3-D Printing Toolpath Generation For Fused Filament Fabrication

Mr. Munagala Venkata Sai Kiran[1], Mr. N.Chitanya.Mitra[2], Mr.Y.Dhana Sekhar[3]
[2]Asst.Professor, Dept of Mechanical
[3]Associate professor, Dept of Mechanical
[1, 2, 3]Kakinada institute of technology and science, divili.

Abstract- *Integration of Computer Aided Design and Manufacturing process in important for any firm during its business operations. An important aspect in this step is modeling of the part using manufacturing features. These features explicitly capture manufacturing attributes. This process is implemented in many of the CAM software for conventional manufacturing processes. But when it comes to special processes like 3D printing, this philosophy has not been implemented.*

The current work investigates into use of feature based modeling to simplify slicing techniques. Based on the modeling, a z-buffer of loops is generated. This z- buffer is modified each time a feature is added to a part.

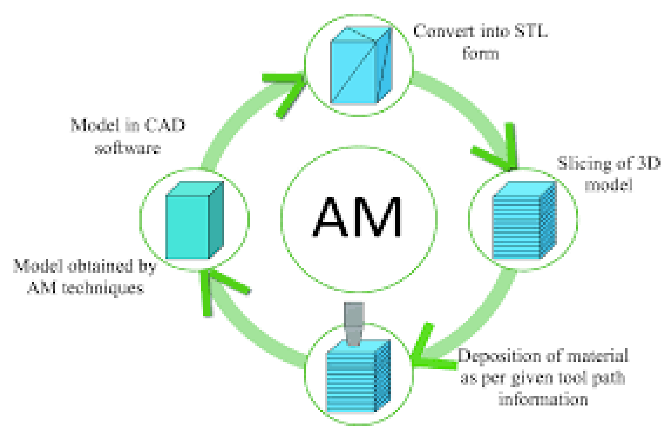
This z-buffer is then used to generate the code. This process helps in quicker modification of code by eliminating the need of exporting and slicing each time. This helps integrating the 3D printing module into any CAD software thus eliminating the slicing procedure partially. This also helps in controlling the errors and tolerances in the part generated by 3D Printing. As a part of implementing this principle, AutoCAD customized using VB.NET.

Keywords- 3D Printing, Feature Based Modeling, Automatic code generation, Z-Buffer, CAD.

I. INTRODUCTION

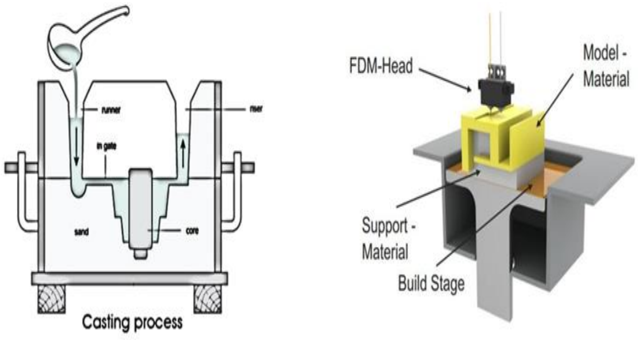
3D Printing – also referred as additive manufacturing – is a domain of large number of Rapid prototyping processes. In this process, material is added layer by layer. The way in which the material is added mainly depends on the material being 3D printed. 3D printing was first introduced by Chuck hill [1]. Since the inception of the process, it has undergone a lot of advancements and is finding wide variety of applications.

The earliest 3D printing technologies first became visible in the late 1980‘s, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry. As an interesting aside, the very first patent application for RP technology was filed by a Dr Kodama, in Japan, in May 1980. Unfortunately for Dr Kodama, the full patent specification was subsequently not filed before the one year deadline after the application, which is particularly disastrous considering that he was a patent lawyer! In real terms, however, the origins of 3D printing can be traced back to 1986, when the first patent was issued for stereo lithography apparatus (SLA). This patent belonged to one Charles (Chuck) Hull, who first invented his SLA machine in 1983. Hull went on to cofound*3D Systems Corporation* — one of the largest and most prolific organizations operating in the 3D printing sector today.



3D Printing Vs Conventional Manufacturing

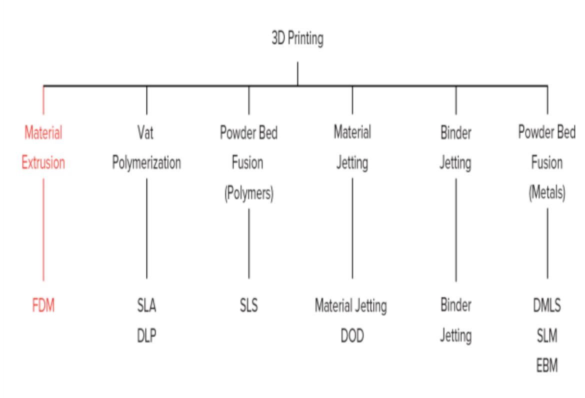
Conventional manufacturing processes involve either material addition processes (like casting, moulding, powder metallurgy, forging etc), or material removal processes (like turning, milling, shaping, drilling, grinding etc). 3D Printing differs from these conventional processes in the way the material is added. As mentioned earlier material is added layer by layer in 3D Printing, while in conventional material addition processes, molten metal is flown into the mould. In other words, 3D Printing relies on ink jet printing technology. the comparison between 3D printing and conventional casting technologies (both are material addition processes).



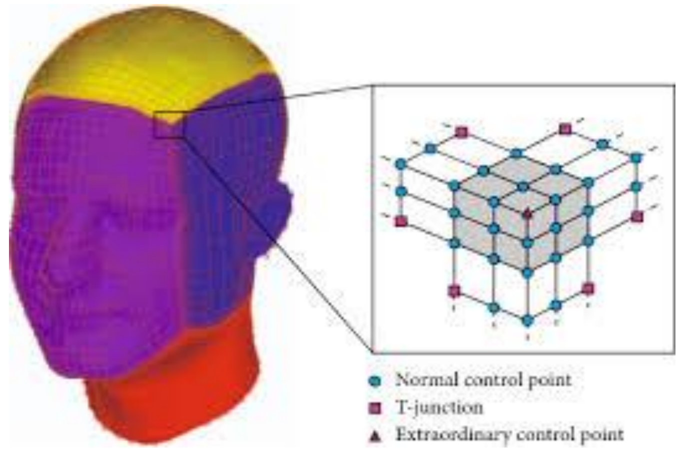
(a) Casting Process (b) 3D Printing Process

Applications of 3D Printing

3D Printing is finding a lot of application in the current industrial and economic scenario. These applications vary from creating customized aids for classroom teaching to 3D printing components for use in rocket engines. Recently NASA in collaboration with Aero jet Rocket dyne (AR) completed the first hot-fire tests on an advanced rocket engine thrust chamber assembly using copper alloy materials. This was the first time a series of rigorous tests confirmed that 3-D manufactured copper parts could withstand the heat and pressure required of combustion engines used in space launches



3D printing, being a tool less manufacturing process, not only reduces the prohibitive costs but also gives unprecedented design freedom thus facilitating the creation of complex geometries and manufacturing them with great ease. This technology also proved to be efficient in the sense that it has very little or almost 0% material wastage of standard materials and throughout product‘s operating life with lighter and stronger design.



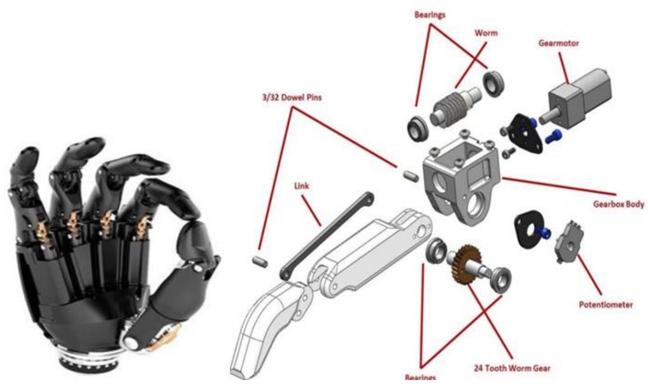
In medicine, a prosthesis (plural: prostheses; from Ancient Greek prosthesis, "addition, application, attachment) is an artificial device that replaces a missing body part, which may be lost through trauma, disease, or congenital conditions. Prosthetic amputee rehabilitation is primarily coordinated by a prosthetics and an inter-disciplinary team of health care professionals

Including psychiatrists, surgeons, physical therapists, and occupational therapists.

The area on which surgery is to be performed is 3D printed so that proper planning of surgery can be made and thus avoid unnecessary complications during surgery. The thesis discussed three main things:

1. Medical 3D modeling and design
2. Applying various additive manufacturing techniques
3. Estimating the usability and dimensional accuracy of the process

Prosthetic Hand as discussed

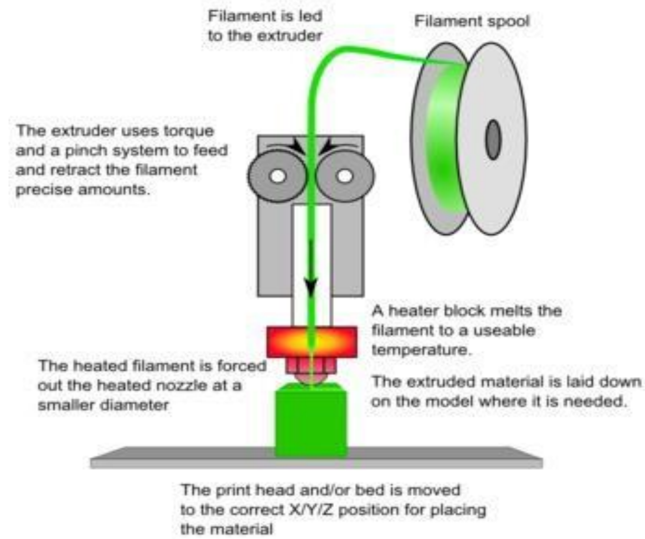


A 3D Printed Prosthetic Hand

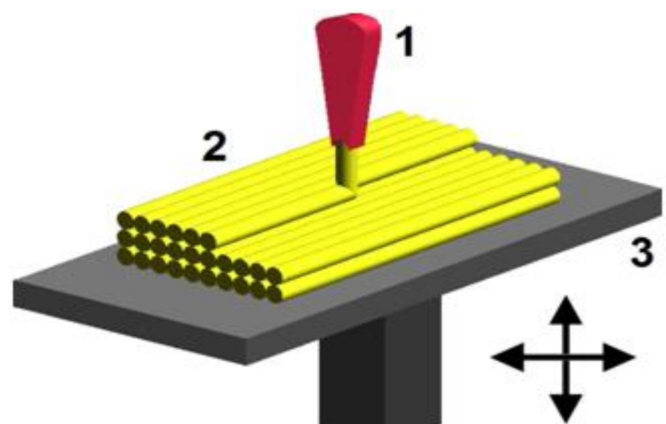
Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data. 3D printing is one the process used in this process. 3D printing/Additive Manufacturing uses Fused Deposition Modeling (FDM) principle. In 3D Printing/Additive Manufacturing, material is printed layer by layer. In other words, material is being added and thus is called Additive Manufacturing.

Fused Deposition Modeling (FDM)

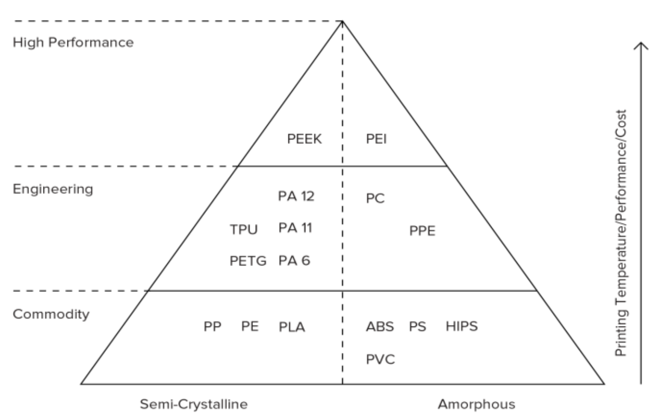
Fused deposition modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. It is one of the techniques used for 3D printing. In FDM/FFF of plastics, the raw material is supplied in the form of a wire called filament. This filament is passed through a heated extruder. During this passage, the material melts. As the extruder moves in the necessary path, the molten plastic gets deposited through the nozzle of extruder. Different types of extruders are used during this process. Most generally Bowden extruders are used in 3D printers. Other extruders are composite extruders which include Fiber Core and Wet Sock extruders.



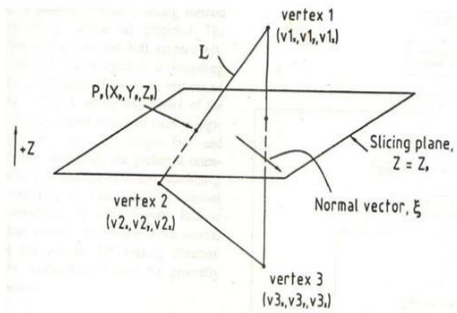
FDM/FFF Filament Feed Principle

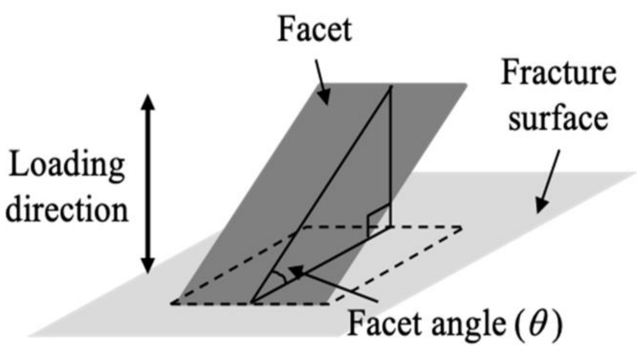


Fused deposition modelling printing principle 1 – nozzle ejecting molten material, 2 – deposited material (modeled part), 3 – controlled movable table.



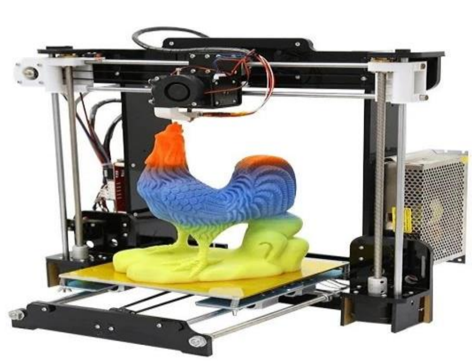
	[Description]
Solid Name	*Name of the STL File*
Facetnormal $n_i\ n_j\ n_k$	$n_i\ n_j\ n_k$ *The unit normal vector of facet*
OuterLoop	
Vertex $v_{1x}\ v_{1y}\ v_{1z}$	$v_{1x}\ v_{1y}\ v_{1z}$ *Coordinates of vertex 1*
Vertex $v_{2x}\ v_{2y}\ v_{2z}$	$v_{2x}\ v_{2y}\ v_{2z}$ *Coordinates of vertex 2*
Vertex $v_{3x}\ v_{3y}\ v_{3z}$	$v_{3x}\ v_{3y}\ v_{3z}$ *Coordinates of vertex 3*
endloop	
endfacet	
endsolid name	





Schematic diagram of Triangle Facet and the working direction

Various types of 3D Printers exist. Most of the printers are Cartesian. An example is shown in Figure 4.1. The sizes of these printers vary from desktop 3D printers to large industrial scale printers. The introduction of desktop 3D printers has paved way for desktop manufacturing. Some desktop 3D printers also use parallel robots.



Desktop 3D Printer

In the current work, WANHAO Duplicator i3 printer has been used

Frame Color	*: Steel Frame (Powder Coated Black)*
Extruder	*: MK10 Single-Extruder (with Steel X-Carriage)*
Filament Size	*: 1.75mm Dedicated*
Layer Capability	*: 0.1mm (100 microns)*
Build Envelope	*: 200mm x 200mm x 180mm (8in. x 8in. x 7in.)*
Build Surface	*: Heated Bed Plate*
Filament Capabilities	*: ABS, PLA, HIPS, PVA, Nylon etc.*
Compatible Software	*: Cura (Open source), Simplify 3D (Details)*
File Type	*: G-code (RepRap (Repetier/Marlin/Sprinter) flavor)*
File Transfer	*: microSD Card & USB*

A drawback of many existing 3D printing technologies is that they only allow one material to be printed at a time, limiting many potential applications which require the integration of different materials in the same object. Multi-material 3D printing solves this problem by allowing objects of complex and heterogeneous arrangements of materials to be manufactured using a single printer. Here, a material must be specified for each voxel (or 3D printing pixel element) inside the final object volume.

G-Codes for 3D Printer programming

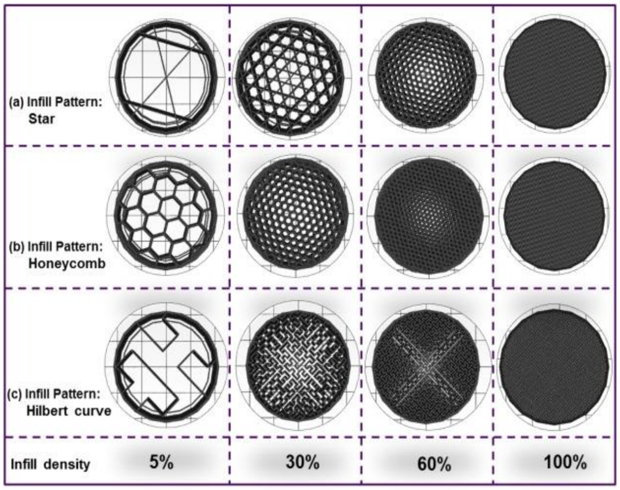
G-Code	Description
G0 & G1	Move
G2 & G3	Controlled Arc Move
G4	Dwell
G10	Tool Offset
G10	Retract
G11	Unretract
G17..19	Plane Selection (CNC specific)
G20	Set Units to Inches
G21	Set Units to Millimeters
G22 G23	Firmware controlled Retract/Precharge
G28	Move to Origin (Home)
G29	Detailed Z-Probe
G29.1	Set Z probe head offset
G29.2	Set Z probe head offset calculated from tool head position
G30	Single Z-Probe
G31	Set or Report Current Probe status
G32	Probe Z and calculate Z plane
G31	Dock Z Probe sled
G32	Undock Z Probe sled
G38.x	Straight Probe (CNC specific)
G38.2	probe toward workpiece, stop on contact, signal error if failure

G38.3	probe toward work piece, stop on contact
G38.4	probe away from work piece, stop on loss of contact, signal error if failure
G38.5	probe away from work piece, stop on loss of contact
G40	Compensation Off (CNC specific)
G54..59	Coordinate System Select (CNC specific)
G80	Cancel Canned Cycle (CNC specific)
G90	Set to Absolute Positioning
G91	Set to Relative Positioning
G92	Set Position
G92.x	Reset Coordinate System Offsets (CNC specific)
G93	Feed Rate Mode (Inverse Time Mode) (CNC specific)
G94	Feed Rate Mode (Units per Minute) (CNC specific)
G100	Calibrate floor or rod radius
G130	Set digital potentiometer value
G131	Remove offset
G132	Calibrate end stop offsets
G133	Measure steps to top
G161	Home axes to minimum
G162	Home axes to maximum

M-Codes for 3D Printer Programming

M-Code	Description
M0	Stop or Unconditional stop
M1	Sleep or Conditional stop
M2	Program End
M3	Spindle On, Clockwise (CNC specific)
M4	Spindle On, Counter-Clockwise (CNC specific)
M5	Spindle Off (CNC specific)
M6	Tool change
M7	Mist Coolant On (CNC specific)
M8	Flood Coolant On (CNC specific)
M9	Coolant Off (CNC specific)
M10	Vacuum On (CNC specific)
M11	Vacuum Off (CNC specific)
M17	Enable/Power all stepper motors
M18	Disable all stepper motors
M20	List SD card
M21	Initialize SD card
M22	Release SD card
M23	Select SD file
M24	Start/resume SD print
M25	Pause SD print
M26	Set SD position
M27	Report SD print status
M28	Begin write to SD card
M29	Stop writing to SD card
M30	Delete a file on the SD card 8.25.1 M30 in grbl
M31	Output time since last M109 or SD card start to serial
M32	Select file and start SD print
M33	Get the long name for an SD card file or folder
M34	Set SD file sorting options
M36	Return file information
M37	Simulation mode
M40	Eject
M41	Loop
M42	Switch I/O pin
M43	Stand by on material exhausted
M48	Measure Z-Probe repeatability

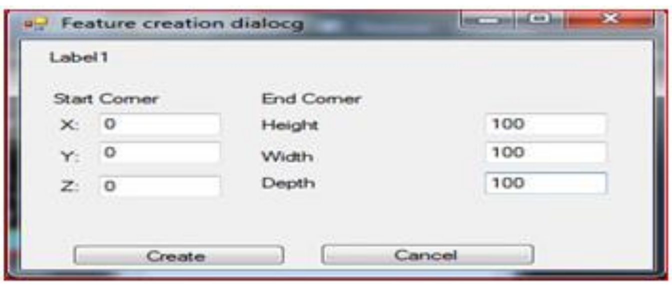
It may be noted here that, since the layer thickness is small and also the thickness of the material being deposited is quite small, the programming is done using commercial/open source slicing engines. When generating the tool path using these codes, the solid body is treated as a shell and the infill is done in a pattern depending on the % of infill given as input. Different types of infill patters that are supported by Slic3r. Cura on the other hand offers only one infill pattern i.e. Grid type.



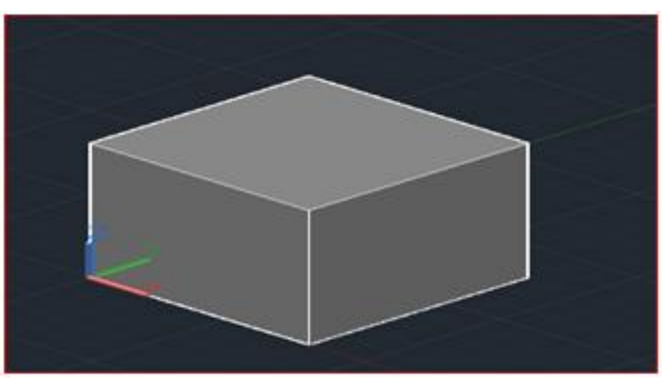
In the current work, the parts which are modeled in Creo/Parametric are 3D printed. As mentioned earlier Cura engine is used for slicing and the generated G-Codes are transferred on to the machine using SD card and 3D Printed using PLA material.

Modeling of hub:

In Feature based hub generation processing enter the first corner value and second corner value

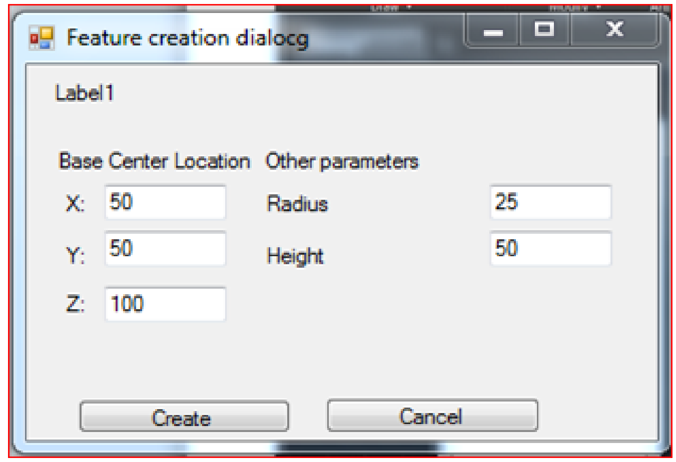


After entering the values in feature based dialog box the boss is generated in Auto Cad



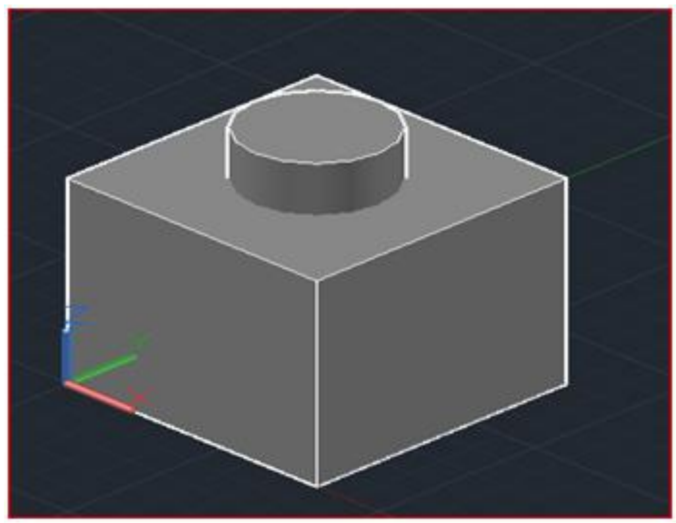
Modeling boss element in auto cad

- **Modeling of shaft:** While designing of shaft we have considering co-ordinate values(x,y,z) and also enter the radius of shaft and length of shaft.



Dialog box for generating shaft element

After entering the values in dialog box the feature based shaft is generated in auto cad



Modeling of shaft in auto cad

II. CONCLUSION

An algorithm is developed so as to use the concept of feature based modeling for 3D printing code generation. The algorithm makes use of parametric curve equations for computing intersection points. There are three stages in implementing the algorithm: i) Feature Based modeling, ii) Sorting the curves as per their Z-level to create a Z-Buffer, iii) Generate G-Code using the Z-buffer.

This z-buffer is then used to generate the code. This process helps in quicker modification of code by eliminating the need of exporting and slicing each time. This helps integrating the 3D printing module into any CAD software thus eliminating the slicing procedure partially.

III. FUTURE SCOPE

present work for feature based modeling for prismatic components only; we can also apply the feature based modeling for non-prismatic components also. Modeling of component in parametric form can improving better surface roughness and quicker modification also possible while modeling of components.

3d printing and multi-material structures in additive manufacturing has allowed for the design and creation of what is called 4d printing. 4d printing is an additive manufacturing process in which the printed object changes shape with time, temperature, or some other type of stimulation. The smart/stimulus responsive materials that are created using 4d printing can be activated to create calculated responses such as self-assembly, self-repair, multi-functionality, reconfiguration and shape shifting. This allows for customized printing of shape changing and shape-memory materials.

4D printing has the potential to find new applications and uses for materials (plastics, composites, metals, etc.) and will create new alloys and composites that were not viable before. The versatility of this technology and materials can lead to advances in multiple fields of industry, including space, commercial and the medical field.

REFERENCES

[1] ―3D Printing.‖ [Online]. Available: https://en.wikipedia.org/wiki/3D_printing.

[2] P. Ventimiglia, ―Design of a Human Hand Prosthesis,‖ *Fac. Worcester Polytech. Inst.*, p. 74, 2012.

[3] ―Fused Deposition Modeling.‖ [Online]. Available: https://en.wikipedia.org/wiki/Fused_deposition_modeling

[4] S. Bhandari and B. Regina, ―3D Printing and Its Applications,‖ *Int. J. Comput. Sci. Inf. Technol. Res. ISSN*, vol. 2, no. 2, pp. 378–380, 2014.

[5] Mcor Technologies, ―How Paper-based 3D Printing Works,‖ pp. 1–10, 2013.

[6] J. Martínez, J. L. Diéguez, E. Ares, A. Pereira, P. Hernández, and J. A. Pérez, ―Comparative between FEM models for FDM parts and their approach to a real mechanical behaviour,‖ *Procedia Eng.*, vol. 63, pp. 878–884, 2013.

[7] Stratasys Direct Manufacturing, ―3D Printing Materials: Choosing the Right Material For Your Application,‖ 2016.

[8] Protolabs, ―Prototyping and Low-Volume Production for Medical Applications: How Rapid Manufacturing Can Increase Speed to Market For Devices And Components,‖ 2015. [Online]. Available: https://www.protolabs.com/resources/whitepapers/2015/medical/.

[9] 3DSystems, ―Top 10 Ways 3D printing Accelerates Product Design,‖ *Scanning*. .

[10] M. Feygin, A. Shkolnik, M. N. Diamond, and E. Dvorskiy, ―Laminated object manufacturing system,‖ WO1997039903A1, 1997.

[11] S. H. Lee, D. G. Ahn, and D. Y. Yang, ―Surface reconstruction for mid-slice generation on variable lamination manufacturing,‖ in *Journal of Materials Processing Technology*, 2002, vol. 130–131, pp. 384–389.

[12] Y. S. Liao and Y. Y. Chiu, ―A new slicing procedure for rapid prototyping systems,‖ *Int. J. Adv. Manuf. Technol.*, vol. 18, no. 8, pp. 579–585, 2001.

[13] Z. Zhao and L. Laperrière, ―Adaptive Direct Slicing of the Solid Model for Rapid Prototyping,‖ *Int. J. Prod. Res.*, vol. 38, no. 1, pp. 69–83, 2000.

[14] C. H. Yeh, Y. W. Chen, M. Y. Shie, and H. Y. Fang, ―Poly(Dopamine)-assisted immobilization of Xu Duan on 3D printed poly(Lactic Acid) scaffolds to up-regulate osteogenic and angiogenic markers of bone marrow stem cells,‖ *Materials (Basel).*, vol. 8, no. 7, pp. 4299–4315, 2015.