# Digital fabrication with FDM 3D printing on prototype development of toys: additive manufacturing and sustainability

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**Abstract.** Additive manufacturing, commonly referred to as 3D printing, is currently one of the most dominant developments in the manufacturing sector. Consumer demands for more customized goods and services, in conjunction with the emergence of advanced manufacturing technologies, are influencing changes in the scope and distribution of manufacturing. In this work, the function of digital fabrication, one of these advanced manufacturing process technologies, is examined. The Digital Manufacturing and even other advanced manufacturing technologies have a significant footprint in all future manufacturing endeavours because of the robustness and mass customization that they provide. The Fused Deposition Modelling (FDM) is a sustainable method used extensively for the development of prototypes for toys. The present study investigates the potential of FDM process as a method for prototype development. Additionally the advantages of FDM process from the viewpoint of sustainable manufacturing integrating innovativeness and do-it-yourself approach at home driven by consumer demand for products such as toys will also be investigated. 3D printing technology such as FDM process, where objects such as toy prototypes are constructed by adding materials layer by layer has been in the forefront of various Digital Manufacturing techniques as it reduces material wastage thereby optimizing resource utilization.

**Keywords**: Additive manufacturing, FDM, model development, digital production

## 1 Introduction

3D printing technology is widely used in diverse fields such as toy industry, automotive, healthcare products, agriculture and aerospace as it allows mass refinement and manufacturing from tailor made designs. With a renewed interest on objects produced by 3D printing processes, an investigation on the effect of printing parameters on the component characteristics is very important as it affects the product performance in various applications [1].

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3D printing as a manufacturing technique was first introduced in the 1980s by Charles Hull. It involves manufacturing of a solid object from 3-d digital design data (CAD Model) [2]. The three-dimensional solid object is produced by adding one layer of material over another layer hence it is also called as additive manufacturing [3]. The layers comprise of thickness obtained by slicing of the object model across a cross-section along the printing direction. In comparison to conventional methods of manufacturing, 3D printing makes possible manufacturing from complex design having fine details with moderation of material usage. Recently there has been a renewed focus on 3D printing processes because of the benefits they offer such as suitability for rapid prototype production, possibility of manufacturing from complex design with intricate features making it a suitable manufacturing process that can be adopted in industries such as automobile, aerospace, healthcare, consumer goods and others [4].

Fig. 1 portrays the chronological order of steps in a 3D printing process starting from product conception to final application of printed products. The process starts with the creation of the CAD model. Then the CAD file is saved in the STL (Standard Tessellation Language) file format after which it is sliced into thin cross-sections and then sent to the printer [5]. This format consisted of a collection of interconnected triangular planar facets that represented the outside surface of an object. Each facet is determined by its vertices and a unit surface normal vector that indicates the direction away from the interior of the portion [6-7].

It has been suggested by authors that 3D printing has the potential to have a beneficial effect on the market for toys and games by lowering the prices involved and fostering greater creativity among these industries' designers [8]. As a result of its ability to experiment with a wide range of shapes, structures, materials, and functionalities, 3D printing can greatly improve toy and gaming product design and creativity, according to a study [9]. Apart frm above, the implementation of 3D fabrication is expected to benefit the toy and gaming industries enormously. For example, some of the concerns that need to be addressed are quality control, safety requirements, intellectual property rights, environmental consequences, and consumer acceptability of toys and games that are manufactured using 3D printing [10].

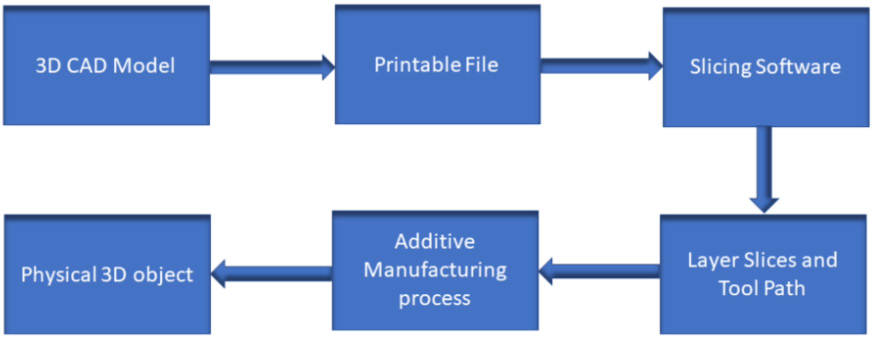



**Fig.1.** Process flow steps of 3D Printing

The prevailing used 3D fabrication technology is fused deposition modelling (FDM). It's relatively simple, inexpensive, and straightforward to operate, and that may explain its widespread adoption [11]. A filament is melted first, and the nozzle is then used to build up the filament layers by layering it successively. Following the deposition of the initial layer, nozzle moves in the z-axis direction, in order to construct subsequent layer, and this process continues until the item is finished [12]. The fact that FDM is accessible, affordable, and versatile makes it a popular technique for 3D printing. Depending on the properties and applications that are desired, FDM can be used to manufacture components using a wide range of filament materials. A schematic representation of the FDM approach can be found in Fig. 2.

In order to construct devices of consistent high quality, 3D printing, like any other manufacturing method, requires materials of high quality that are subject to rigorous criteria. Parts that are fully functional can be manufactured using 3D printing technology in a broad a range of materials, such as ceramics, metals, and Polymer materials, as well as their mixtures in the form of hybrids, composites, or functionally graded materials (FGMs) [13].

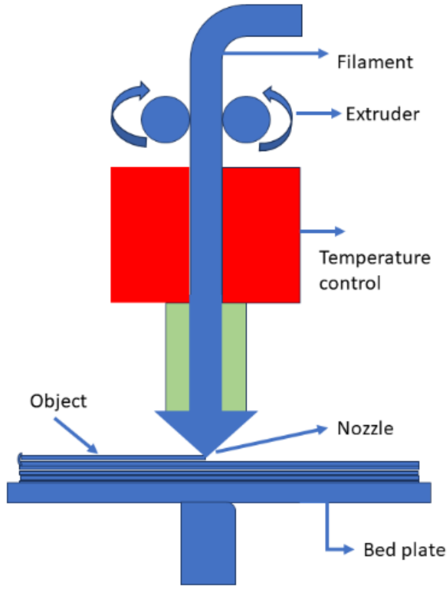



**Fig. 2.** Schematics of FDM process

PLA and PET-G are often the most commonly used materials for three-dimensional printing in the construction of prototypes and toys that aid in the production process. Polyethylene terephthalate glycol-modified (PETG) is a material that is less prevalent but finds use in water-resistant [14] and repair scenarios. The thermoplastic polymers poly-lactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are the leading materials for 3D fabrication technology in compared to other materials. In addition to being readily available, the materials are inexpensive. PLA (Polylactic acid) being a comparatively cheap and light weight material is frequently used for 3D printing purpose. It is environment friendly, degraded biologically as it is obtained from source materials such as corn, wheat and other starch containing crops. PLA usage leads to petroleum conservation as pollution is lowered [15]. PLA production and its subsequent metamorphosis during printing require less amount of energy compared to other materials. The commonest thermoplastic material used as printing material is ABS (Acrylonitrile butadiene styrene). It is an affordable material and it is compatible to various 3D printing processes [16].

The significant parameters in FDM process are: nozzle temperature, temperature of the build platform, object or prototype size, layer thickness and cooling fan speed. The infill percentage also has to be taken into account. The infill of a 3D printed part distinguishes its inside morphology. The amount of infill is critical as it impacts the strength, weight and time requirement for printed parts. Infill morphology patterns can be solid, hollow, grid, honeycomb and lattice design as depicted in fig.3.

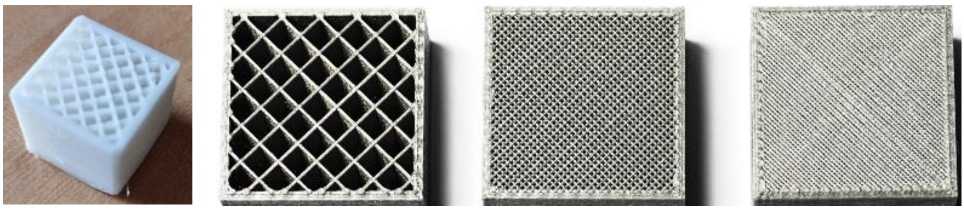


**Fig. 3.** variouspattern of infill percentage

The selection of the infill is determined by the design of the part as well as its intended use. Infill material supports top layers thereby preventing their collapse and war page. However too much increase in infill density increases part weight with a simultaneous decrease of strength. Therefore a fine balance has to be stuck between material optimisation and weight when selecting infill percentage. Infill also effects the time required for printing because the adhesion between the layers and the extrusion rate changes. Excessive infill prolongs the printing because there are more layers to print and slow extrusion rate. Not having enough infill can shorten the period of time it takes to print by necessitating fewer layers and a more rapid extrusion process.

It is essential for FDM process to have a secure adhesion between the layers of a part that has been deposited. Molten thermoplastic is pressed against the layer that was printed earlier when it is extruded via the nozzle of FDM machine. The combination of elevated temperature and pressure causes that layer to re-melt, which in turn enables it to form a connection with the layer that came before it. The machine makes multiple laps around the outside edge, known as the shell, and then fills its interior, known as the infill, featuring an internal, low-density structure.

For fast prints, the default settings of most workstation 3-DP-FDM printers—20% infill density and a 1 mm shell thickness typically provide a good balance between strength and printing speed. Depending on the component parts, there is a requirement for orientation and support structure in order to create. When the overhang lesser than 45 degrees, supports are required. Depending on orientation of the part and the direction in which the building is being constructed, the strength of the part will differ.

Warping is one of the most frequently encountered types of errors that can occur in FDM process. As the extruded material cools and solidifies, its dimensions shrink. Due to the diverse cooling rates of different parts of the printed body, the dimensions of those parts also differ after the part has been manufactured. By accumulating internal tensions caused by differential cooling, underlying layer is lifted, resulting in warping of the layer. Various approaches are there to eliminate warping. One approach is to keep close monitoring of the temperature in the FDM system, with particular focus on the build platform and chamber. It is furthermore possible to enhance adhesion among the component and the build platform in order to reduce the amount of warping that occurs.

## 2 Design and product prototype

A desktop FDM 3D printer is utilized in order to generate all of the prototypes. First, a computer-aided design (CAD) model of specimen as shown in figure 4 that will be printed must be created in order to begin printing. The cad model was prepared using Solid Works. Once the model is created it is then converted into a .STL file format. It is then necessary to slice it into particular layer with predefined parameters like layer depth and printing temperature before the object can be fully created. A machine code specific to the 3D printer was generated, containing the instructions for printing with the help of the slicing program utilized in the process of producing the specimen that is required.

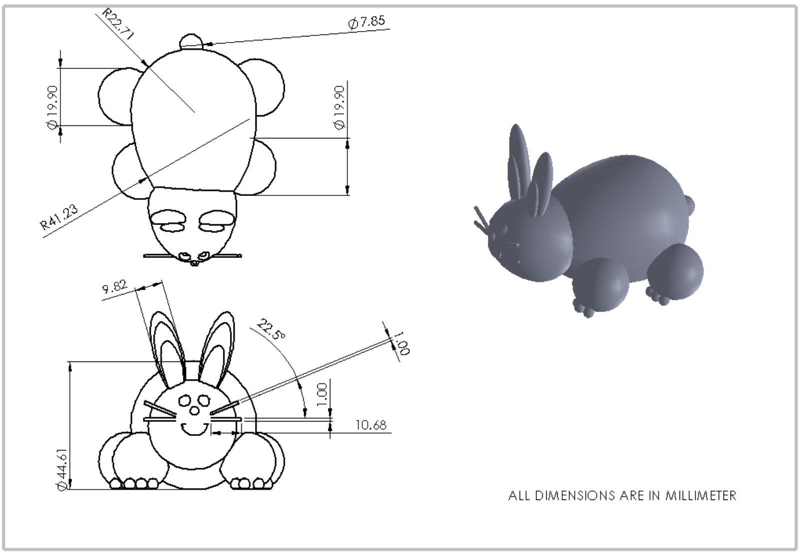


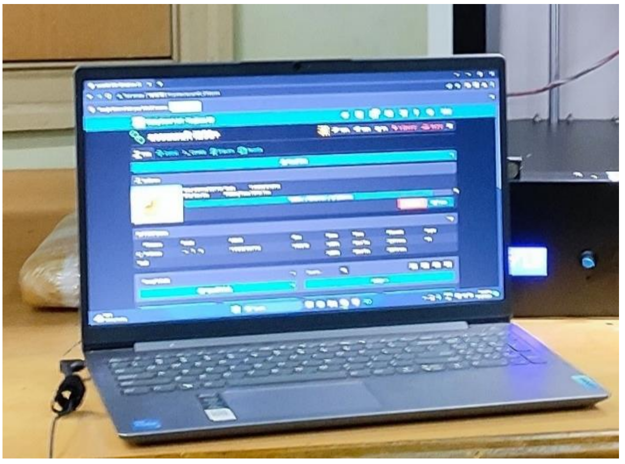

**Fig. 4**. 3D model of the prototype

For the production of the necessary specimens, PLA filaments were used, a thermoplastic that is both biodegradable and environmentally sustainable. PLA is a material that is produced from corn starch or other natural sources.PLA is an excellent choice than other materials. PLA is easy to work with, has a low shrinking rate, and comes in a wide range of colour options. All of these experiments were conducted using filaments having diameter of 1.75 mm. Further information on these materials and parameters are found in the Table 1.

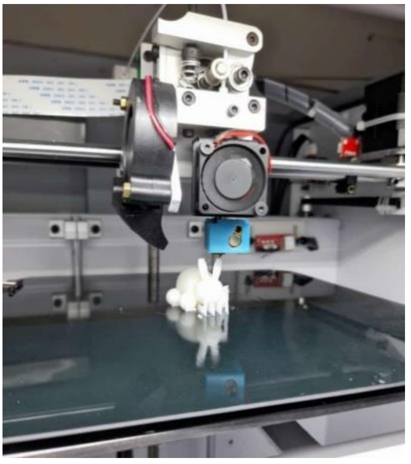
**Table 2: Technical specifications**

| **Specifications** | |
|---|---|
| Model material | PLA |
| Filament Diameter: | 1.75 mm |
| Build dimension | 200mm x 250mm x 300mm (H x W x L) |
| Layer depth | 0.2 mm |
| Printed Output exactness | +/- 150 microns |
| File input type | . STL |
| Print head | Single nozzle |
| XYZ motions | High precision linear guide rails |
| Connectivity | USB, Wifi. |

The printer is scheduled to feed the filament through an extrusion head once the nozzle has reached the temperature that is desired. The X, Y, and Z axes are all able to be traversed by this extrusion head because it is connected to a three-axis system. In order to deposit the material layer by layer along a path that has been predetermined by the design, the printer extrudes the molten material into thin strands of material. After it has been placed, the substance helps to cool down and become solid. There are several situations in which you can speed up the cooling process by attaching fans to the extrusion head. It is necessary to make many passes in order to fill an area. After the printer has completed a layer, the build platform is pushed downward, and the machine proceeds to begin working on the subsequent layer automatically. It is necessary to repeat this step until the component is completed. The experimental setup and detailed fabrication view are shown in figure 5 (i) and (ii) respectively. Process parameters for making the model are shown in table 2.



(i)



(ii)

**Fig. 5**. (i) Experimental setup (ii) fabrication view

**Table 2.** Process parameter for the model

| Parameters | Values |
|---|---|
| Layer thickness | 0.2 |
| Infill percentage | 40 |
| Nozzle Temperature ($^0$C) | 210 |
| Build plate Temperature ($^0$C) | 60 |
| Nozzle Size (mm) | 0.4 |
| Shell/Wall thickness | 0.8 mm |
| Printing Speed (mm $s^{-1}$) | 50 |

# 3 Results and discussion

First, it is necessary to determine whether is it possible to move the X-Y coordinate in the right-left direction manually. The material that has been wrapped around the glass bed should be carefully opened up, and then the glass bed should be placed in the location that has been designated for it, with the side that has been taped with aluminium foil. Next, use the four screws that are located horizontally at each corner to tighten the glass bed.

Standard 3D printers typically feature a printing nozzle that can move in all three spatial dimensions (x, y, and z) and allow for either a single or multiple feed materials. The components are manufactured sequentially under the control of the 3D computer-aided design (CAD) model and associated data. Present study maintained a consistent build orientation to minimize this effect. The printing speed is yet another process parameter that has the potential to control the mechanical properties of the material. Each of the printer's motors, together with the control for the X and Y axes as well as the motor for the extruder moves at a predetermined speed that is determined by the printing speed. Miazio [17] conducted research to determine whether the speed of the print affects strength of PLA specimens that were produced via FDM tools. When the printing speed is increased, the amount of sample that is produced reduces. In terms of durability and printing time, it was established that the optimal printing speed, which was 60 mm $s^{-1}$, was the most effective. There is a possibility that a slower printing speed leads to improved mechanical properties of objects; however, this comes at the cost of a significantly extended printing period. For the purpose of minimizing the impact of this effect, this study maintained a constant printing speed.

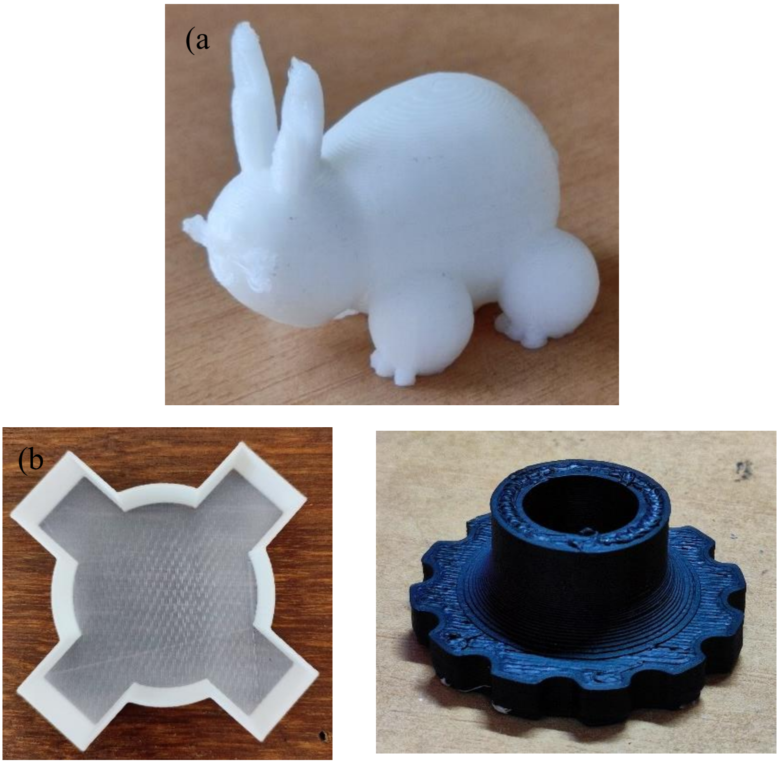



**Fig. 6.** Development of toy (a)and components(b)prototype

One more process factor that greatly affects the material's mechanical characteristics is the printing temperature, sometimes called extrusion temperature. The printing method considers heating the extruder to extrusion temperature. The temperature changes for a number of reasons, including the printing speed and the kind of printing material (PLA, ABS, or the filament source). Hsueh et al. (2021) [18] explored how the printing temperature affects mechanical and thermal characteristics of PLA and PETG that were 3D printed. The materials were subjected to tension, compression, and bending tests at various printing temperatures to ascertain the magnitude of the influence. The temperatures used to heat for PLA were between 180 and 220 degrees Celsius. Keeping all these parameters in consideration, some of the prototypes prepared are being reflected in Fig. 6.

Among the several types of 3D printing machines, FDM printers are the most widely used. These printers range from desktop plug-and-play printers designed for society to professional systems that are chosen by industrial businesses. Fused deposition modelling (FDM) printers are typically outfitted with a nozzle (or nozzles) that melt and extrude filament material, depositing an item layer by layer in accordance with a certain code. While used at home, FDM printers are simple and safe to use. Prints are not required to have complicated post-processing processes, and the variety of materials and upgrades continues to expand in connection with the rising popularity of these printers. As a consequence of this, manufacturers consistently introduce new kinds of machines, tools, and materials to the market in order to enhance FDM 3D printing processes and satisfy customer demand simultaneously.

## 4 Conclusion

In terms of design, it is recommended to make the wall thickness a multiple of the diameter of the nozzle. This is a common rule of thumb. Wall thickness should be maintained at a minimum of 1.2 mm. The density of the part can be altered by using the FDM technique. It is possible for the infill to range anywhere from 0% to 100%, depending on the application. It allows one to consider the infill type to be straight, octagonal, or rounded. Fabrication involves orientation and support structure, depending on the component. When the overhang is lesser than 45°, supports are needed. The part's strength is dependent upon its orientation and the building's fabrication direction. At this exploratory stage of study into AM's effects on industrial sustainability, deep-dive individual and comparative case studies of sectors, organizations, products, and components are needed, along with AM-based production system models. Such studies may offer a view on the ways in which AM affects sustainability, including the manner in which possibilities are exploited and sustainability benefits are realized, the challenges that prevent these benefits from being captured, and the specific contexts in which each occurs. Through the utilization of computer-aided design (CAD) software for distributed manufacturing paradigm, the findings of this study make it abundantly evident that customers are able to produce goods of greater value for a lower cost. This study provided a quantitative analysis of the cost reductions that may be realized by consumers who build their own toys and games by utilizing free and open-source designs in conjunction through a desktop fused filament 3D printer. The quality of typical complex toys was investigated through case studies, and it showed a satisfactory prototype in an engineering sense.

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