Parametric Study on Printing Time and Cost of Component in 3D Printing

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Abstract:The field of Rapid Prototyping (RP) encompasses a wide variety of new methods, technologies and applications that has already stimulated some fascinating research in the past few decades. Among various RP techniques, 3D printing has become particularly popular in recent a year that enables fabrication of objects that find applications not only in engineering field but also in daily life. In this paper, a CAD drawing of a component is made in AutoCAD software and converted into STL file. Afterwards, Slicer software have been used to see the effect of triangulation on output file size and compare it for solid, hollow and fillet component. Effect of number of layers, layer thickness and orientation on printing time and cost have been studied for solid, hollow and fillet components. The study shows that when solid component converts into hollow there is a 67% increase in number of triangles and this increase is 600% when shape changes from hollow to fillet. This also increases the STL file size due to formation of shorter triangulation which provides better approximation. In the study, the effect of layer thickness and use of support material in fabricating the component on printing time and cost is determined. In addition, the optimum angle of orientation from x, y or z axis is also suggested in the study that require less support material resulting in reduced printing time and thereby offering low cost in fabrication of the part.

Keywords: Rapid Prototyping, Printing Time, Printing Cost, Stereolithography (STL).

1. INTRODUCTION

In competitive market, there is requirement for shorter product development time as the product life cycles have been reduced due to increased variety and customization. The field of rapid prototyping encompasses a variety of new methods technologies and applications to manufacture the product with wide applications of dispersion and deposition principle [1]. In literature, 3D printing is popularly known by varied names such as additive manufacturing (AM), solid-free form (SFF), rapid prototyping (RP) [2]. In simple terms it is the process of fabricating materials layer by layer for a given drawing which was first described in 1986 by Charles Hull [3]. This technology creates objects by adding materials to reduce waste while reaching satisfactory geometric accuracy [4]. To accomplish 3D printing, a meshed 3D computer model is created by acquiring an image data or structures built in computer-aided design (CAD) software by a STL (Surface Tessellation Language) file. Thereafter, this mesh data is further sliced to create a build file of 2D layers and subsequently sent to 3D printing machine [5, 6]. To convert a CAD file into a STL file, the continuous geometry of the CAD file is transformed into small triangles, header, coordinates or triplet list of x, y, and z coordinates as well as the normal vector to the triangles. Once a model is defined, the boundary of the model is tessellated into a collection of triangular facets, approximating the intended design of the part and written to a file in the STL format [7]. There is a loss of accuracy during slicing process as continuous contours are replaced by discrete stair steps by the algorithm [8].

The current study has following two objectives:

- To study the variation in number of triangles and its effect on output file size, weight and cost of printing for solid, hollow and fillet object.
- To study the effect of layer thickness and orientation on printing time and cost for solid, hollow and fillet object.

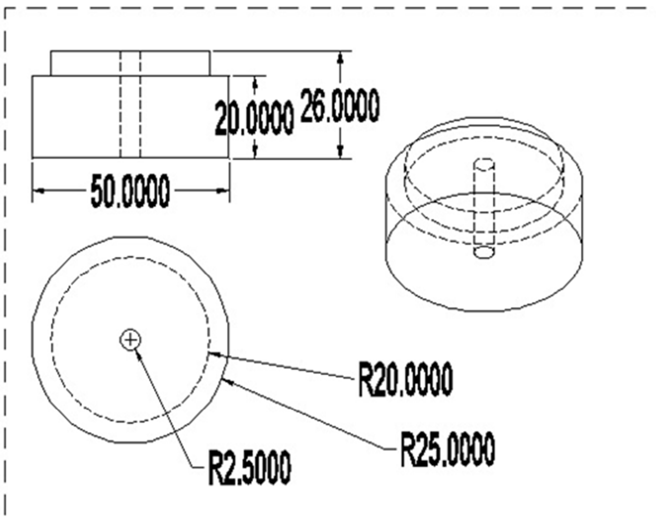


Figure 1: CAD model of the object

2. METHODOLOGY

In this work, following steps have been adopted to accomplish the study:

i. Selection of a three-dimensional object for the study.
ii. Preparation of CAD model of the selected object.
iii. Conversion of CAD model of object into STL format.
iv. Analysis of STL file and reporting the findings.

3. PREPARATION OF CAD MODEL

A three dimensional CAD design of a cylindrical object selected for the study has been prepared using AutoCAD software. The object has 50 mm diameter and 20 mm length mounted by another cylindrical portion of 40 mm diameter and 6 mm height as shown in Figure 1.

4. CONVERSION OF CAD MODEL TO STL FILE

The CAD file obtained has to be converted into stereolithography (STL) file. The accuracy of this conversion depends upon the number of data sets. The generation of STL triangulation can be made more efficient by using large data sets [9]. The given surface is divided into a number of triangles which are defined by the coordinates of three vertices and a surface with a direction normal to the solid volume of the object [10]. A factor called 'triangulation tolerance' is used to determine the size of STL file which specifies how smooth the approximation of the surface or solid will be. In simple terms, it determines the proximity of the triangles that approximates the surface [11]. The STL file for the object is shown is Figure 2.

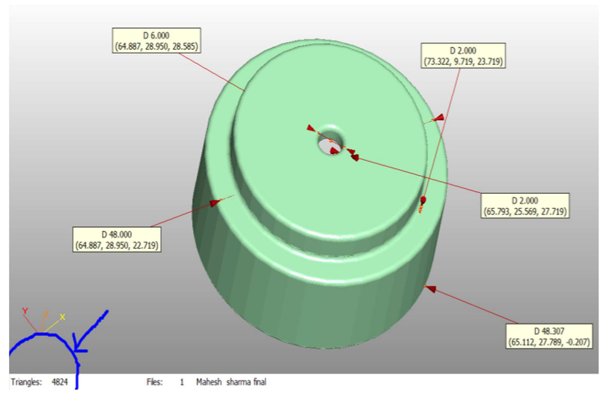


Figure 2: STL file format of the object

Figure 3 shows the three types STL files for solid, hollow and fillet model. In hollow model thickness was taken 5 mm on vertical faces and 4 mm on horizontal face of upper cylinder. A fillet of 1mm radius was taken for the study.

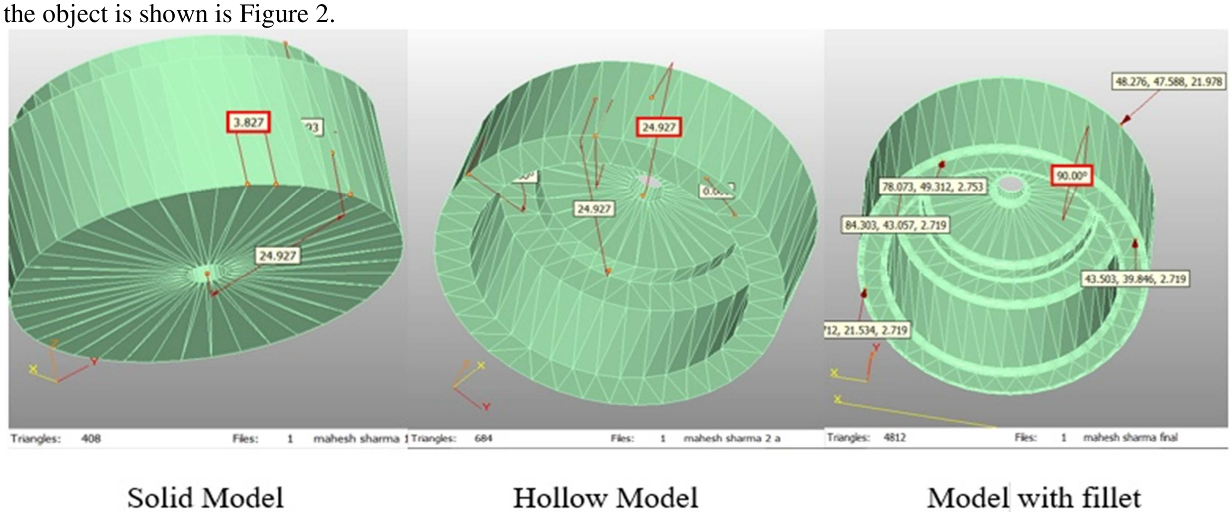


Figure 3: STL model in three form solid, hollow and fillet (Using 3D Tool).

5. RESULT AND ANALYSIS

5.1 Effect of number of triangles

The CAD file of all three types of objects was converted into STL format and number of triangles was noted. The output file size (kb) is calculated as per following relation [9]:
File Size= ((No. of triangles *50) + 84))/1000

Table 1: STL file size and triangles

Object Type	No. of Triangles	STL file size (kb)
Solid	408	20.484
Hollow	684	34.284
Fillet	4824	241.284

Table1 gives the information about triangles and file size. Each triangle of STL file contains 50 bytes; 12 floating- point numbers plus an unsigned integer. For solid part, file size is less and for hollow about 67% increase is there. On creating fillet of 1mm, it increases to 600%.

File size determines how close the sides of the triangle that lie along the edges are to the actual edges of the surface. Hence, the smaller the triangulation tolerance, the bigger the file size and better is the approximation [9].The file size does not significantly influence the production time and cost. It is the basic information for the system memory assessment and achieving better surface by increasing triangulation. By increasing triangles more closeness of edges of triangles is seen which increase the surface finish.

5.2 Effect of weight of the object

The material of object chosen for study is Acrylonitrile

Butadiene Styrene (ABS) plastic having density as 1.05 × 10-3 g/mm³ [12]. Table 2 shows the relative weight and volume of material for the three different forms.

Table 2: Volume and weight of three different types of object geometry

Type of object	Volume (mm^3)	Weight (g)
Solid	46115.32	48.42
Hollow	21222.17	22.28
Fillet	21144.49	22.20

5.3 Effect of layer thickness on printing time

Following process parameters have been considered for calculating the printing time at different layer thickness [12]:

- Shell thickness of layers: 0.8mm
- Bottom / Top Thickness: 0.3mm
- Fill Density: 20%
- Nozzle Diameter: 0.4mm
- Print Speed: 50 mm/sec.
- Support type - Touching build plate
- Filament Diameter (mm) - 2.85

Table 3: Printing time for generation of solid, hollow and fillet forms of the part at 0º orientation

Layer Thickness (mm)	No. of layers	Printing time		
		Solid	Hollow	Fillet
0.02	1286	10 hr. 6 min.	10 hr. 51 min.	10hr. 57 min.
0.04	644	5 hr. 9 min.	5 hr. 30 min.	5 hr. 34 min.
0.06	429	3 hr. 28 min.	3 hr. 41 min.	3 hr. 44 min.
0.08	322	2 hr. 38 min.	2 hr. 48 min.	2 hr. 50 min.
0.1	258	2 hr. 8 min.	2 hr. 15 min.	2 hr. 17 min.
0.2	130	1 hr. 9min.	1 hr. 12 min.	1 hr. 12 min.
0.5	52	0 hr. 31 min.	0 hr. 32 min.	0 hr. 32 min.

From these results it is clear that lower layer thickness increases the accuracy of the prototype but also increases the time to build the model. It shows that the number of layers increases with decrease in layer thickness for solid, hollow and fillet object. It can be seen that for 0.02 mm layer thickness, printing time is less for solid form of object as compared to other two forms but as layer thickness increases the difference is insignificant.

It can be seen that the number of layers also depends on the building orientation. Number of layer is increasing up to 90º building orientation and remains same for 0° and 180º. Data shows that generation time for solid object at 90º and 180º is more as compared to 0º building orientation. This is because at 0º orientation, no need of supporting material is there to print in comparison to other two.

Table 4: Printing time for generation of solid, hollow and fillet forms of the part at 90ºorientation

Layer Thickness (mm)	No. of layers	Printing time		
		Solid	Hollow	Fillet
0.02	2482	11 hr. 18 min.	9 hr. 28 min.	9 hr. 40 min.
0.04	1242	5 hr. 43 min.	4 hr. 49 min.	4 hr. 55 min.
0.06	828	3 hr. 49 min.	3 hr. 12 min.	3 hr. 16 min.
0.08	621	2 hr. 53 min.	2 hr. 26 min.	2 hr. 29 min.
0.1	497	2 hr. 19 min.	1 hr. 57 min.	1 hr. 59 min.
0.2	249	1 hr. 13 min.	1 hr. 3 min.	1 hr. 4 min.
0.5	100	0 hr. 32 min.	0 hr. 28 min.	0 hr. 29 min.

Table 5: Printing time for generation of solid, hollow and fillet forms of the part at 180º orientation

Layer Thickness (mm)	No. of layers	Printing time		
		Solid	Hollow	Fillet
0.02	1286	10 hr. 50 min.	8 hr. 47 min.	8 hr. 46 min.
0.04	644	5 hr. 31 min.	4 hr. 29 min.	4 hr. 28 min.
0.06	429	3 hr. 42 min.	3 hr. 00 min.	3 hr. 00 min.
0.08	322	2 hr. 49 min.	2 hr. 18 min.	2 hr. 18 min.
0.1	258	2 hr. 16 min.	1 hr. 51 min.	1 hr. 51 min.
0.2	130	1 hr. 12min.	1 hr. 00 min.	1 hr. 00 min.
0.5	52	0 hr. 33 min.	0 hr. 28 min.	0 hr. 28 min.

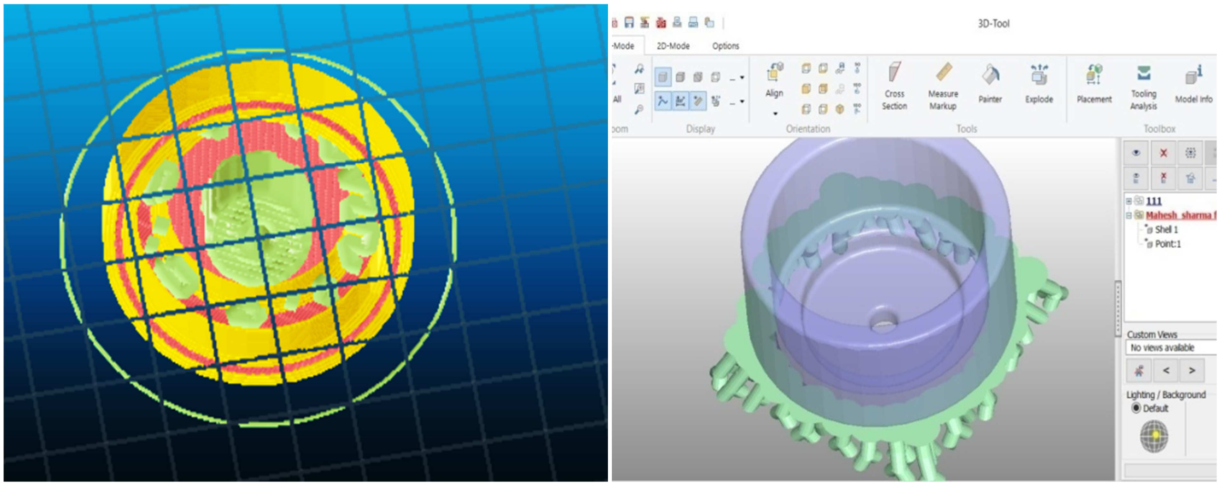


Figure 4: Bottom view of fillet object with supporting material

Figure 4 shows that supporting material plays a vital role on pintinting time at different building orientation of the object. For solid object, printing time at 0 º orientations is less as compared to 90º and 180º orientations because support material is less in 0º.

5.4 Printing cost of the object in three different orientations

In this section, the printing cost in three different orientations has been compared on the basis of input data taken from table 6.

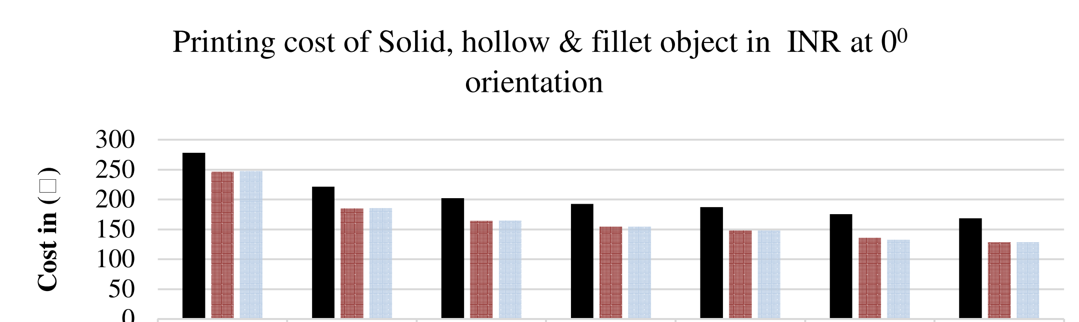
Table 6: Constant input data for printing cost of product [13][14]

Electricity Tariff (INR/kWh):	7.15
Printer Power (Watts):	50
Filament Cost (INR/kg):	1400
Printer Purchase (INR):	400000
Average Daily Usage (hours) :	12
Printer Lifetime (years):	10
Repairs Costs (%):	10
Other Costs(labour) (INR):	80
Failure Rate (%):	10

Figures 5, 6 and 7 show that generally printing cost decreases for corresponding decrease in layer thickness for all orientations. However, lower layer thickness obviously increases the printing time and suitable trade-off has to be made for achieving optimum efficiency.

6. CONCLUSION

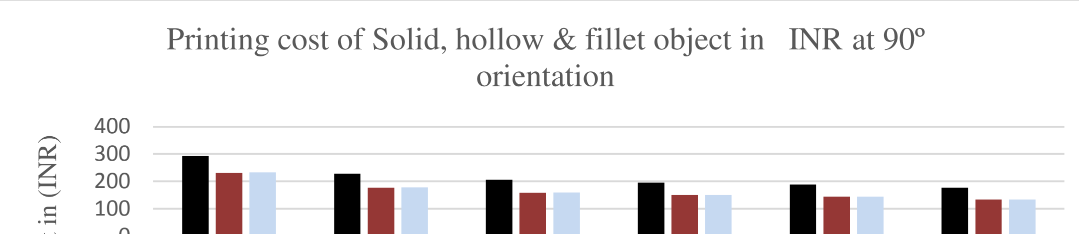
3D printing is, undoubtedly, the most important and widely used additive manufacturing technique which is economically viable particularly for hollow and complex parts. During transition of solid to hollow part, tessellation increases which is more pronounced in case of hollow to fillet transition. File size is a function of number of triangles or number of tessellation which is highest in case of fillet part. However, for achieving smaller triangulation tolerance and better approximation, one has to increase the file size. For short run and large quantity of single parts, one can use smaller file size according to dimensional stability of the system requirement. Number of layers increases with decrease in layer thickness but are usually not affected by the orientation angle chosen for the fabrication. On the basis of study, it has been found that use of support material has significant effect on the printing time and cost. In addition, it is important to mention that selection of optimum angle of orientation from x, y or z axis is necessary to obtain reduced printing time and cost.



	0.5	0.2	0.1	0.08	0.06	0.04	0.02
Solid	278.15	221.5	202.23	192.7	186.98	175.73	168.48
Hollow	246.47	185.25	164.46	154.35	148.06	136.04	128.41
Fillet	247.49	185.89	164.91	154.61	148.32	132.92	128.23

Layer Thickness in (mm)

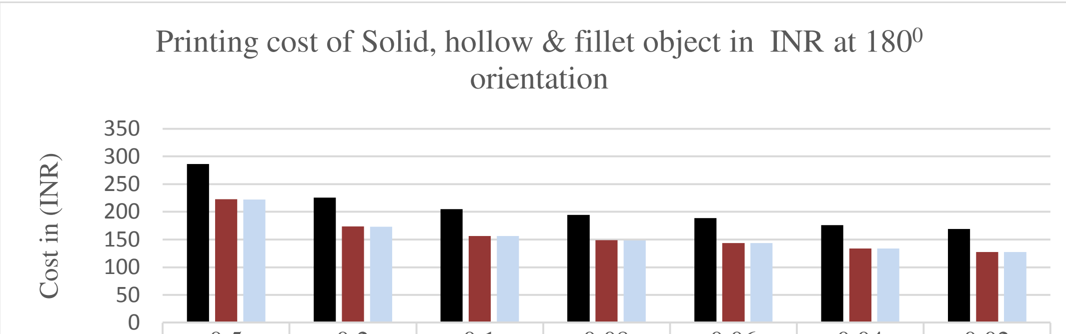
Figure 5: Printing cost of Solid, hollow & fillet object in INR at 0^0 orientation.



	0.5	0.2	0.1	0.08	0.06	0.04
Solid	291.88	227.98	206.24	195.56	189.08	176.49
Hollow	230.64	177.43	158.93	150.16	144.63	134.33
Fillet	232.81	178.45	159.57	150.61	144.88	134.39

Layer Thickness in (mm)
Solid Hollow Fillet

Figure 6: Printing cost of Solid, hollow & fillet object in INR at 90^0 orientation



	0.5	0.2	0.1	0.08	0.06	0.04	0.02
Solid	286.54	225.7	204.91	194.8	188.5	176.3	169.24
hollow	222.82	173.62	156.64	148.63	143.48	133.75	127.65
fillet	222.51	173.3	156.52	148.51	143.56	133.63	127.53

Layer Thickness in (mm)
Solid hollow fillet

Figure 7: Printing cost of solid, hollow & fillet object in INR at 180^0 orientation

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