologies in small art workshops can favor their permanence by assuming great advantages such as easy accessibility, low cost and free modification, adapting to specific needs of each workshop.

There are several casting process; Sand casting [1], casting with gasifiable molds [2], shell casting [3], the lost wax casting technique [4], and finally the microfusion [5], a variant of lost wax, which is used to make small detailed parts such as jewelry. On the other hand in jewelry is also commonly used a technique called electroforming [6], This technique does not melt the model to turn it into metal, but it is a process that covers the pieces with a very thin metal layer (microns) by using an electric current.

For the creation of molds, for the processes of casting lost wax, there are 3D printers that produce more detailed objects directly in wax, these machines are integrated in the industrial foundry and specialized in the processes of creation of jewelry, where they have revolutionized the production [7], although they are expensive and therefore are not accessible to small craft workshops. Another technology of 3D printing established at industrial levels is "selective laser sintering" (SLS), which builds objects directly in metal. The metallic objects created by this type of 3D printer have approximately 99.99 percent density, and therefore can be used instead of traditional metal parts in the vast majority of applications [8]. However, the cost of the printed model is also high, so that they are not a viable alternative to artistic casting either.

With the appearance of additive manufacturing, appears the idea of replacing wax models used in casting with lost wax by computer-designed models manufactured using low-cost 3D printers. To make these models there are two different materials, the PLA used by the FDM (Fused Deposed Material) printers and the resin used by the DLP (Digital Light Processing) printers. Computer-designed models allow for greater complexity than can be achieved with the use of traditional hand-modeling techniques [9, 10].

This form of construction, where the successive layers of material are placed adapting to the required shapes, produces a laminar texture in the objects that represent a problem for the creation of final pieces. This texture can be smoothed, either by physicochemical processes or by using high resolution printers. In Figure 1, we can see the results obtained by using the two models of low cost printers indicated (FDM and DLP). It can be seen, on the one hand how the model of a PLA figure of 10 cm in height, used as a mold in the process of lost PLA, leaves a clear laminar texture in the bronze figure. On the other hand, the 2 cm high resin model also leaves a laminar texture when the piece is covered with bronze using the electroforming technique.

Fig 1 Examples of figures made by PLA and resin molds.

In this article, it is proposed, from the FabLab of the University of La Laguna (ULL), the construction of an open source DLP type printer, which improves the resolution of existing low cost printers. This proposal aims to provide an accessible and modifiable digital manufacturing tool, so that small art workshops can use these technologies, through manufacturing spaces such as makerspaces, for the creation of metal pieces less than 2 cm tall.

It is important to point out that a complementary objective of this work is to provide a new open design, in addition to existing initiatives within the maker's philosophy where developments are accessible by the developer community. The proposed design is designed to be carried out in digital manufacturing spaces that already have 3D FDM type 3D printing machines or even laser cutting machines (although this last machinery is not essential.)

II. Materials and Methods

A. *Improving the resolution of low cost 3D printers*

The resolution of 3D printers of the FDM type is conditioned by the manner of manufacturing the objects, by means of stacked layers of molten material. The molten PLA comes out of a nozzle that is normally 0.4 mm, which allows obtaining a resolution on the x, y (width and length) of 0.4 mm (400 microns). The resolution of the z axis depends on the motors and screws used to move the nozzle on the z axis. Usually in these printers, the precision can range between a maximum of 0.05 mm and a minimum of 0.3 mm. This comes to give the height of each layer that is built, so the layers have a resolution of between 50-300 microns.

DLP printers do not deposit a thread, but manufacture by a light that passes through an LCD screen and hardens a photosensitive resin. In this case, the resolution of the x and y axes depends on the resolution of the screen. Low-cost 3D printers of this type usually have a resolution of 2560 x 1440 pixels for a 5.5-inch screen (often referred to as 2K screens). This comes to give a detail of the axes x and y of 40 microns. The resolution of the z-axis, as in the PLA printers, depends on the motors and screws used to move the printing table on the z-axis. In most low-cost printers are usually between 35 - 50 microns

TABLE I
COMPARING THE RESOLUTION OF THE FDM AND DLP PRINTERS

Resolution	Low cost 3D Printer FDM	Low cost 3D Printer DLP
Resolution X, Y	400 microns	40 microns
Resolution Z	50 – 300 microns	35 – 50 microns

In order to improve these resolutions it is proposed to create a printer that improves on the one hand the quality of the LCD panel, which influences the resolution X, Y and on the other hand the mechanical characteristics of motors and screws that directly influence the resolution on the Z axis In this research work, we intend to design a DLP printer that can have 30% more resolution in all three axes. This will be possible in the x and y axes, changing the LCD screen with a resolution of 2K for a screen with more resolution, in this case 3940 x 2160 pixels (they are called 4K screens). This comes to give a resolution of 30 microns on the x and y axis. On the other hand, if a motor with a lower rotation step (0,9 degree Nema17 stepper motor) and a higher quality lead screw is selected (Ball screw), the layer height (z-axis) can be improved to 20-25 microns. It is expected that with these resolutions, the problem of the laminar texture will be solved.

TABLE II
EXPECTED RESOLUTIONS OF 3D PRINTER DESIGNED

Estimated Resolution	DLP 3D Printer FabLab ULL
Resolution X, Y	30 microns
Resolutionn Z	20 - 25 microns

B. Design of a high resolution and low cost DLP printer

The use of better quality elements directly influences the final price of the printer, so the proposal of this article is to develop a high resolution DLP printer, but whose price is equal to or lowers than the low cost models existing in the market. It is also intended that the printer be open source, so that any artistic workshop can access the manufacture and modification of it, without additional costs.

DLP printers have traditionally been more expensive than FDM printers, however in recent years there have been open source proposals for this type of printers, as well as low cost proprietary models. Among the open source initiatives stands out the one carried out by Josep Prusa, creator of the Prusai3 FDM printer. The printer Prusai3 has been for years, the printer selected as a gateway in the world of digital manufacturing, since it combined a low price, with the ability to manipulate and improve the printer itself [11]. In 2018, Prusa Research, launched Prusa SL1 3D resin printer (DLP), with the same philosophy of low cost and open source of its FDM models. This printer is equipped with a high resolution LCD panel (4K) and its current price is 1599 euros or 1299 if you buy the kit to assemble it yourself (https://www.prusa3d.es/6472-2/). On the other hand, there are resin printers that, despite not being open source, can be considered very low cost and therefore an interesting option for small art workshops. Among this type of printers stands out the Wanhao Duplicator 7, manufactured by Wanhao in China. This company, of recent appearance, since it began to sell out of China in the year 2012, has as main characteristic its low price and acceptable qualities. In particular, the Wanhao Duplicator 7 model can be obtained for around 550 euros and offers a 2K LCD panel and better resolutions than any FDM printer.

Taking as reference these two options of 3D printers, the prusa SL1 as an open source model and the Wanaho Duplicator 7 as a low cost model, it is intended to design an open source printer that combines both working philosophies, the high resolution of the first and the low cost of the second. To do this, a design is proposed that allows the printer to be built, using methods that can be replicated by any user at a very low cost. Among the chosen design options, a repository of 3D pieces will be created to print on PLA in 3D printers of the FDM type, a list of prepared pieces will also be made for its manufacture by cutting machine, a free control software will be chosen and finally the printer will be provided with a low-cost open source electronics such as Arduino. However, and in order to achieve higher resolution and therefore minimize the effect of the laminar texture, the printer will be provided with a 4K LCD panel, a 0,9 degree Nema17 stepper motor and a precision ball screw.

For the design of the first functional prototype, the components of the printer have been divided into several categories: Parts for 3D printing, parts for laser cutting, electronic components and mechanical parts purchased. In Figure 2 you can see an image of the CAD design of the printer.

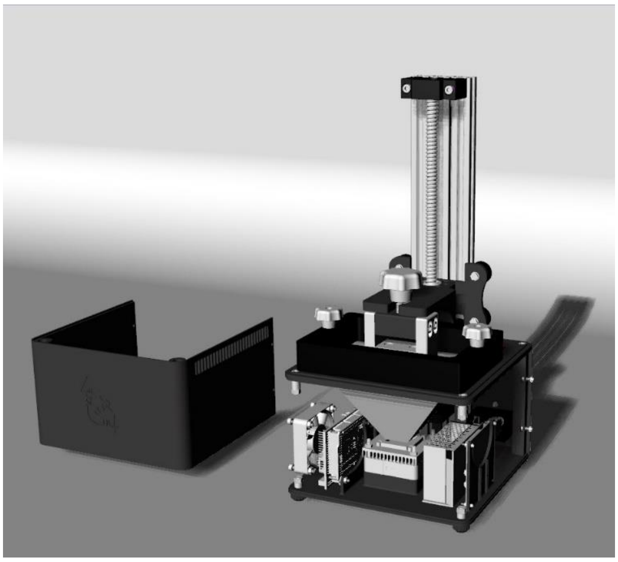

Fig. 2 Full design of the high resolution 3D printer FabLab ULL.

1) 3D Printed parts

The design of the pieces has been made with the Fusion360 application, a free 3D modeling software for small businesses and DIY enthusiasts. The pieces are currently in the final modeling phase, as they are being printed and tested using a prototype to ensure that the design is correct. Once we have the final design of all the printed components, the files (in STEP neutral format and in f3d format) will be included in a repository so that anyone can access them, both to print them and to modify them.

A total of 17 components have been designed, with a total of 31 different pieces that make up all the non-metallic parts of the structure (figure 3).

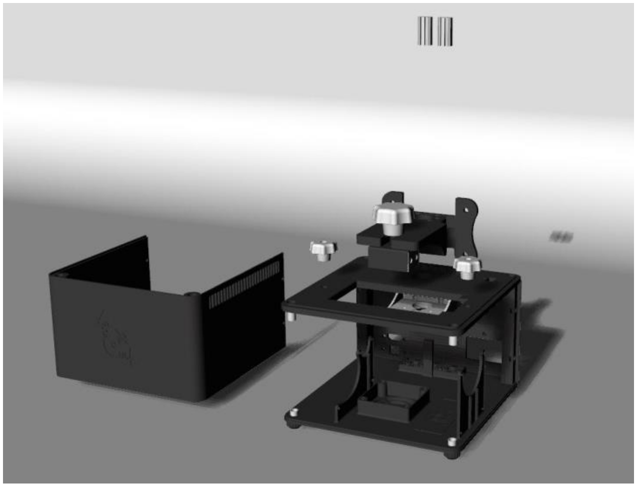

Fig. 3 All the non-metallic parts of the structure

After analyzing all the components, one by one (Figure 4), of the DLP printer designed by the FabLab ULL and assuming that they are replicated in a 3D printer type FDM, it is obtained that a printing time of 84.93 hours and approximately one kilo of PLA with a cost estimate of 49 euros.

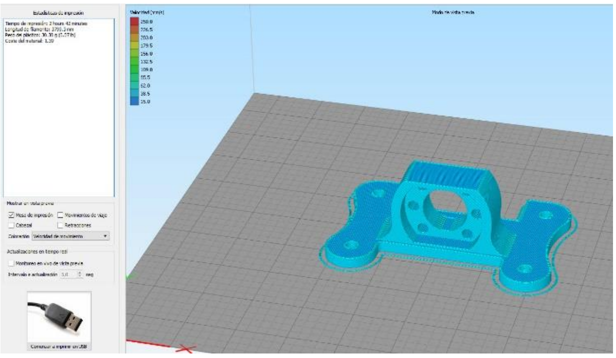

Fig. 4 Calculation of printing times, material expense and price of each component

A sample of some of the printed pieces, for the creation of the first prototype can be seen in figure 5. In the image it can be seen the assembly of some of the electronic and mechanical elements to validate the design of the pieces.

Fig. 5 3D printed parts

2) Laser cutting parts

Two pieces have been designed to be carried out by cutting machines (scissors can be used in case of not having said machinery). The parts designed for this procedure are the reflection cover and the top cover. In the repository the DXF and PDF files of these parts developments will be added so that these pieces can be made by any user. The reflection cover will need to be constructed with a reflective material. The estimated cost in material for the two pieces is around 5 euros. In Figure 6 you can see the development drawing of the reflection cover.

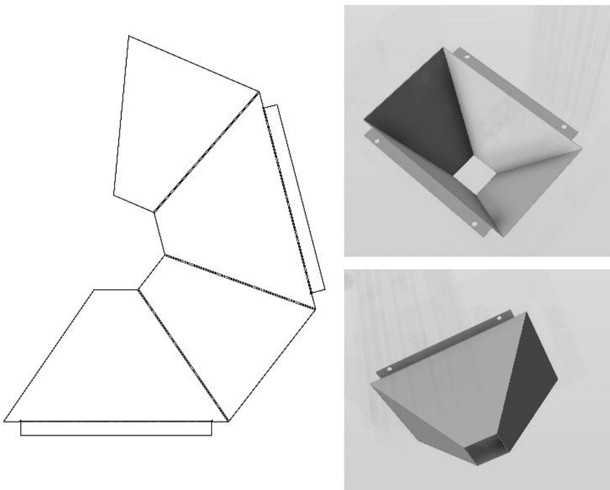

Fig. 6 Development drawing of the reflection cover

3) Electronic components

In this section, highlights the Arduino Mega 2560 with RAMP 1.4 including the DRV8825 drivers, as well as the LCD Panel (5.5 inch 2160x3840) with video board. This panel called 4K will improve the resolution of the printer in X and Y and is the most expensive component of the designed printer, with a cost higher than 200 euros. Also included in this section is a 0,9 degree Nema17 stepper motor. This motor allows that the movement in the Z axis has greater precision and therefore a better resolution. The rest of the electronic components include the 405 nm UV LED, the switches, two fans, two connectors and a 12 V 5A power supply. Some of these components can be seen mounted on the base in Figure 5 and the total cost of all of them can be calculated at 278.35 euros.

4) Mechanical parts purchased

This section includes those mechanical parts that are purchased by the user, such as V-slot 20x20 mm extruded aluminum profiles, the flexible shaft coupling, the Ball Screw, four V wheels and all the screws necessary for the assembly of the set (Figure5). The total cost of these pieces amounts to 108.93 euros. This price can be lowered significantly if the screw is installed of a lower quality choosing a Lead Screw 8 mm Thread 2 mm (300 mm length) with anti-backlash system (most of the low cost 3D DLP printer use this screw).

5) Control Software

For the management and preparation of the 3D models, one of the free and open source programs existing today will be chosen. Some of them are quite used, for example Photonic3D (suitable for developments with Rasperry Pi), or Creation Workshop Slicing and Control Software (suitable for Windows, Mac, Arduino,..). Many low-cost DLP printers recommend the use of some of these programs and for the prototype developed in the FabLab ULL, Creator Workshop has been chosen. The control software will be included in the documentation repository of the designed printer.

III. RESULTS

As a result of the design process of all the parts and the selection of components, it is obtained that the final cost foreseen for the printer, amounts to 441.3 euros. Table 3 shows the breakdown of the cost of the components according to their classification:

TABLE III
EXPECTED COST OF THE 3D DLP PRINTER:

Pieza	Cost in euros [a]
3D printed parts	49,0
Laser cutting parts	5,0
Electronic components	278,4
Mechanical parts purchased	108,9
Control Software	0
TOTAL	441,3 euros

As described in section A, the expected resolutions (theoretical) of the printer designed in the FabLab of the University of La Laguna are the following:

TABLE IV
EXPECTED RESOLUTIONS OF 3D PRINTER DESIGNED

Resolution	DLP 3D Printer FabLab ULL
Resolution X, Y	30 microns
Resolution Z	25 microns

IV. Conclusions

The expected cost of the DLP printer designed is significantly lower than the options available in the market. This price can only be achieved if a 3D printer type FDM is previously available, as is the case with most digital manufacturing spaces such as makerspaces.

The expected accuracy, in the absence of verification, is superior to low cost printers that can be purchased for the same price.

The open source policy of this development allows any small workshop to have access to this technology and not only test it, but also modify and improve the design according to their own needs.

V. Future works

As future work, we intend to test the functioning of the 3D printer designed, as well as calibrate the actual resolution obtained with a functional prototype of it. For calibration, printed samples will be verified by high resolution images. The final goal is to have a design with a higher resolution than those that can be found in the market of low cost printers. On the other hand, once this tool is available, tests of the creation of metallic micro sculptures will be carried out with micro fusion and electroforming processes.

Once the final resolution has been verified and a definitive design is available, an open source repository will be created where all the 3D models designed will be made available, as well as the technical documentation of all the electronic and mechanical components.

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