

DETERMINATION OF INFLUENCE OF PART ORIENTATION ON PRODUCTION TIME IN 3D PRINTING

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Rapid Prototyping and Rapid Manufacturing have significant role in modern production of parts. One of the crucial aspects in all manufacturing is production time (besides the consumption of material and all other elements). In 3D printing several parameters have influence on production like quality of finished surface, mechanical properties of the part, part accuracy, consumption of material for building part and support and building time. In this paper the influence of part orientation on production time will be discussed.

Keywords: Rapid prototyping, Part orientation, Printing time.

INTRODUCTION

The main activity in technological preparation of production is manufacturing process planning and process optimization. These activities are crucial part of modern global production in order to create optimal process plans in accordance to productivity, cost-effectiveness, production accuracy and surface quality, (Lukic et al., 2017).

One of the first step in modern part design is the possibility of simulation of static stress on created model (for example using Finite Element Method on shaft, (Asonja et al., 2016)). The next step is Rapid Prototyping.

“Rapid Prototyping (RP) enables the quick production of physical models using three-dimensional Computer-Aided Design (CAD) data. Used in a wide range of industries, it allows companies to turn innovative ideas into successful end products rapidly and efficiently.” (Chartier & Badev, 2013, p. 489).

“RP is an essential part of the process of system designing and it is quite beneficial as far as reduction of project cost and risk is concerned.

Depending on the technologies involved, it is referred to as Solid Freeform Fabrication (SFF) or freeform fabrication, digital fabrication, automated freeform fabrication, 3D printing, solid imaging, layer-based manufacturing, laser prototyping and additive manufacturing.” (Chartier & Badev, 2013, p. 489).

Additive manufacturing presents less wasteful technology than any subtractive method and among many potential sustainability benefits, three stand out: improved resource efficiency, extended product life and reconfigured value chains, (Ford & Despeisse, 2016).

In general product manufacturing, time is one of the parameters for optimization. It depends on several aspects such as, demanded product quality, complexity of production, consumption of material, machine characteristics, number of parts etc. In serial production and in small series production and prototyping the usage of Additive Manufacturing and Computer Aided Technologies, has greatly shorten the time of part production, as well as time for design and creating prototypes.

Alexander, Allen and Dutta (1998) in their work determine the influence of part orientation in layered manufacturing on cost of production. One of the direct influence in their work on cost is production time based on part orientation (others are part accuracy, volume of support material, part contact area with the support etc.).

Many authors done their work on optimizing the part orientation in AM for different aspects. For example, Cheng et al. (1995) worked on multi-objective optimization of part-building orientation in stereolithography considering part accuracy and build time. Their main criteria was part accuracy and after that was satisfied the build time was considered. The authors take in consideration only the number of slices for the build time. They developed the algorithm for deriving the optimal part orientation.

Thrimurhthulu, Pandey and Venkata Reddy (2004) developed the methodology for determining the optimal part orientation based on surface roughness and build time in Fused Deposition Modeling.

In the work of Durgun and Ertan (2014) it is shown that raster angle and part orientation have

affected the surface roughness, mechanical properties and production cost (production time and support material).

All of the previous work have one thing in common. In order for the optimization model to be precise more conditions has to be considered (build time, surface accuracy, surface roughness, etc.). In this paper only one segment is going to be analyzed and that is the build time and how does part orientation have influence on it in Fused Deposition Modeling process.

ADDITIVE MANUFACTURING, RAPID PROTOTYPING AND RAPID MANUFACTURING

“Additive manufacturing (AM) is layer-based automated fabrication process for making scaled 3-dimensional physical objects directly from 3D-CAD data without using part-dependent tools. It was originally called ‘3D Printing’ and is still frequently called that.” (Gebhardt, 2011, p. 2)

In Figure 1 the application sheet of Additive manufacturing is represented.

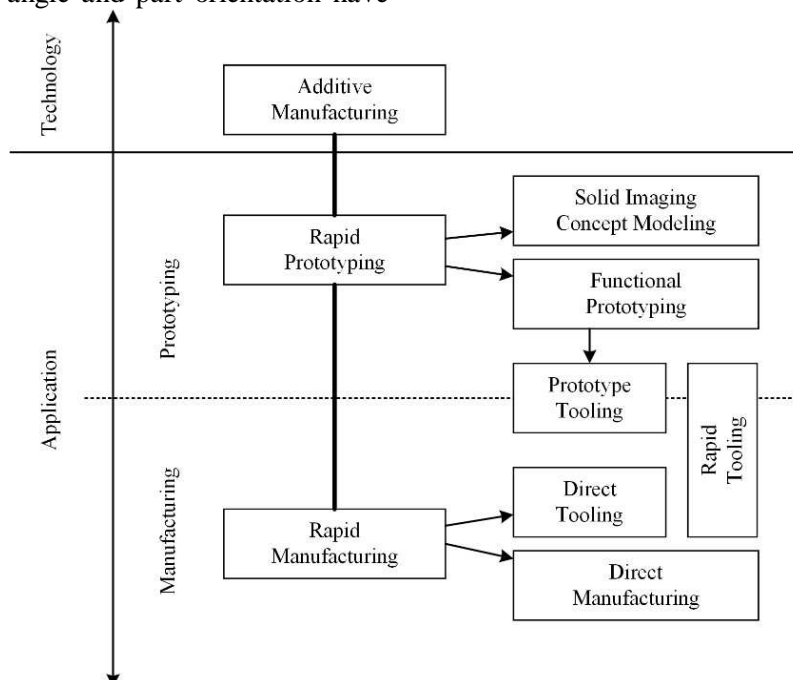


Figure 1: Additive Manufacturing (AM) Application Sheet: Technology – and Application Level Definitions (Gebhardt, 2011)

Figure 1 describes two basic levels: Technology level where Additive Manufacturing belongs because all of AM processes represents the

technology for creating finished part, and Application level where AM is used for creating

physical part. In that level there are Rapid prototyping and Rapid manufacturing.

For Rapid prototyping there are two processes:

- Solid Imaging and Concept Modeling – this is a prototype model for determining spatial design of parts and basically represents concept of a model
- Functional Prototyping – prototypes that show some of the characteristics of finished part in order to examine functionality.

Rapid Manufacturing represents all finished parts (parts that have all demanded properties). In this segment there are two concepts depending on usage of the finished part. If the part is used in product assembly it is Direct Manufacturing, or if the part is used for creating the mold or tool (used in machine for injection of plastic) it is Direct Tooling.

Direct Tooling is used for creating molds and tools for series production. But when there is need for small series production, these tools are too expensive so Prototype Tooling process takes place to describe building parts for creating temporary molds.

Both Direct Tooling and Prototype Tooling are named Rapid Tooling.

Additive manufacturing process

Selection of the most suitable AM process for particular application can be difficult because there are many technologies and materials available today. Selecting appropriate technology depends on wanted dimensional accuracy, surface finish and post processing requirements.

AM have many different technologies due to the way of layer creation and material used (Redwood, 2018):

- **VAT photopolymerization** (SLA – Stereolithography, DLP – Digital Light Processing, CDLP – Continuous Digital Light Processing)
- **Material extrusion** (FDM – Fused deposition modeling)
- **Material Jetting** (MJ – Material Jetting, NPJ – NanoParticle Jetting, DOD – Drop on Demand)
- **Binder Jetting** (BJ)
- **Powder bed fusion** (MJF – Multi Jet Fusion, SLS – Selective Laser Sintering, DMLS/SLM –

Direct Metal Laser Sintering/Selective Laser Melting, EBM – Electron Beam Melting)

- **Direct energy deposition** (LENS – Laser Engineering Net Shape, EBAM – Electron Beam Additive Manufacturing)
- **Sheet lamination** (LOM – Laminated Object Manufacturing)

Basic steps of AM process are:

1. Creation of 3D model. 3D model is used for manufacturing object. It can be created in two ways: using CAD software or by digitalization of existing 3D object (with 3D scanner)
2. Conversion of CAD file to one of standard 3D printing formats (STL, AMF, 3MF, etc.)
3. Setting up the machine. In order to set up part for 3D printing it is required to import prepared file and to set up printing parameters.
4. Printing of part. In this step machine controlled by computer prints part. The procedure depends on AM process type (SLS, SLA, FDM...)
5. Removing the part. After printing, depending on process type, some of the procedures needs to be applied (for example cooling of part) and then part can be removed. Additional post processing can occur (cleaning, painting, polishing...).

Fused Deposition Modeling (FDM) – technology, materials and application

Fused Deposition Modeling is, in technological sense, on somewhat lower level than other AM technologies. FDM process forms solid models, extruding and depositing liquid thermoplastic material in layers on moving platform. Extrusion of materials is done on temperature lower than melting point of thermoplastic material. The temperature of the platform is lower than temperature of nozzle (extrusion is done via extruder head and nozzle) so that thermoplastic rapidly hardens. FDM process is relatively simple but it is constricted to thermoplastic materials and wax for precise casting.

Material used in this process is in fiber form, called filament, wound on spool. Using servomotor filament is unwinding and transfers to printing head where it melts and extrudes through nozzle on the printing surface. After depositing, material is cooling and eventually solidifies (over couple of seconds). After the formation of layer, printing

head moves up and the process of depositing is repeated.

Layer width is determined by nozzle size. Layer thickness depends on printer resolution. Resolution of model must be defined in initial printing settings.

The range of the material used in FDM process is wide and depends on desired part characteristics. Some of the materials used in FDM process and their application are:

- Acrylonitrile Butadiene Styrene (ABS)– very durable, lightweight and slightly flexible. It requires temperature of 210-250°C. It is widely used and it is one of the cheapest materials. Disadvantage is that it has intense fumes during printing.
- Polylactic acid (PLA) – biodegradable thermoplastic from renewable resources and has biocompatibility with a human body. It requires lower temperature than ABS and it is also used in numerous applications.
- Polyvinil alcohol (PVA) and High Impact Polystyrene (HIPS) – these two materials are used mainly for printing support in printers with dual extruder but also have many different applications too. Feature of these materials is that they can be dissolved (PVA in water and HIPS in colorless liquid hydrocarbon). PVA is used for printing models with overhangs that normally would not be printed, and HIPS is used in food industry for packaging, for trays in medicine etc.
- Nylon – material that is not widely spread as ABS or PLA but have some useful characteristics. There are different types that are used in varieties of industry such as automotive industry (Nylon PA6Polymer – durable material, tough with high tensile strength, gloss and elasticity) and others. It can be dyed with fabric dye and needs to be stored in dry places because of ability to absorb water from air.
- Wood – type of filament that is used to model objects that looks and smells like wood. It contains mixture of recycled wood and binding polymer.
- PolyEthylene Terephthalate (PET) – hard and shockproof material used for lightweight models.
- PETT (tough glass) – similar to PLA and tougher than PET. It is biocompatible, strong

and FDA approved for manufacturing food containers.

- Polycarbonate (PC) – industrial grade material, extremely strong and impact resistant. Because of its characteristics (like biocompatibility and ability to be sterilized) it is used for prototyping, functional testing, tooling and composite work.

EXPERIMENT

Determining of printing time based on part orientation was done on PrimaCreator P120 3D printer with usage of PLA material.

3D printer PrimaCreator P120 (Figure 2) is FDM printer with single extruder. Other characteristics are shown in Table 1.



Figure 2: PrimaCreator P120 3D printer

Table 1: Characteristics of PrimaCreator P120 printer

Property	Value
Build volume	120 x 120 x 120 mm
Layer resolution	0.1 mm
Nozzle diameter	0.4 mm
Print speed	Max 55 mm/s
Operating nozzle temperature	Max 250 °C
Platform temperature	Max 60 °C
Filament diameter	1.75 mm
Removable platform	No
File format	STL/OBJ

PrimaCreator P120 can work with variety of materials such as ABS, PLA, HIPS and similar. The characteristics of PLA material used in experiment are shown in Table 2.

Table 2: Characteristics of PLA material used in experiment

Property	Value
Technical Name	Polylactic Acid (PLA)
Chemical Formula	$(C_3H_4O_2)_n$
Color	White
Melt Temperature	157-170 °C
Typical Injection Molding Temperature	178-240 °C
Heat Deflection Temperature (HDT)	49-52 °C at 0.46 MPa
Tensile Strength	61-66 MPa
Flexural Strength	48-110 MPa
Specific Gravity	1.24
Shrink Rate	0.37-0.41 %

The model was made in AutoCAD 2015 software and exported as STL file, and as such used with Cura software, version 15.04.6 for slicing and creation of G-code. Parameters used for printing part in all four cases are the same:

- Thickness of layer is set to 0.1 mm
- Shell thickness is set to 0.4 mm (minimal size because the nozzle size is 0.4 mm).
- Infill of the part is 100 %
- Print speed is set to 50 mm/s
- Printing temperature is 195 °C, and temperature of the bed is 55 °C.
- Support is set to be done everywhere, and the type of support is grid.
- Filament is set to 1.75 (filament thickness) and usage is 100%

CAD model is shown in Figure 3, and printed part is shown in Figure 4.

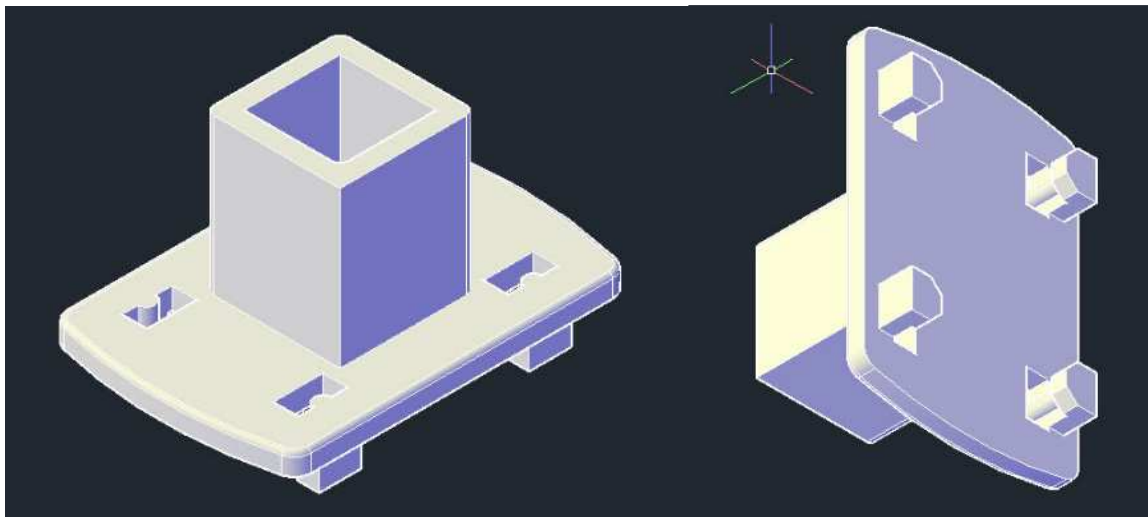


Figure 3: CAD model of part used for determining printing time based on part orientation

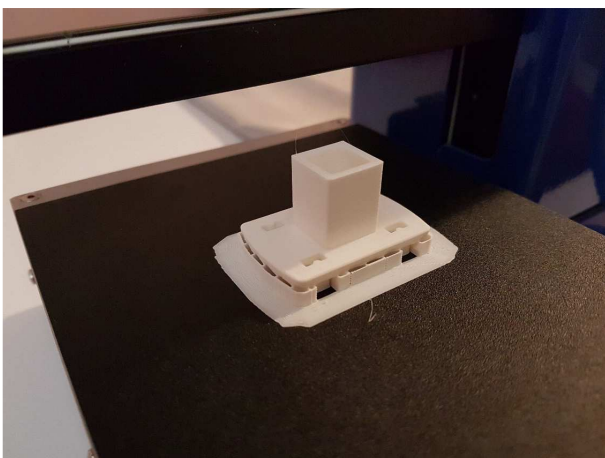


Figure 4: Example of printed part

In Table 3 it is shown the production times determined by software and actual production times on 3D printer and in the Figure 5 through Figure 8 the different positions of production part can be seen.

Table 3: Comparative table of software production time and production time on 3D printer

Different part orientation positions	Estimated time by software [min]	Determined time after printing [min]
Position 1	92	145
Position 2	80	117
Position 3	131	190
Position 4	76	107

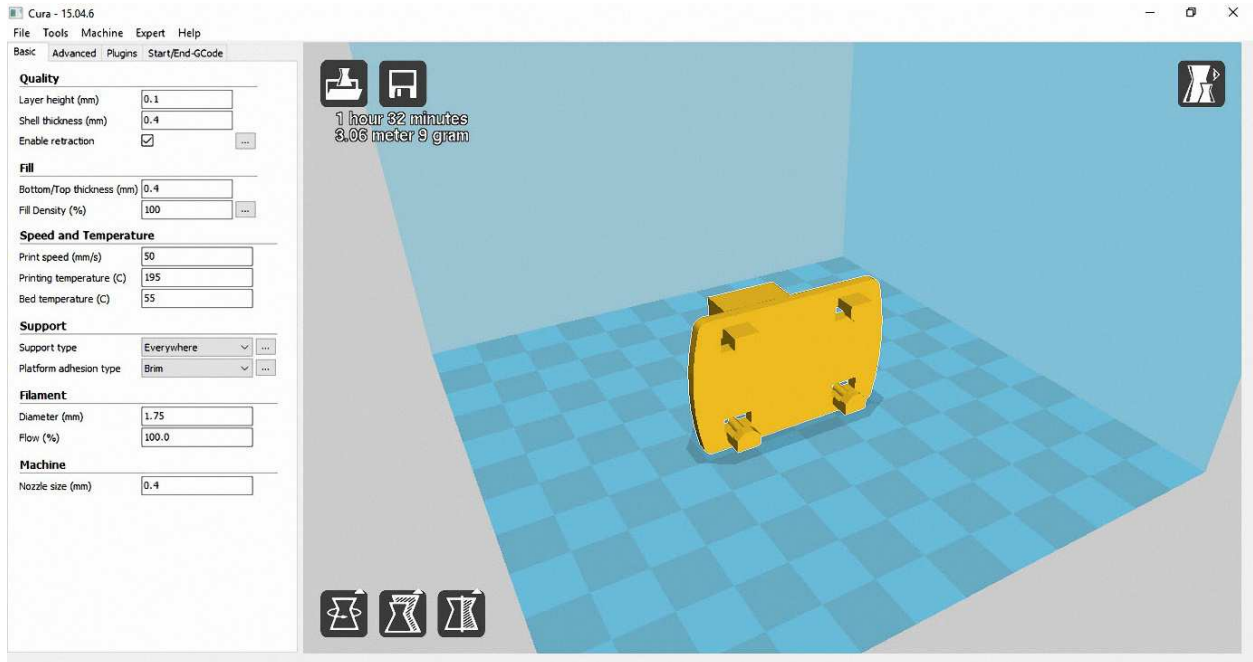


Figure 5: Position 1

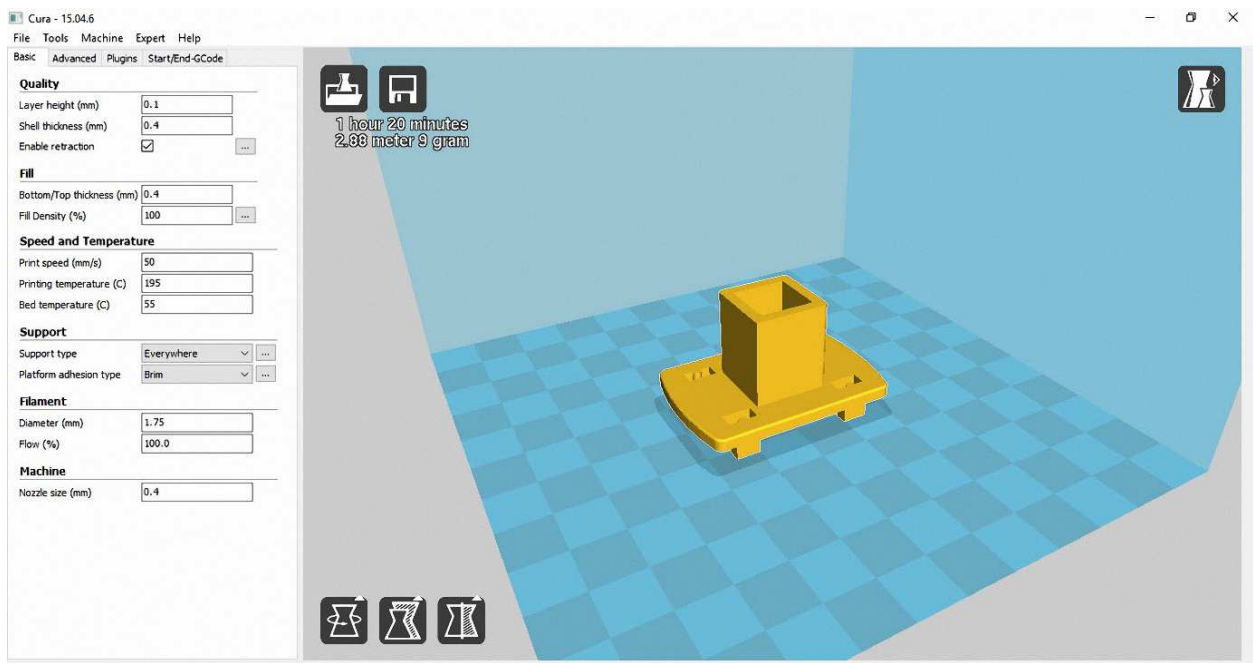


Figure 6: Position 2

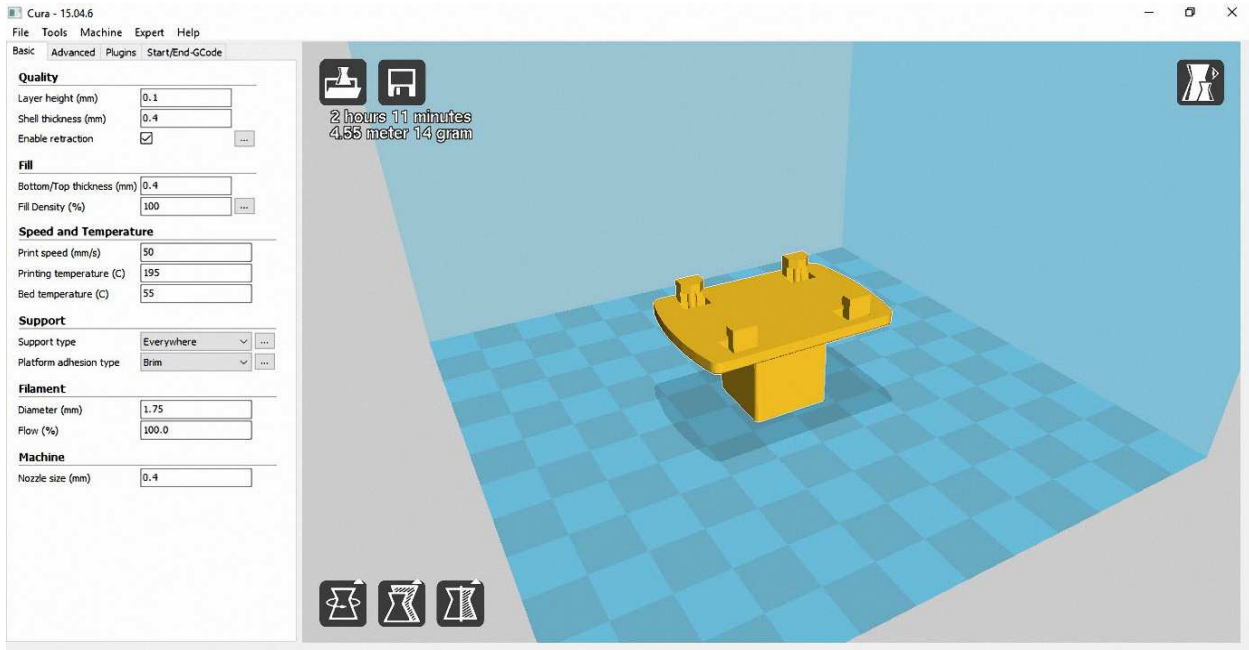


Figure 7: Position 3

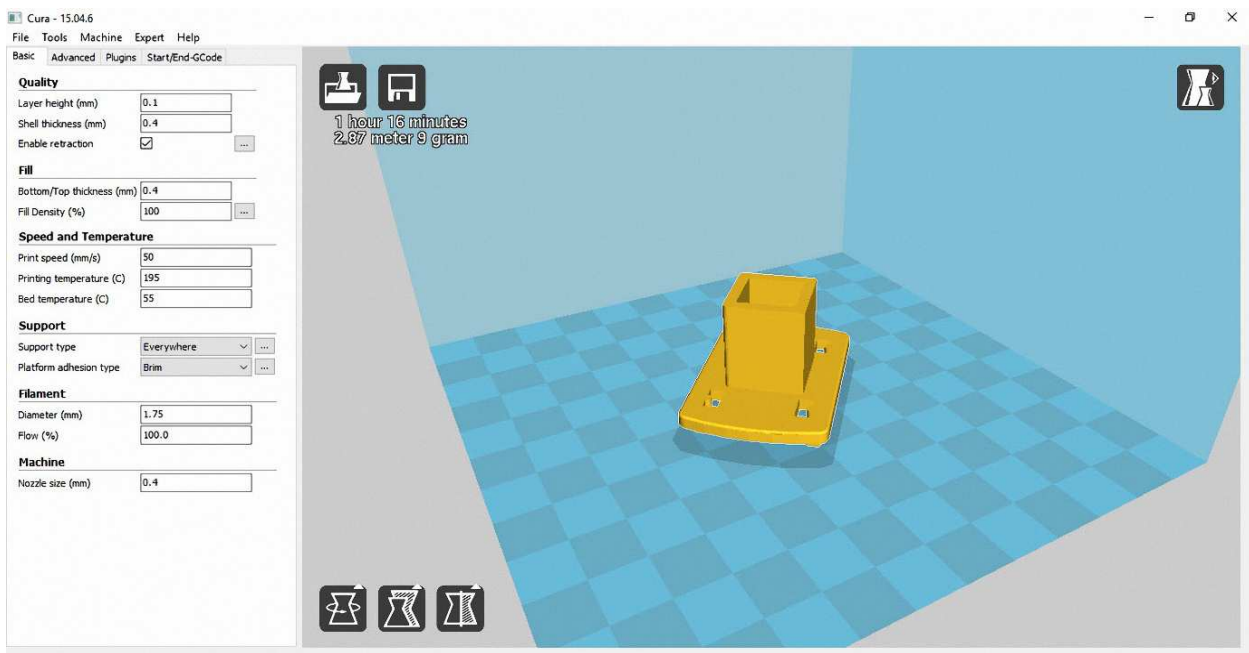


Figure 8: Position 4

DISCUSSION

The data obtained from experiment are graphically presented in Figure 9.

From the graph it can be determined that there is huge difference between estimated time and print time for each individual position. Also, it is shown that if the same part is oriented differently the print time varies.

The difference between estimated software time and real print time can be from several reasons:

- Software used for slicing (Cura) is recommended by the manufacturer but is used for multiple types of 3D printers, that behaves differently.
- Some of the technical aspects can't be predicted, for example, time to reach specific temperature of extruder head and printing bead. They vary because of incomplete information (printer temperature before printing etc.)

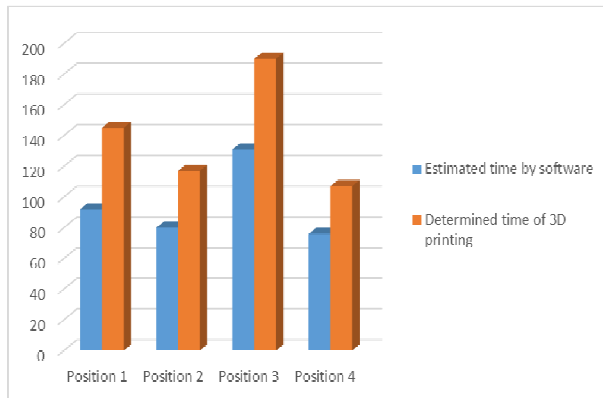


Figure 9: Time determined by Cura software and time measured in printing by part position

For the positions 1 and 3, printing time is greater than the time of the positions 2 and 4. This is due to different printing of support for part (in order for the part to be printed correctly the position and amount of material for support is different). The difference also comes from different number of slices. Also, in position 2 and 4, although the shape of the support and number of part slices (same height of the printed part) is the same there is still a difference in printing time, just by changing the part orientation. This is probably because of different paths in layer printing algorithm.

In the works described in introduction, all researchers came to the conclusion that part orientation affect production time, but all research was conducted in correlation with 2 or 3 conditions with production time (surface roughness, part accuracy etc.). So it can not be concluded to what extend the part orientation have influence only on production time.

CONCLUSION

This paper considers the influence of part orientation on printing time. In rapid prototyping, and production in general, there are different parameters that have impact on cost of production. Introducing additive manufacturing in modern production there are many gains, especially in production of parts in small series. As such, in AM itself there are many technical parameters that determine production time and production quality such as part orientation.

It is shown that:

- There is a difference in production time between the predicted and real time

- Even the slightest change in part orientation can affect production time
- The number of slices has impact on production time, but even in cases where the number of slices is the same, in different part orientation, there is still difference in time.

It can be concluded that with the change of the part orientation the printing time can be influenced. The experiment conducted on printer PrimaCreator P120 shows that part orientation has great impact on printing time and also on usage of material (for printing support, etc.). By properly determining the part orientation it can be influenced on production time, and thereby lowering production costs of production process.

In some future research the primary goal will be to determine the parameters for part orientation in order to achieve optimal production time.

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UTVRĐIVANJE UTICAJA ORJENTACIJE DELA NA VREME PROIZVODNJE PRI 3D ŠTAMPANJU

Brza izrada prototipova (Rapid Prototyping) i brza proizvodnja (Rapid Manufacturing) imaju značajnu ulogu u modernoj proizvodnji delova. Jedan od najznačajnijih aspekata u celokupnoj proizvodnji je vreme proizvodnje (pored potrošnje materijala i drugih elemenata). U 3D štampanju više parametara ima uticaj na samu proizvodnju kao što je kvalitet završne površine, mehanička svojstva dela, preciznost izrađenog dela, potrošnja materijala za izradu dela i podloge, vreme izrade. U ovom radu biće diskutovano o tome kakav je uticaj orijentacije dela na vreme proizvodnje.

Ključne reči: Brza izrada prototipova, Orijentacija dela, Vreme štampanja.