

COMPARATIVE STUDY BETWEEN THE GENERATIONS OF 3D PRINTED PARTS BY THERMOPLASTIC OR OPTICAL POLYMERIZATION

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ABSTRACT: The work is focused on the identification of specific elements that can have influence on specific generation of components for equipment used in unconventional technologies. In the first chapter are analyzed the specific processes that allow the generation of component by 3D printing thermoplastic solution type FDM or photo polymerization by DLP or SLA solution. They are determinate the similarities and differences between transfers of the energy for thermic plasticization and the transformation in solid structure from liquid material in the second part with CAM system. In the third part are analyzed the solutions to generated constructive components or assemblies by 3D processes CAM-CNC process. In the fourth part of the work was analyzed the specific 3D printing parts through this process of printing considered. In the last chapter it is determined the economic aspects of the parts generated by the 3D printed process used. The analysis will be done both by optical and dimensional measurement of the part in different points and by dimensional measurement of the part with digital measuring devices and optical method. The paper also refers to the methodology of generating of the part and the influence of the way they generated on the characteristics of the generated parts.
KEY WORDS: 3D printing, surface dimension, FDM printing, DLP printing, fabrication parts, statistical data

1. CONSIDERATIONS ON THE PROCESS OF FDM AND DLP OR SLA 3D PRINTING

For the realization of assemblies or components for areas specific to conventional and non-conventional technologies, both the cost of realization and the technological accuracy and dimensioning of their realization and mounting are important. Additive-generating technologies it is the object of many studies in several works both nationally and internationally. Some of these concerns the problems of mechanical resistance [1], others on technological labor of product [2, 3], but also of functionality of this component [4].

The process of generating a part from a geometric point of view is relatively similar in the three-generation processes. For both types of printing processes FDM (fuse deposit modelling) and DLP (digital light processing) or SLA (stereo lithography) in the first phase, the CAD drawing of the part that is intended to perform physically must made in the same type. The importance of generation is evident for printing processes that are very accurate. For models that are for general use, but also for industrial type, it is possible to see that the most accurate printers are DLP-type [5, 6], followed by SLA type [7, 8] and the lowest precision of generating is FDM [9, 10]. In view of the latter conclusion, it is possible to say that depending on the functional role of the generated element, the printing principle and the method of generating chosen for the solid body.

Printers from the same range of printer used to generate the part with 3D printing process. For FDM are used a printer type Fabrikator Mini (Figure 1.). Printer price 180 Euro.

Figure 1. FABRIKATOR MINI FDM 3D printer [10]

The printing characteristics from printer consideration are:

- Print size 80x80x80 mm,
- Filament 1.75 mm,
- Z positioning precision 2,5 microns,
- XY positioning precision 11 microns,
- Printing speed for good structure 10 to 50 mm/sec, recommendation from [22], very good 10 to 20 mm/sec, good <40 mm/sec, normal<50 mm/sec,
- Nozzle diameter 0,4 mm,
- Nozzle plug maximum 250-degree C.

For printing with DLP printing type are using an ANYCUBIC PHOTON printer type (Figure 2.). Printer price 381 Euro.

The printing characteristics from printer consideration are:

- Print size 115x65x155 mm,
- XY DPI 47 micron,
- Z axis resolution 1.25 micron,
- Printing speed suggested 10 to 20 mm/hour,
- Rated power 40 Watt,
- UV 405 nanometer photosensitive resin,
- Suggested layer thickness 25 to 100 microns.

Figure 2. ANYCUBIC PHOTON DLP 3D printer [6]

For SLA are using a printer MOAI (Figure 3.). Printer price 1088 Euro. The printing characteristics from printer consideration are:

- Print size 130x130x180 mm,
- XY DPI 70 micron,
- Z axis resolution 15 micron,
- Printing speed suggested 0.9 to 2.0 mm/hour,
- Rated power 40 Watt,
- Laser power 150 m Watt,
- UV 405 nanometer photosensitive resin,
- Suggested layer thickness 25 to 100 microns.

Figure 3. MOAI SLA 3D printer [8]

In order to obtain a unified comparison, we will generate the solid body with maximum accuracy possible.

In (Figure 4.) it can see the first of the three parts CAD (Computer Aided Design) generated. The solution is for the variant without orifice.

For the highest possible resolution in the Fusion 360 program used to achieve the solid, 10.184 triangles are generated (Figure 2.). The dimensions of the surfaces generated are centralized in (Table 1.).

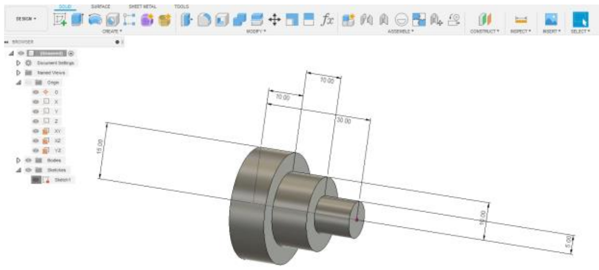

Figure 4. Columns setup

For the highest possible resolution in the Fusion 360 program used to achieve the solid, 10.184 triangles are generated (Figure 5.). The dimensions of the surfaces generated are centralized in (Table 1.).

Table 1. The dimension of generated elements

No.	Diameter in mm	Height in mm	Orifice 1 in mm	Orifice 2 in mm	Orifice 3 in mm
1	30	10	5	8	25
2	20	10	5	8	15
3	10	10	5	8	5

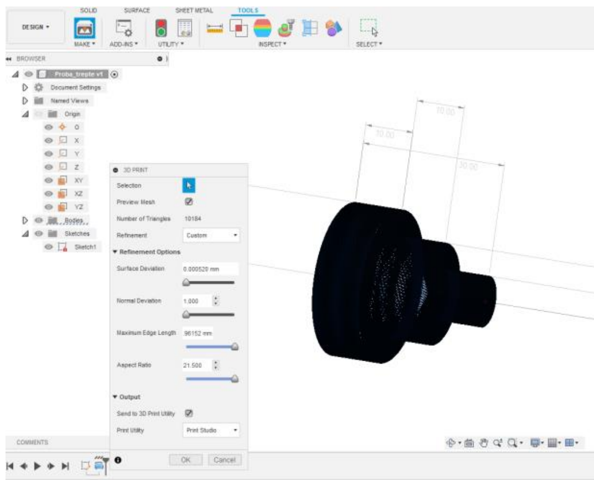

Figure 5. Part triangles generated without orifice custom version

The resolution for height generation are 2.088, for medium are 908 and for lower 572 triangles.

The analysis from the point of view of generated points on the circumference of the circle function of diameter and the resolution chosen is centralized in (Table 2.).

Table 2. The points in circumference in function resolution

No.	Resolution	30 mm	20 mm	10 mm
1	Custom	124	118	24
2	Height	174	92	58
3	Medium	98	78	54
4	Lower	60	58	36

From the analysis, it is possible to see that although the number of triangles is higher in the custom variant for certain diameters the number of points on the periphery of the circle is lower than that of the high solution. It recommended choosing the solution adopted in the technological generation process presented in (Table 3.) at which the dimension of line generated is the important element. For FDM thermal deposit of material, we can note that at a nozzle diameter of 0.4 mm with a distance between the nozzle and the print area of 0.2 mm we have a width of the generation route of 0.4 mm. For the optical curing processes, we have the diameter of the focal point specific to the optical element used as precision DP (distance point) in (Table 3.). To determine the maximum number of points on the periphery of the circular element will divide the perimeter of the circle to the DP.

Table 3. The points in circumference in function of type printing

No.	Deposit type	DP in mm	30 mm max	20 mm max	10 mm max
1	FDM	0,4	236	157	79
2	DLP	0,05	1884	1256	628
3	SLA	0,075	1256	837	419

If we compare the data resulting from (Table 2.) with those from (Table 3.) it is possible to noted that for the process of printing by thermal process acceptable results are obtained for a high precision of the generation of circles. However, for the other two processes we have much higher technological accuracy than the graphical generation of the solid part.

2. TECHNOLOGICAL CONSIDERATON ON SIMILARITIES AND DIFFERENCE BETWEEN TRANSFER OF ENERGY IN 3D PRINTING PART

From the point of view of the implementation of the CAD part to generate the solid part the processes are similar as shown in the first part of the work. Not the same compatibility is from the CAM (Computer Aided Manufacturing) point of view of the product of the component. Differences are both in terms of how the positioning of the solid body to printing it, but also from the point of view of the functional role of the supporting elements in the print process of the part.

2.1 Consideration on positioning solid body for printing

In the 3D printing process, both the solid positioning on the print surface is important and its orientation respectively. Some of the CAM programs have optimal orientation and centering in the center of the print area. It is possible to check the positioning on the print area so that there is no space between the lower surface of the body part for printing and the print area. These aspects are similar for any of the analyzed 3D printing processes.

Many programs allow positioning the solid body after certain functional rules that the programmer can consider and differ from optimal positioning considerations. Such an aspect is that of functional surfaces especially for generating FDM printing process, but not only. Due to this observation, the positioning of the solid body is very important. For the solid body considered in its forms the placement in printing process is optimum in central position to any of the print variants. In (Figure 6.) it is possible to see the positioning and auto orientation of part for DLP – SLA singular printing part.

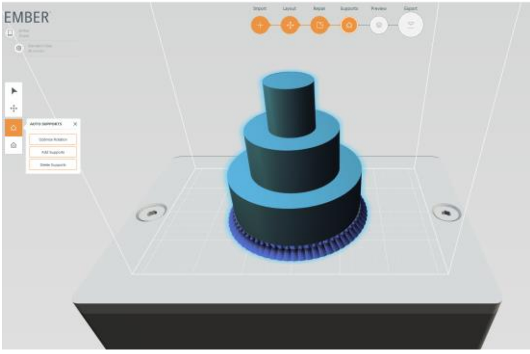

Figure 6. Positioning of solid body for singular printing DLP or SLA

In (Figure 7.) it is possible to see the positioning of part and auto orientation for FDM singular printing part.

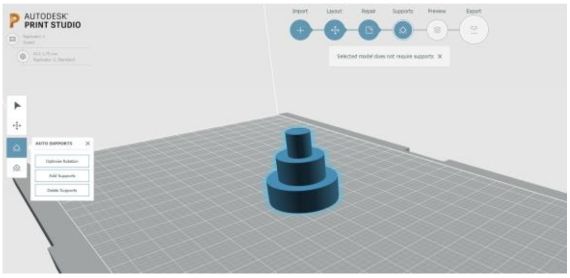

Figure 7. Positioning of solid body for singular printing FDM

However, if multiple items printed at the same time, an airier positioning for the FDM print body part (Figure 8.) and as balanced as the surface of the DLP and SLA variants recommended (Figure 9.).

Due to the size of the print area, but also of the size of the body generated that are subject to the 3D printing process, the components are grouped for the FDM case (Figure 8.) in group of three components.

We grouped the components that have a cavity or hole, separated by the one without the orifice. For this part are used the program IdeaMaker [11] (free program) which have a part for verify the integrity of the solid part generated and a part for orientation and generated the structure for support of the generated structure.

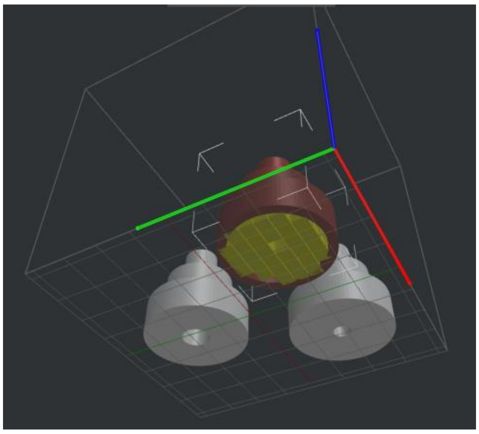

Figure 8. Positioning of solid body for multiple part for printing FDM

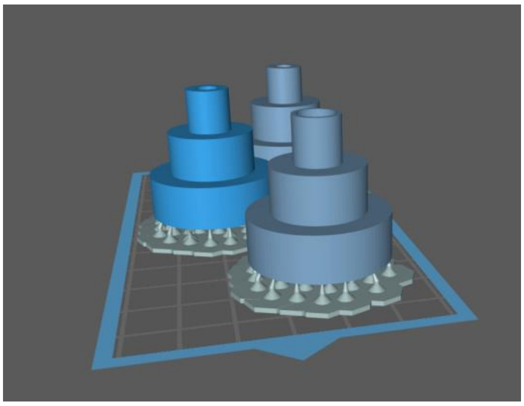

Figure 9. Positioning of solid body for multiple part for printing DLP or SLA

In figure, it is possible to see that only the structure with cavity had supports yellow color in figure.

For the DLP or SLA part solid body for printing are used the program ChiToBox [12] (free program) which have a part for verify the integrity of the solid part generated and a part for orientation and generated the structure for support of the generated structure. In figure, it is possible to see that all of the solid body had supports.

It is possible to see that from the point of view of generating for the DLP and SLA variants have a bottom structure flat and support elements of the lower part cone type. This is not necessary when generating part with FDM printing solution. Important to note that the role of inferior items is only for support and not to retrieve requests force developed in the print process as DLP and SLA variants.

2.2 Consideration on integrity structure of solid body for printing

The integrity of the solid bodies generated from the CAD part is important in order not to obtain the components with missing areas on the outside or inside part missing. Due to this, it is important to take in consideration that this operation. If there are defects of missing surfaces, interior structure gaps or other types of defects they must be automatically or manual corrected. Correction it is possible to make in the programs mentioned or in programs dedicated to the aspects of which the program dedicated like Meshmixer program from AutoDesk Corporation (free version) [18].

Regardless of the type of printer used in the making of the parts, this phase must not be missing.

2.3 Consideration on supports structure for printing

How the transfer or support elements generated to have an important role in the printing process.

Usual for the case of FDM printing between the supporting surface and the one that represents the solid body there will be a free space of one layer or maximum two. The role of this layer is to allow both a lighter detachment of the supporting elements, but also not to affect the generated surface of the solid body.

Compared to the previously mentioned role for supports due to the usual way of generating in the FDM printing process in the DLP or SLA printing process their role is a very high-importance on the mechanical aspects. Due to this aspect, both the positioning of the parts on the print surface and the dimensions of the supporting elements sections are important. Since the aspects of the placement of the supports but also their disposition it is take in consideration in other studied in previous works, we will no longer insist on this point [13-16].

3. CONSIDERATION ON GENERATION CONSTRUCTIVE PART BY CAM-CNC PROCESS FOR 3D PRINTING PARTS

An important step in the preparation of the 3D printing process is the generation of layer-related making parts. From the point of view of the generation of the layers, their processes are different between the methods in the study.

The DLP layer generation is an optical system. The layer is writing in HEX system and it consists in generation of the layer simultaneously by lighting at maximum or minimum intensity of light LEDs. In this way on the part of the liquid resin layer acts the light of the violet color 405 nanometers to allow the realization of the curing process. It therefore follows that the process it is possible to generate in the whole layer simultaneously. This makes the generation process relatively fast and with good productivity.

In (Figure 10.) it is possible to observe both the positioning of the parts in order to generate at the left side and a picture of the layer 196 of the 700 layers that it is possible to generate in order to make the components. The processing time is 2 hours and 54 minutes with a layer exposure duration of 6.5 seconds. At the bottom are eight layers with an exposure time of 50 seconds.

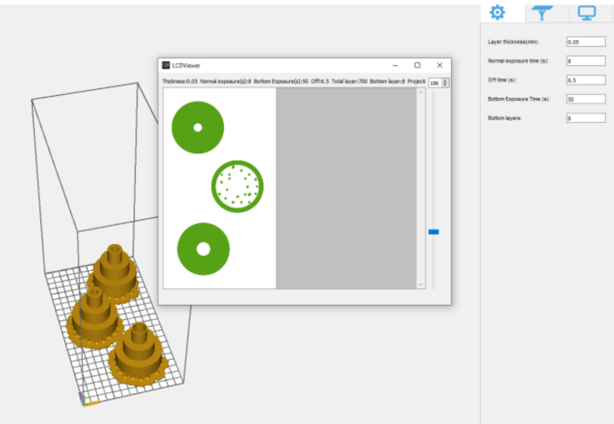

Figure 10. Positioning of solid body for multiple part for printing DLP or SLA

For the generation of layers was used the own program of the DLP printer type ANYCUBIC Photon Slicer64 [17]. An important step to check the integrity of the structure of the generated assembly is to check the structure to printing from defects, but also to correct them. This step it is possible to be make both with previously mentioned programs [12, 18] but with the program specifically designed for this Photon File Validator [19] operation. For the chosen milestones and position chosen this step is not necessary to achieve because, there can be no errors. A high advantage of the verification program is also that it provides information about the resin consumption used for the production of the parts. It must be observed (Figure 11.) that we can have an approximate information of the printing processing and an estimate of the cost of printing the components.

We thus confirm the processing time of 2 hours and 54 minutes, the number of layers generated 700, the lack of defects in the generation of layers (green information text) and the consumption of 29.6 milliliters resin. This value is compared with the value from generation part by printing.

Programs capable of working in the control G code adapted to each type of process it is possible to use to achieve layers for printing with FDM or SLA printers.

For FDM printing process it is possible to use two programs, which complement each other. First, it is the generation slicer program. For this part are used the Cura from Ultimaker program [20]. In the figure, it is possible to see both the layout of the parts for the generation of layers, but also how to select the parameters specific to the processing process.

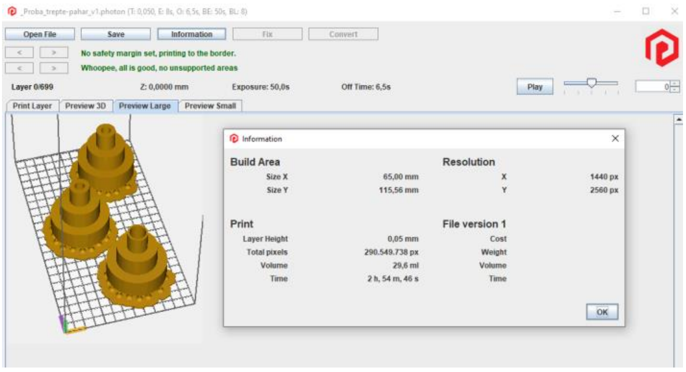

Figure 11. Verification of the slicer product for printing DLP

Some of these variables presented in picture it is important to be mentioned because they have influence on the quality of the parts made in terms of both rugoses and mechanical strength.

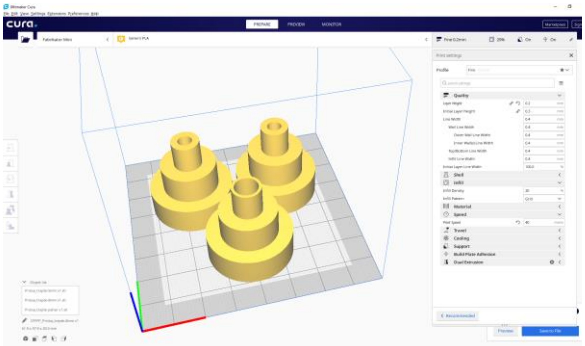

Figure 12. Positioning of solid body for multiple part for printing FDM

The main parameters involved in the layer generation process are:

- First layer thickness 0.3 millimeter,
- Layer thickness 0.2 millimeter,
- Print speed in all areas 40 millimeters/second,
- Print temperature 210 degrees Celsius with mass heated to 30 degrees Celsius from the printing process,
- Infill 20%
- Bottom and top layer three.

It is possible to see that from the point of view of the realization we have a printing time of 1 hour and 59 minutes, with an estimated consumption of 17 grams and a wire length used by 5.71 meters [Figure 13.].

In addition, for this type of FDM printing there are programs for checking the slicing program and correcting it where this is required. It is worth mentioning the RapR3D Visual G Code Editor [21] program that allows us to verify, made the identification of the parties in the program that have problems of generation, and we can intervene if it is necessary.

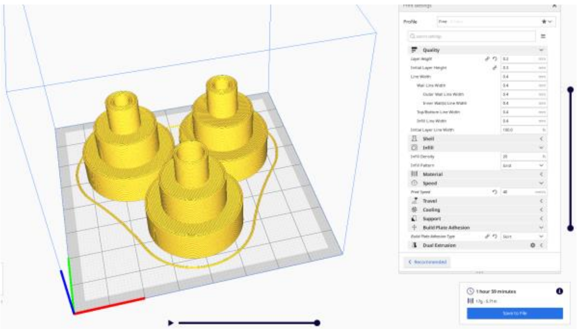

Figure 13. Layer generation for multiple part for FDM printing

In (Figure 14.) it is possible to see both the tree structure of the program generated on the left with color and the layer generated.

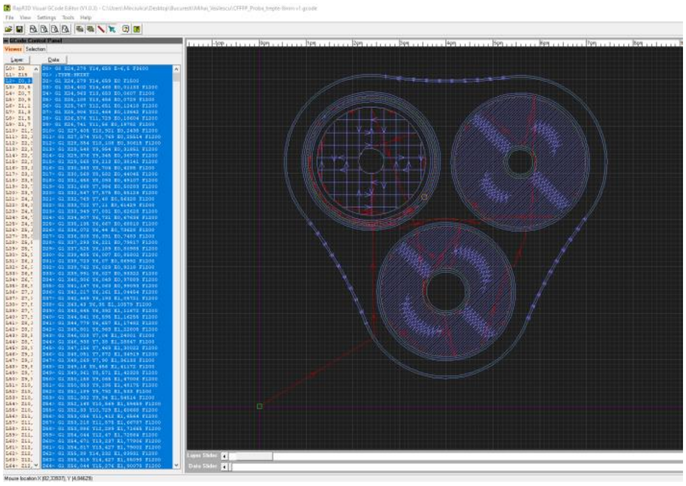

Figure 14. Verify layer generation for multiple part for FDM printing

Because layer generation mode is similar for SLA printing with the FDM printing on both the layer generation and the verification side of this we will not insist on this stage.

4. ANALYZING THE PARTS GENERATED BY THE CONSIDERED PROCESSES

Since the FDM print side has been analyzed in previous works for both prismatic and cylindrical landmarks, we will no longer analyses it in this paper.

The components printed on the DLP principle it is possible to see in (Figure 15.) and the data relating to printed parts shown in (Table 4, 5, 6.).

For the pieces it is determinate the mass with the side of the supporting elements. It is possible to observe their weight of 42 grams. It is possible to see that in the printing process the type of supports are high thickness. They have an effective diameter in the medium area of the 1.08 mm bracket. The printing it is possible to made with 8 seconds time for the generation of layer and 50 seconds for the lower grip that have 1.09 mm thick. In (Figure 16.)

The mass of the parts it is possible to see that is without the supporting elements of 34.4 grams. Therefore, a mass of supports 7,60 grams materials printed.

Figure 15. Multiple part for DLP printed with supports

Figure 16. Multiple part for DLP printed

Table 4. The dimension of generated elements hole 5 mm DLP printed

No.	Diameter in mm	Height in mm	Orifice 1 in mm
1	31,45	10,95	5,03
2	20,93	9,94	
3	10,55	9,93	5,14

Table 5. The dimension of generated elements hole 8 mm DLP printed

No.	Diameter in mm	Height in mm	Orifice 2 in mm
1	31,44	11,01	8,07
2	20,94	9,87	
3	10,54	9,95	8,31

Table 6. The dimension of generated elements hole 5 mm with cavity DLP printed

No.	Diameter in mm	Height inner in mm	Height inner in mm	Orifice 3 in mm
1	31,52	7,36	10,14	25,96
2	20,95	10,61	9,89	15,41
3	10,55		9,84	5,04

From the analysis of the measured data, it is possible to observe that there is a match between the data obtained for the central orifice. The exterior dimensions show an increase from projected values (Figure 17).

For the dimensions of the hole, you can see that there is a difference between the inner diameter at the base of the marker and the one at the top.

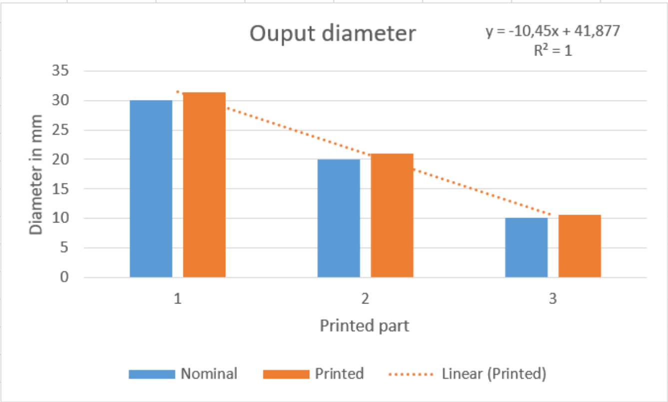

Figure 17. Deviation of exterior diameter for part for DLP printed

From the realized analysis it can be observed that in order to obtain a part at nominal value by printing the projected values must be corrected on the outside, height and inside with a value according to the regression equation determined in (Figure 17.).

5. ECONOMIC ASPECTS FOR THE FDM AND DLP 3D PRINTING PROCESS

In terms of cost of made the 3D printed components we have several types of costs. Most of them directly related to the realization of the components reason why they it is possible to called direct productive costs. Indirect productive costs are generally the same regardless of the technological process of 3D printing the parts.

5.1 Consideration on design and working costs

The design activity costs are relatively identical whichever print process you choose. The main reason is that the stages of the implementation of CAD-CAM-CNC are identical which it is possible to see from the comparative descriptions in the previous sub-chapters. For our parts, we will consider a duration of 1 hour with a cost of five Euro/hour.

5.2 Consideration on material costs

For the 3D printing of the parts, we need several types of materials.

The first of these is to enable the 3D printing process to make this to be possible to make it. We have material used for process that ensures the operation of cleaning the active surface. The materials used for cleaning have a relatively small value, being usually of paper type to erase flat surfaces or materials for cleaning the working surfaces. An important remark for DLP and SLA cases is the liquid to dissolve the remaining resin on the surface that is type 91% Isopropyl Alcohol (IPA) 10.72 Euro. It usually not reused so it is possible to calculate at an 8-hour production of 2 litters.

Another type of material is to increase the adhesion to printing or materials used to remove resides from the printed surface. The adhesion material commonly used for FDM printing and it is dependent on the type of material used for printing. The cost of this material is low. It is possible to approximate to 0.2 euros per series of printed series of parts. In the DLP and SLA processes, this type of cost is zero Euro.

The third type of cost is the materials for making the parts. The cost of the material from which the components are printed is dependent on the type of material used. Thus, the FDM for PLA material file for 1-kilogram good qualities has a cost of 18 to 60 Euro. Higher cost if it is use fiber-type or metal particles in PLA structure. For the resin used for the production of the parts by means of DLP and SLA, a cost per liter of material of 60 to 90 euros may be considered.

Finally, yet importantly are consumable materials that need to replace after a number of print processes. Because the value of these materials depends both on the parameters of the processing process, but also by the material that is processed their cost is difficult to estimate. For each of the processes in part, it is determined as a percentage of the cost of the material used to achieve the benchmark with a value of 10% of that cost.

5.3 Consideration on material costs

The cost of energy is dependent on the hourly power consumed by the printer and the duration of its unit price.

5.4 Consideration on investment costs

The investment cost is mostly dependent on the cost of the printer and respectively the number of components that expected to print in a calendar of one month. From calculations made for printed benchmarks it is possible to say that the cost is double to DLP compared to FDM and 20% higher at SLA front of DLP.

6. CONCLUSION

From the analysis realized it is possible to see on the one hand that the software solution for the generation of print layers is far behind the print accuracy for most of the printing processes.

Determining the cost elements in software programs does not fully respect the reality of the real printing process. This information requires for each of the procedures the calculation of the costs to make it in the final phase depending on the acquisition costs of the materials and the duration of the component's realization.

From a qualitative and dimensional point of view, the best results obtained with the DLP process, followed at the low distance from the SLA and the lowest results are for the FDM process. If, however, we consider only strictly the layout of the printing costs

7. ACKNOWLEDGEMENTS

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