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Comparing the accuracy of 3D slicer software in printed end-use parts

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Abstract. This study aims to compare the accuracy offered by 3D Slicer Software in printing end-use parts inside a Fused Deposition Modeling process of Additive Manufacturing. The purpose, in particular, is to investigate the surface quality and the dimensional stability of the manufactured parts comparing the effect of selecting a different 3D Slicer tool among *Simplify3D, Cura* and *Slic3r 3D*. With this scope, parts were produced using these process tools while results were analysed in terms of accuracy, production time and consumption of material. Results, graphically and visually presented, show significant differences in the dimensional and surface accuracy with an optimum outcome offered by the *Simplify3D* as best 3D slicer tool. The *Simplify3D* slicer has essential advantages in printed end-use parts because creates the 3D models with significantly better accuracy and quality support.

1. Introduction

The Fused Deposition Modeling (FDM) [1] is a relatively new technique for Additive Manufacturing (AM) [2], perfectly integrable as a process step in a modern and flexible manufacturing system [3]. This process is based on a technological evolution of the Rapid Prototyping (RP) process [4] that has evolved and expanded with the scope to produce end-use parts and final products [5, 6] embracing from medical applications [7] to architecture [8], aerospace [9] or automotive[10].

The FDM has achieved a large increase in all spheres of applications nowadays, from the professional one to the amateur domain. In this additive manufacturing process, wax or plastics are extruded, layer by layer, through a nozzle which follows the cross-section of a part, forming the part's geometry [11]. When a layer is done, the platform descends and the nozzle starts with the inflexion of the following layer [12]. This technology can use different types of materials including ABS [13,14], polyamide [13], polylactide [15], polyethene and polypropylene (including their reinforcements [16]), considering also unexpected materials as melted wax such as wood thermoplastics [17], advanced metals and ceramics [18]. The process can also benefit of 3D slicer software to transform a blueprint/model that it creates for printing and transfers to the machine, determines the speed of extrusion, optimizes the tool path for printing the object and controls the orientation of an object and the formation of layers [19-20]. Commercial FDM printers were developed and established by Stratasys [21]. The RepRap project [22] was started in 2005 in developed low-cost do-it-yourself FDM printers. Based on the RepRap, other printers were developed such as Makerbot [23], Ultimaker [24]) also allowing low-cost 3D printers to possibly produce end-use parts and reproduce parts of themselves. In the integration with a 3D printer, a good 3D slicer software is very important. If a good slicer tool is used, it will surely get better results, even from a mediocre 3D printer. Otherwise, any valid 3D slicer tool will create a geometry based on an STL-file successfully, describing coordinates, printed speed, nozzle and bed temperatures, advanced dimensional accuracy, support requirements and other accuracy variables (further detailed in [25]). An FDM process with a commercial printer was used to create several rapid prototyping models. The application of the appropriate slicer software for processing has a direct impact on the quality of the printed parts, as in the case shown in Figure 1.

With this work, we want to showcase a subset of slicing tools to compare the accuracy offered by 3D slicer tools for parts production were the used upgraded low-cost FDM printer. The following 3D slicer software was compared: *Cura* (Free), *Slic3r* (Free) and *Simplify3D* ($150) [26]; examining the differences in terms of print quality as well as the selection of optimal processing parameters in the case of a low-cost/easy accessible FDM printer. The aspect of the accuracy of final products is not trivial for the use of such a technology on real market-oriented applications (as reported in [27-29]).

Figure 1. RP in-scale model of a Solar Car [30].

For this purpose, we selected two final parts that we printed on the same printer and processed the selected slicer tools under the same criteria. The aim is to examine the impact of slicing tools on the accuracy of 3D printed parts and the difference between slicer tools versus the print quality that is being achieved.

2. Experimental Setup

For the testing, two end-use parts were used: the *Phone Holder* (figure 2) and the *Pendant* (figure 3). The selected elements can have wide use in the demand of the customer because the design can be customized at the customer's request to change and adapt to a wider extent. In the dimensional accuracy and quality testing experiment, they are well-representing requirements that are required from parts for the free market as in the manufacturing of the RP model in the automotive industry. After executing additive manufacturing, the final parts were used to test the models in comparing the accuracy of the 3D Slicer software.

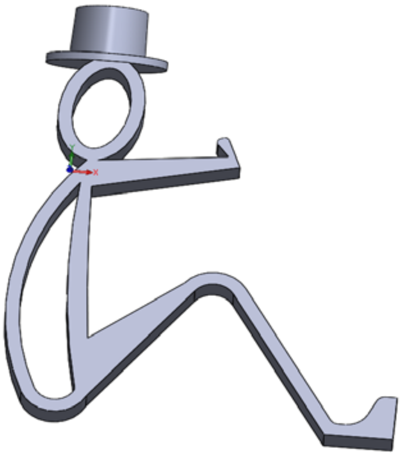

Figure 2. The CAD model of the Phone Holder (in SolidWorks software).

Figure 3. The CAD model of the Pendant (in SolidWorks software).

2.1. FDM printing technology

The printer used in this research was a low-cost 3D printer (*Infitary M508*) based on FDM technology as shown in figure 4.

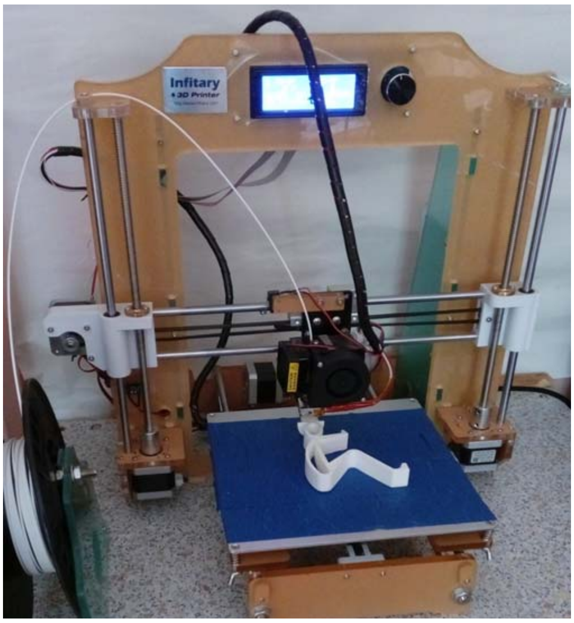

Figure 4. Low-cost 3D printer (*Infitary M508*) based on FDM technology.

The main technical characteristics of the desktop 3D printer used during the investigation including the independent variables are listed in table 1.

Table 1. Main technical characteristics of the desktop 3D printer.

Technical characteristics	3D printer *Infitary M508*
Printing technology	Fused Deposition Modeling
Standard nozzle	0.4mm
Best printing size	200x200x180mm
Support off-line print	Micro SD card printing

Print speed	30 – 120mm/s
Extruder head temperature	185 – 260 ^{0}C
Hot bed temperature	0 – 100 ^{0}C
Print head number	One
Printing materials diameter	1.75mm
Printing materials	PLA, ABS, HIPS etc.
XY axis positioning accuracy	0.012mm
Z axis positioning accuracy	0.004mm
Support file format	STL, G-code, OBJ

Using the selected low-cost FDM 3D printer, the manufacturing can be made in-house, which would enable time and cost savings.

2.2. Used material

Materials used to fabricate custom-parts were Polylactic Acid (PLA), a biodegradable thermoplastic derived from corn starch and sugar cane. PLA is environmentally friendly, safe to use and it is now the most advised used material for 3D printers. All parts are printed with PLA filament of the diameter 1.75 mm and machine nozzle size 0,4 mm. PLA has high mechanical strength and also good properties [31,32], able to expand its potential applications. The manufacturing temperature of PLA can be up to 230 ^{0}C, and the print bed temperature usually used is 50 ^{0}C.

2.3. Slicing software used

It is very important to have the right slicing software because, with the appropriate setting, the best quality print is possible. The slicing software that converts digital 3D models based on the settings to the 3D printer and to create a part. The slicer calculates how much material it will need and how long it will take to do it. In conclusion, all processed information is generated into a *GCode* file that is sent to the printer. For the comparison of the accuracy of slicer tools, three of the most popular following packages (as of February 2019 [26]) were selected:

- *Cura*, free open-source software developed by *Ultimaker* includes all settings for 3D printer slicing application [33]. The basic settings menu has possibilities the view mode Layers, Transparent, Overhang and Normal which are distributed in different tabs as and the following operations: rotate, scale and mirror.
- *Slic3r,* free open-source software, developed by Alessandro Ranellucci supported by several contributors [34]. Editing the model is performed via a four-tab interface: *Platter, Print Settings, Filament Settings* and *Printer Settings*.
- *Simplify3D*, one of the most common slicing software on the market. The software allows a huge variety of options to settings offering: extruders, layer control, various infill methods, temperature and cooling settings, import of *STL, OBJ* or *3MF* files, scale, rotate and repair 3D model. The software is compatible with many different printers, and it provides very good speed and control.

2.4. Slicing software configuration

For every part (the pendant and the holder) the same slicing software configuration was used to set the print parameters. The basic settings menu of *Cura* (version *15.04*) printed the pendant and the phone holder as shown in figure 5. Identically, the setting print parameters were used by slicer software *Cura, Simplify3D* and *Slic3r* (version *1.3.0*) for printing parts.

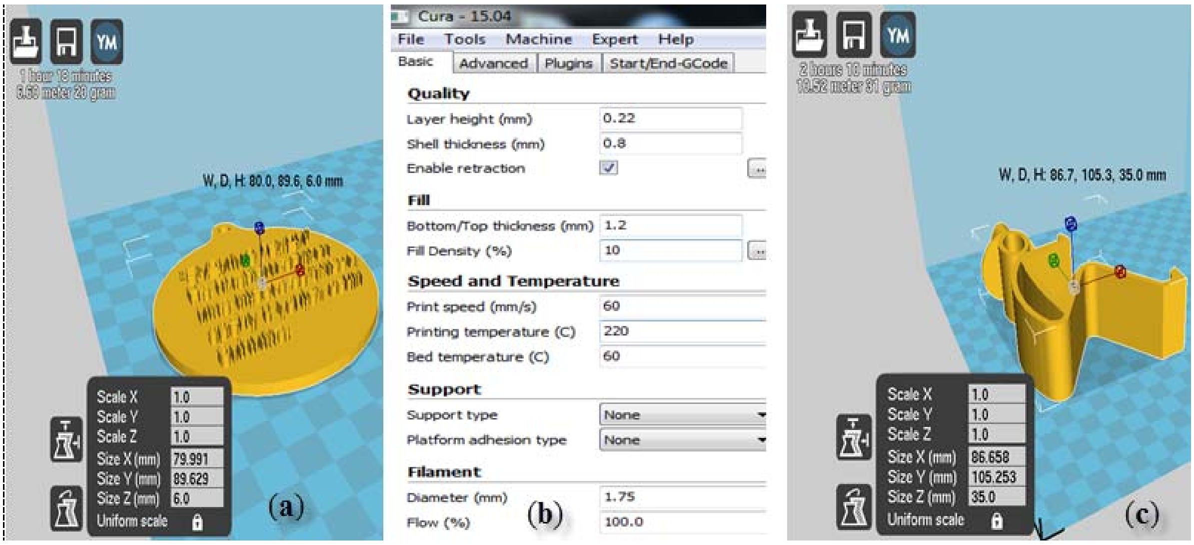

Figure 5. Basic settings of *Cura* (ver. 15.04) (**b**) as used to print the pendant (**a**) and the phone holder (**c**).

Two end-use parts were the set with the same print parameters used in *Cura, Simplify3D* and *Slic3r* as listed in table 2.

Table 2. 3D slicer settings print parameters adopted.

3D slicer settings print parameters	*Cura,Slic3r, Simplify*
Quality: Layer height	0.22 mm
Shell thickness	0.8 mm
Nozzle size	0.4 mm
Fill: Bottom/Top thickness	1.2 mm
Fill Density	10 %
Fill Pattern	Rectilinear
Print speed	60 mm/s
Extruder head temperature	220 ^{0}C
Bed temperature	60 ^{0}C
PLA filament: diameter	1.75 mm
Support structure build	None
Platform adhesion type	None
Flow compensation	100 %
Print time: (Pendant-*Cura*)	1h 18min
Print time: (Holder-*Cura*)	2h 10min
Print time: (Pendant-*Slic3r)*	1h 21min
Print time: (Holder-*Slic3r*)	2h 15min
Print time: (Pendant-*Simplify)*	58 minutes
Print time: (Holder- *Simplify)*	2h 5min

All parts have been printed using a low-cost 3D printer (*Infitary M508*), as represented in figure 4, without support structures and also without raft which improved the print platform adhesion.

2.5 Metric used for accuracy of slicing software and measuring print quality

For deviations between the printed part and the original part, the following metrics were used for measuring part deviations: very small deviation (<0.2 mm), small deviation (0.2–1 mm), rough deviation (1–2 mm) in the normal surface. Missing material in the shortest perpendicular: very small gap (<1 mm), small gap (1–2 mm), large gap (2–8 mm). Furthermore, the metric used for measuring text print quality was: Perfect, Readable, Partially readable, Not readable.

3. Results and discussion

The dimensional accuracy measurement of each printed part has been done using the *Digital Vernier Calliper* that offers a calliper precision of 0.01 mm. In Figure 6 (I) and (II) the locations used for measures are shown. Results of dimensional accuracy concerning the use of different slicing tools are listed in table 3. In particular, 5 samples for each slicer tool were considered, calculating the average value, as reported in columns under the label *'absolute'* (mm). For each of these mean values, the deviation in respect to the reference value has been calculated in mm and percentage. Observations on the achieved results for the accuracy of the printed parts analyzed were made for each used slicer tool. Figure 7 shows the pendants as done by printing the same geometry using three different slicer tools: *Slic3r, Cura* and *Simplify3D.*

3.1 Observed results for Slic3r software

The measurement results show that the dimensional deviation between the 3D model and the value of the printed parts for the indicated labels (a) to (j) (table 3) was in the range from 0.10 mm to 0.61 mm and in percentage 1.34% to 6.72%. According to the metric for measuring parts deviations in the surface normal, it belonged to the category of "small deviation" (0.2-1 mm). The measurement of the shortest perpendicular, label (g) and (h) (figure 6), was realized with a deviation from 0.12 mm to 0.20 mm, which belongs to the class: "very small gap (<1 mm)". As regards the readability as a quality indicator for the size and details of the visibility of the letters that were printed, the Slic3r tool did not become the required quality, as shown in Figure 7. Print time for the Pendant: 1 hour 21 minutes, and of the Holder: 2 hours 15 minutes.

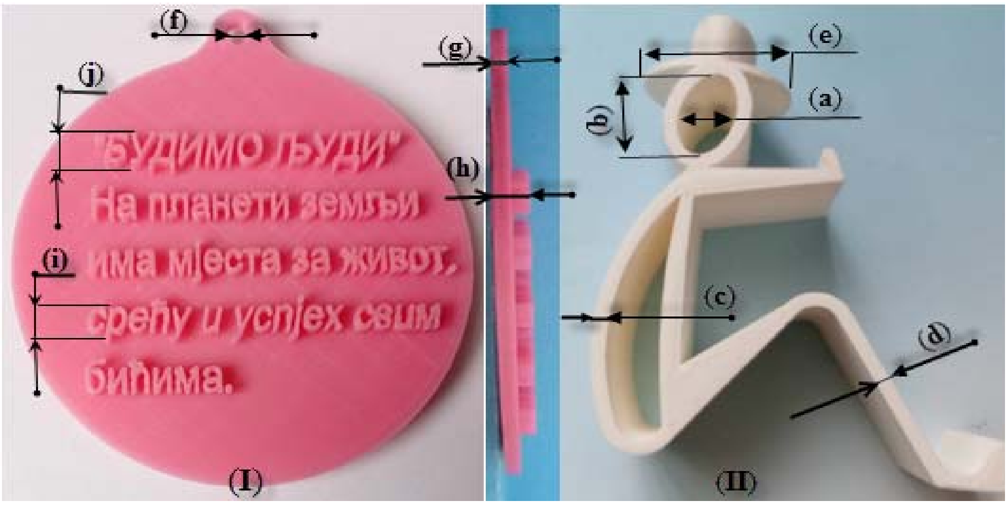

Figure 6. (I) Locations measured with the calliper by the pendant and (II) locations measured with the calliper by the phone holder.

Table 3. Results of the measurement dimensional accuracy by the pendant, figure 6 (I), and the phone holder, figure 6 (II) with different slicing tools.

	Reference	*Slic3r*			*CURA*			*Simplify3D*		
Label	Model [mm]	absolute [mm]	deviation [mm]	[%]	absolute [mm]	deviation [mm]	[%]	absolute [mm]	deviation [mm]	[%]
(a)	12.00	11.63	0.37	3.08%	11.77	0.23	1.91%	11.86	0.14	1.16%
(b)	21.00	20.61	0.61	2.90%	20.66	0.34	1.62%	20.96	0.04	0.19%
(c)	3.00	3.10	0.10	3.33%	3.05	0.05	1.66%	3.02	0.02	0.66%

(d)	3.00	3.19	0.19	6.33%	3.13	0.13	4.33%	3.12	0.12	4.00%
(e)	26.00	25.65	0.35	1.34%	25.68	0.32	1.23%	25.80	0.20	0.77%
(f)	5.00	4.81	0.19	3.80%	4.81	0.19	3.80%	4.85	0.15	3.00%
(g)	3.00	2.88	0.12	4.00%	2.92	0.08	2.66%	2.99	0.01	0.33%
(h)	6.00	5.80	0.20	3.33%	6.22	0.22	3.66%	5.85	0.15	2.50%
(i)	4.11	4.34	0.23	5.59%	4.29	0.18	4.37%	4.25	0.14	3.40%
(j)	5.65	6.03	0.38	6.72%	6.01	0.36	6.37%	5.93	0.28	4.95%

3.2 Observed results for Cura (version 15.04) software
It is possible to say that better dimensional accuracy respect to the use of *Slic3r* slicer tool was achieved when using *Cura 3D*. The dimensional deviation between the 3D model and the printed parts, as measured in the normal direction in respect to the surface, ranged from 0.05 mm to 0.36 mm (from 1.23% to 6.37%). These results fall inside the class of: "small deviation" (0.2-1 mm). The dimensional accuracy in the shortest perpendicular was achieved in deviation from 0.08 mm to 0.22 mm, label (g) and (h) shown in figure 6, which belongs to the class: "very small gap" (<1 mm). The pendant with complex letters done printed with good quality achieved a high level of detail, shown in figure 7. Print time for the Pendant: 1 hour 18 minutes, and of the Holder: 2 hours 10 minutes.

3.3 Observed results for Simplify3D software
The *Simplify3D* slicer software has achieved the best quality and dimensional accuracy of printed parts. The dimensional deviation in the surface normal was done in the range from 0.02 mm to 0.28 mm and in the percentage 0.19% to 4.95%. These results belong to the class: "small deviation" (0.2-1 mm). The deviation in the shortest perpendicular also was done with the best accuracy: from 0.01 mm to 0.15 mm, and these results belong to the very small class (<1 mm). The visually analyzed quality and accuracy of the printed complete letters are readable and close to the original shape, shown in figure 7. Print time for the Pendant: 58 minutes, and of the Holder: 2 hours 05 minutes.

Figure 7. Photograph of the pendants manufactured by printing from three different slicer tools: *Slic3r*, *Cura* and *Simplify3D.*

4. Conclusions
For quality test comparison, the corresponding parts that were printed on a low-cost 3D printer were selected and processed with three 3D slicer software: *Slic3r* and *Cura* (open source and free) and *Simplify3D* (powerful and professional). The comparison of the precision in the printed parts showed significant differences in the quality achieved with the three tools used.

According to the metric for measuring parts deviations in terms of dimensional accuracy in the surface normal, the *Slic3r* software has done from 0.10 mm to 0.61 mm which belongs to the class from small deviation. But if visibility is taken into consideration as an indicator of surface and letter quality, then the Slic3r software has not achieved a satisfactory quality level.

The *Cura* (version 15.04) software achieved better dimensional accuracy than the *Slic3r* slicer tool. The dimensional deviation between the 3D model and the printed parts was done from 0.05 mm to 0.36 mm, which is also in the range of small deviation. The surface and complex letters of parts, *Cura* was done with good quality and achieved a high level of detail.

The *Simplify3D* slicer software has achieved the best quality and dimensional accuracy of printed parts. The dimensional deviation was in the range from 0.02 mm to 0.28 mm. The visually analyzed quality of surface and letters of the printed parts are corresponding and close to the original shape.

Thus, it is possible to conclude that the slicer *Cura* gave good, but not necessarily accurate results. *Simplify3D* slicer has essential advantages because it has many detailed settings of the 3D model and also creates better quality support. The recommended software is firstly the Simplify slicer, then the free *Cura* slicer for processing not only low-cost but also semi-professional and professional 3D printers.

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