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3D DLP ADDITIVE MANUFACTURING: PRINTER AND VALIDATION

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Abstract. *Additive Manufacturing, also called 3D printing, has revolutionized design and product manufacturing and has been considered potential technology to change drastically the majority of present industries. Among the AM processes, Digital Light Processing (DLP) enables printing parts about 100 times faster than classical ones as FDM (Fused Deposition Modeling). This work aims to study the concepts of DLP 3D printer and presents the development of a prototype printer. A bench test was assembled to validate the principle of technology applying a regular video projector to emit an entire layer, stepper motor to continuous movimentation on Z-axis and two commercial acrylic based resins (white and black) using the techniques Top-Down and Bottom-Up. Smalls gears were manufactured and its morphology was visually analyzed. The suitable luminous energy density values obtained were 208.4 lm*s/mm^3 and 264.1 lm*s/mm^3 for the white and black resins respectively, the printing rate reaches more than 300 mm^3/min whit reasonable quality. The design goals of a functional 3D DLP printer and tests whit the resins were satisfactorily performed for Top-Down and Bottom-Up techniques .*

Keywords: *3D Printing, Additive Manufacturing, Prototyping, DLP.*

1. INTRODUCTION

Additive manufacturing (AM) is gaining prominence in the media and conquered the imagination of researchers in multiple areas. The basic principle of this technology is that a model, initially generated using a three-dimensional Computer-Aided Design (3D CAD) system, can be fabricated directly without the need for process planning (Gibson; *et al*., 2014; Lovo and Fortulan, 2016; Tang and Zhao, 2016; Volpato *et al*., 2017). The key to how AM works is that parts are made by adding material in layers or continuously according to the original CAD (Gibson; *et al*., 2014).

The Digital Light Processing (DLP) is an AM technology that utilizes photopolymerization process to fabricate 3D objects (Pallarolas, 2013; Barnatt, 2016). A DLP 3D printer projects the image of the part's cross section onto the surface of the resin, when a regular video projector can be used where the white light emitted provides enough UV light to resin polymerization. The exposed resin hardens while the machine's build platform (Z-axis) displaces "step by step" or continually as Continuous Liquid Interface Production called CLIP (Cunico, 2013; Tumbleston *et al*., 2015; Moin *et al*., 2016). The Figure 1 shows schematics illustrations of Top-Down and Bottom-Up the processes, both employed in the present work.

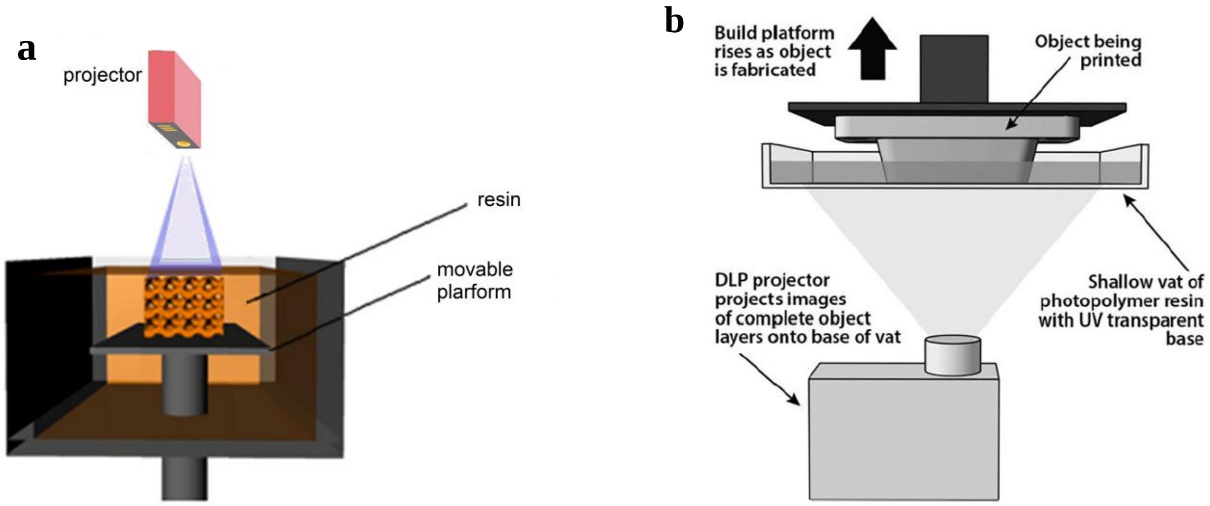

Figure 1. DLP schematic illustration. (a) Top-Down configuration, adapted from Wendel (2008). (b) Bottom-Up configuration (Barnatt, 2016).

Table 1 allows comparing general DLP 3D printer's characteristics observed in machines that employs Top-Down and Bottom-Up techniques.

Table 1. Characteristics of Top-Down and Bottom-Up techniques.

Technique	Advantages	Disadvantages
Top-Down	Easy monitoring Allows high viscosity resins	More expensive Require resin redistribution Require resin levelling
Bottom-Up	More economical Does not require leveling Lower resin consumption Uncured resin flows into the vat	Vat degradation Bottom adhesion Allows only high density resins

This work aims to develop a DLP 3D printer prototype for use the techniques Top-Down and Bottom-Up. Furthermore, it was expected to obtain the suitable building parameters by using the 3D printer prototype developed in this study.

2. MATERIALS AND METHODS

Information about DLP 3D printers were found in literature, printer's technical manual and patents, enabling the comprehension of the common problems in this technology. Afterwards, the main requirements of the design were raised in order to delimit the scope and mitigate possible errors.

The concept considered decisions of functions and solutions according the design requirements resulting: light projection in bottom-Up and Top-Down configurations; activation of linear motion by stepper motor; positioning in the Z axis by recirculating ball screw; linear ball bearings for guides; vat of silicon; polypropylene film with thickness of 0.2 mm manufactured by SPEX SamplePrep and aluminium for machine framework. It was also used a magnifying glass with 75 mm from Western manufacturer for light focusing and isopropyl alcohol for post-processing.

A common projector model Sony 3LCD VPL ES4 with light output of 2200 lumens was chosen. The resins tested were the types Snow White and Deep Black from Fun to Do manufacturer.

Figure 2 shows the optical principle employed in this work and the test bench used in Bottom-Up configuration with vat of Ø22 mm x 30 mm height and bottom covered with polypropylene film.

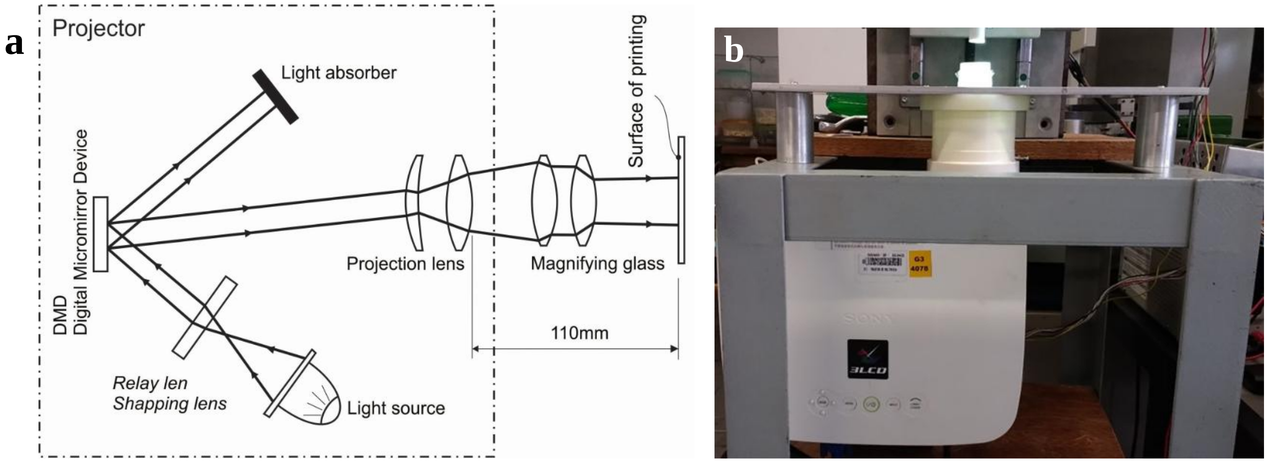

Figure 2. Test bench. (a) Optical principle employed. (b) The test bench used in Bottom-Up configuration.

The cross sections of the object to be printed were represented in a PowerPoint slide and it was projected onto the resin vat where both resins were tested. The Figure 3 shows the slides where the white part represents the object section on a black background, in (a) a small gear and in (b) two slides for holed cube.

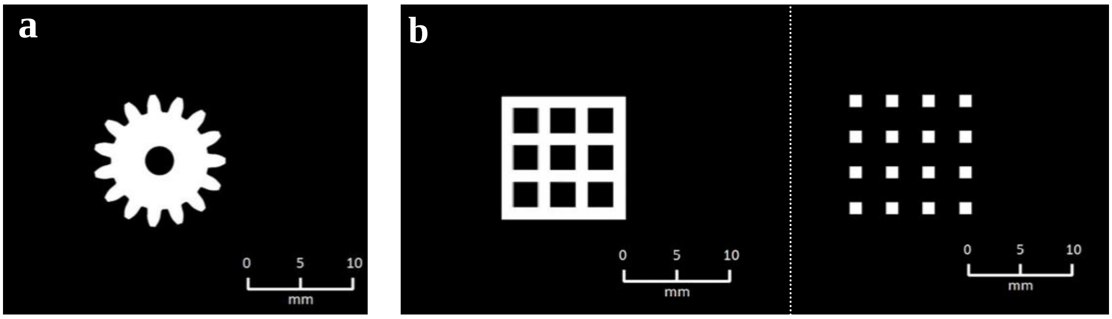

Figure 3. Cross sections slides. (a) Small gear. (b) Two slides for holed cube.

An important parameter in the DLP process is the Luminous Energy Density (*Uv*), which represents the amount of energy per unit volume. The calculation of this parameter for each manufactured test parts was done by Eq. (1):

$$Uv = \frac{L \times \Delta T}{A \times \Delta E} \tag{1}$$

Where:
L is the quantity of lumens (lm)
ΔT is the exposure time (s)
A is the cross-section (mm^2)
ΔE is the layer thickness (mm)

3. RESULTS AND DISCUSSION

Tests were performed to determine suitable printing parameters for the Top-Down configuration. Parts were made using Snow White resin (Fig. 4) and Deep Black resin (Fig. 5).

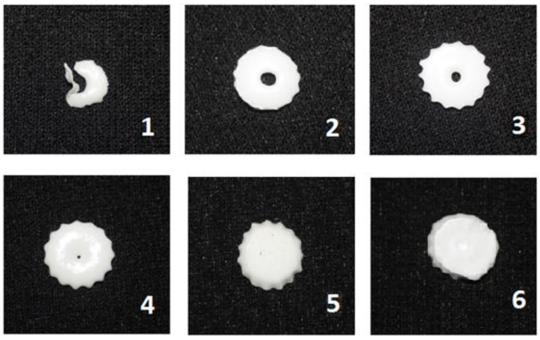

Figure 4. Small gears in Snow White resin.

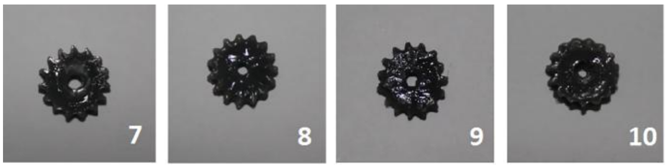

Figure 5. Small gears in Deep Black resin.

The parts shown in the Fig. 4 and Fig. 5 were made using different printing times for both resins. The results of Tab. 2 were obtained for different exposure times utilizing Snow White and Deep Black resins.

Table 2. Experiments parameters results for Top-Down configuration tests.

Part number	Resin color	Exposure time (*s*)	Thickness (*mm*)	Luminous energy density ($lm*s/mm^3$)
1	White	30	0.40	260.6
2	White	40	0.55	256.6
3	White	45	0.75	208.4
4	White	60	1.10	189.5
5	White	140	1.92	253.3
6	White	150	2.10	248.1
7	Black	80	1.31	252.7
8	Black	165	2.17	264.1
9	Black	170	2.21	271.9
10	Black	180	2.32	271.8

In the tests with Snow White resin the part 3 offered more accuracy and richness of details for projected object, which required luminous energy density of 208.4 $lm*s/mm^3$ for its manufacture. In the tests with Deep Black resin, the part 8 presented better resolution, with luminous energy density for its production of 264.1 $lm*s/mm^3$. In general, the parts with black resin presented higher quality when compared with the white resin. This phenomenon were observed and justified by their color, where the black resin is less translucent than the white, therefore the light spreads less and the object is solidified more effectively.

For the Bottom-Up configuration, the initial parameters of the test bench were determined such as focal length and amount of light needed to polymerize the resin.

Exposures of the slides shown in Fig. 3(b) were performed. The first slide was exposed 3 times, interspersed with the second slide. Figure 6 shows the newly prototyped bored hub still adhered to the PVC punch.

Figure 6. Newly prototyped bored hub with Bottom-Up configuration.

It was observed that some parts did not have perfect adhesion to the punch. It is possible to see in the Fig. 6 the non-homogeneous adhesion between printed material and PVC punch which contributed to flawed printed geometry. The parts with black resin presented higher quality when compared with the white resin as occurred with Top-Down tests.

The polypropylene film avoids adhesion between printed parts and bottom vat. The use of the polypropylene on the bottom of the printing vat proved to be an interesting artifice to ensure the quality of printed parts by Bottom-Up technique.

4. CONCLUSIONS

In this work, it was developed a prototype of a 3D DLP printer with simple and feasible design for use the techniques Top-Down and Bottom-Up and tests were performed with two types of resins.

The DLP printing is low cost and relatively precise compared to most common printing techniques as FDM and SLS. In addition, the good printing speed makes this technique promising for more application in general manufacturing.

Equipment and materials used to perform this study demonstrates the relative simplicity of 3D DLP printing practice. The results obtained in this work motivates more studies concerning DLP 3D printing with bigger vat volume for production of larger pieces as well as tests with other resins types and addition of particulate material to improve mechanical and optical properties.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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