



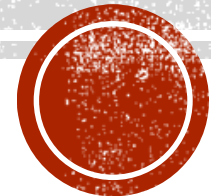
CAD FOR ADDITIVE MANUFACTURING

Dr. J. Ramkumar

Professor

Department of Mechanical Engineering and Design

IIT Kanpur



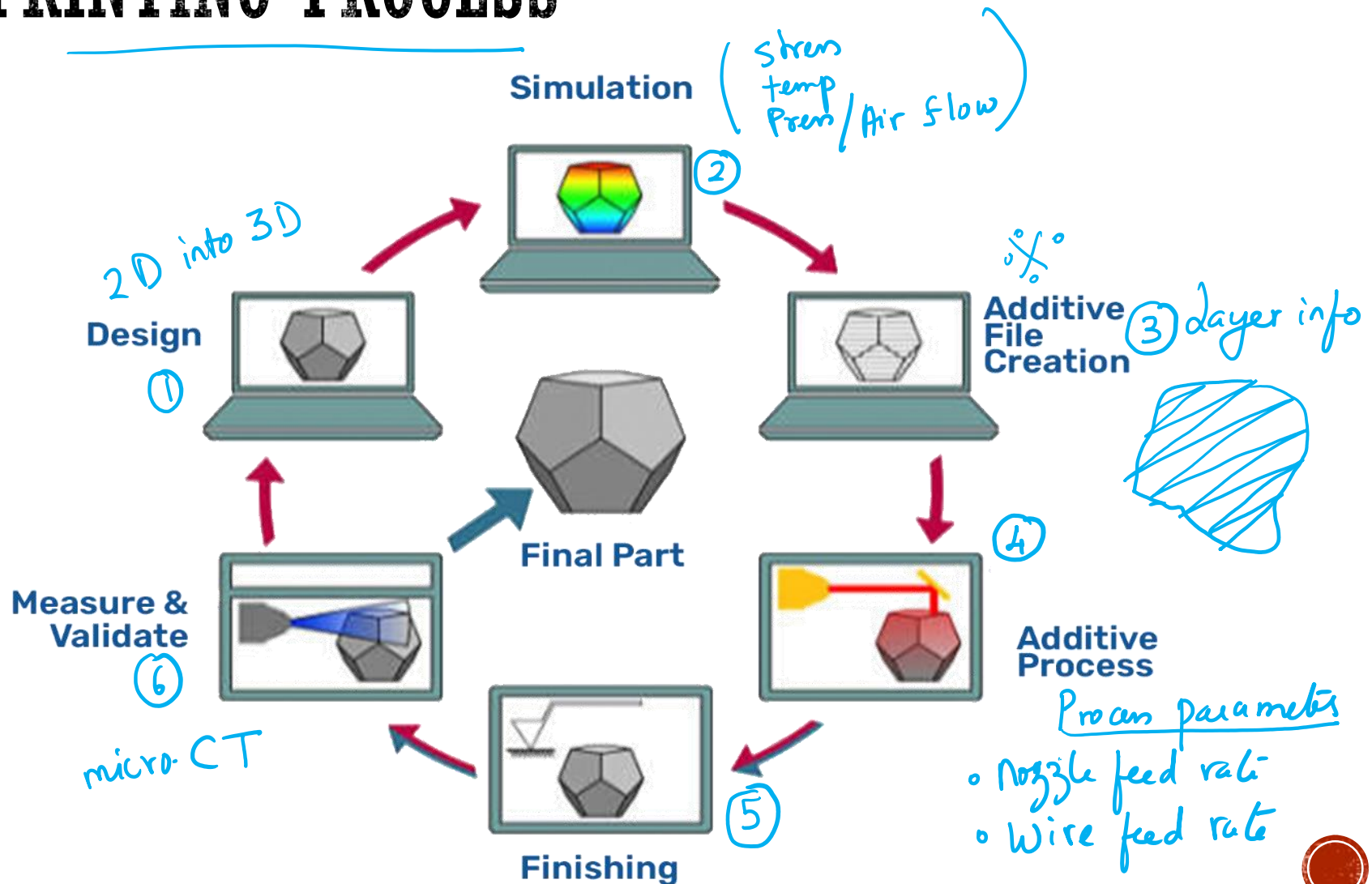


CONTENTS

- Printing process
- CAD file formats
- CAD CAM software
- Modelling and Data Processing
- Issues with STL file format
- AMF file format
- Slicing
- Design consideration
- Machine setup



PRINTING PROCESS



CAD FILE FORMATS

3D → Reverse Engineering

- In AM, the part to be manufactured is designed by a CAD tool that contains all the printing information.
- All AM processes begin with CAD conceptualization and model conversion into a machine-readable file. After sending the file to the machine, the part is printed.
- An experienced designer can create a CAD file via user interface, 3D scanning an existing part, or both.
- CAD models used in AM are sliced and stacked to form the desired part. SAT (or ACIS), DXF, STP, and STL are the most common 3D CAD model formats.

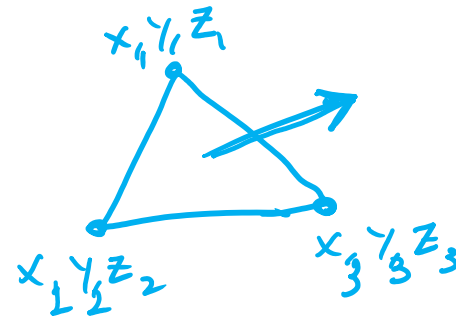
machine - readable files → neutral files



CAD FILE FORMATS

- STL, which stands for "stereolithography," is the most common AM format.
- This file format specifies ASCII or binary representations of 2D and 3D object surface geometry, but not color or texture. ★
- The STL file contains triangular facets identified by a unit normal and three vertices (corners) using a three-dimensional Cartesian coordinate system.
- Two non-standard variations of the binary STL file can be used to include color information.

★ .STL



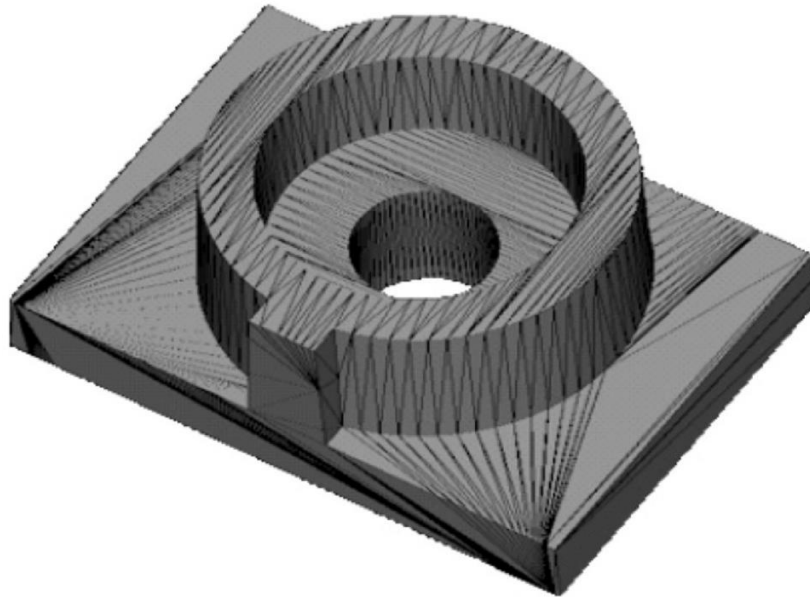
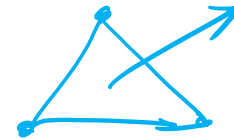
CAD FILE FORMATS



- As geometry changes, triangle facet density changes. STL files can't represent colors, textures, materials, and other printed object properties.
- This standard is known as Additive Manufacturing File Format (AMF) and it is an XML-based format. Any CAD/CAM software to describe the geometry, composition, color, materials, and lattices of any object to be fabricated with AM technologies can use it .



CAD FILE FORMATS



Typical STL file.



CAD/CAM SOFTWARE

- There are many AM software solutions available. The software can be categorized by purpose. Software is used for 3D printing, scanning, improving part performance, and process simulation.
- Powermill, NX Cam, and Camufacturing/Master-cam are used.
- The PowerMiLL CAM solution programs toolpaths for 3- and 5-axis CNC machines, produces smooth surface finishes, and simulates toolpaths.
- Siemens' NX Cam is a high-end CAD/CAM/CAE design, engineering analysis, and manufacturing solution. Robotics software is plentiful.

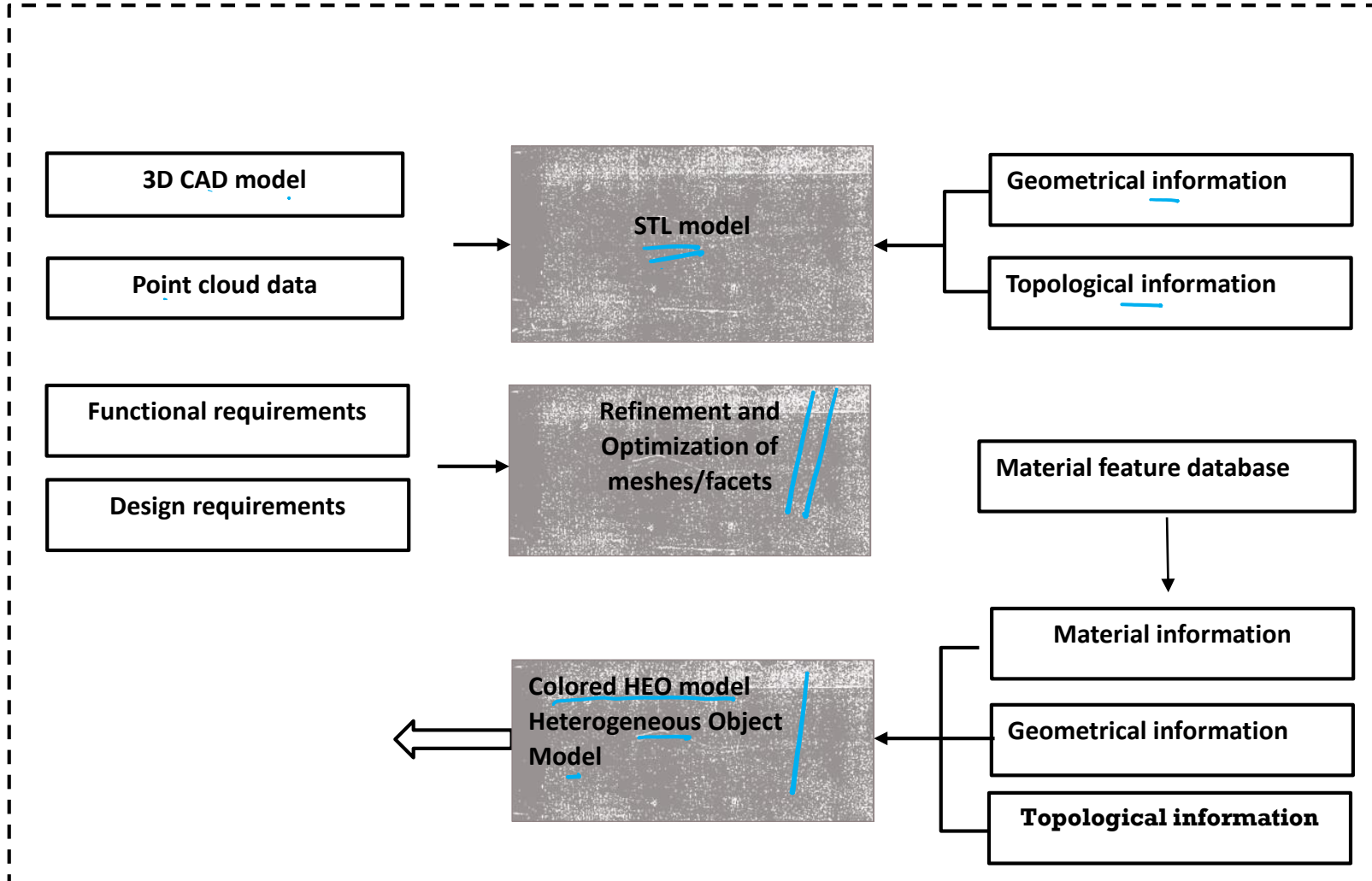


CAD/CAM SOFTWARE

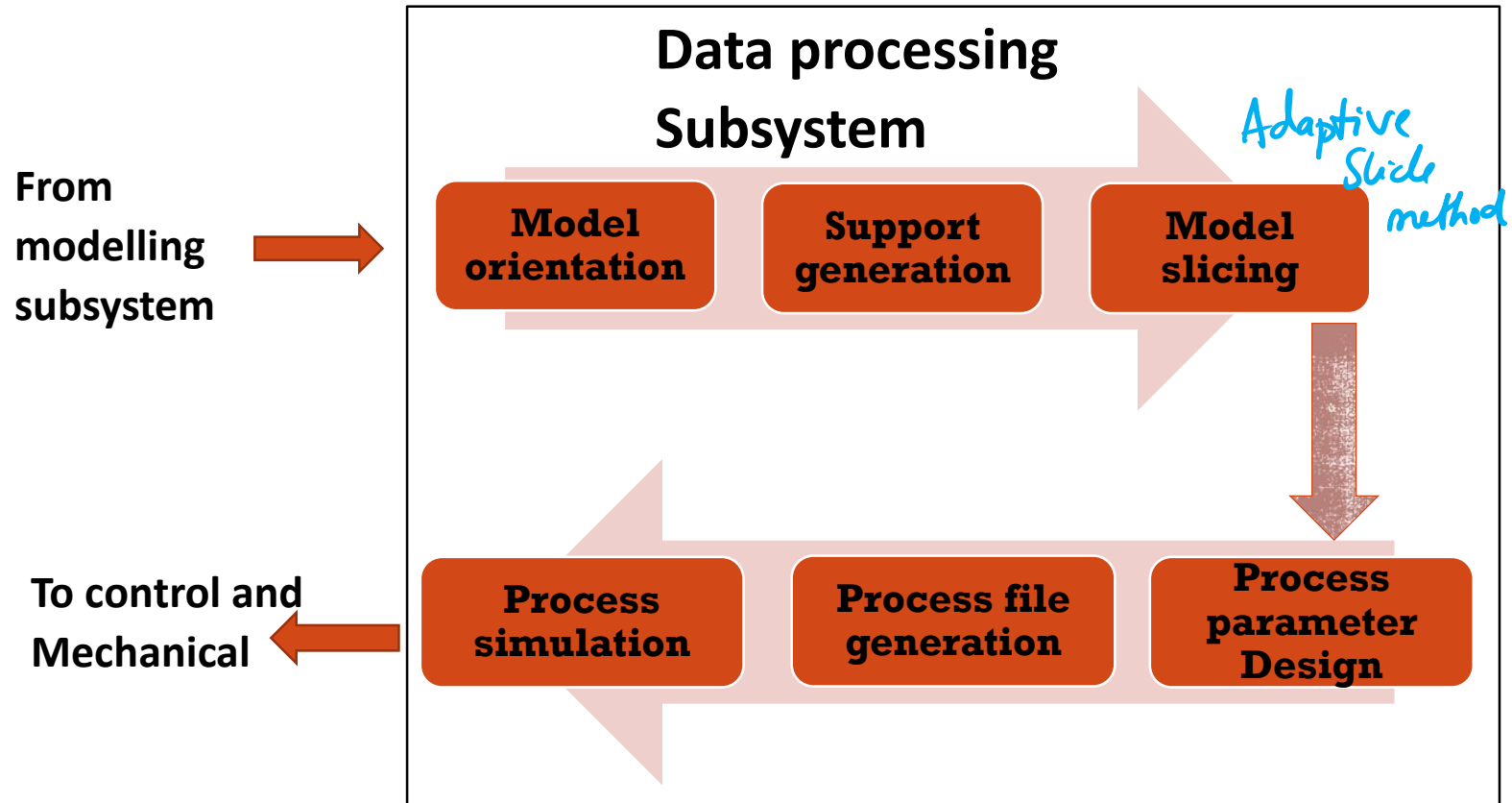
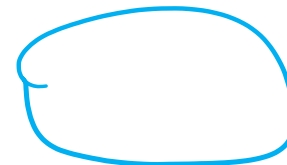
- PoweMill introduced "PowerMill Additive" It's a plugin for DED-driven additive or hybrid manufacturing.
- It uses PowerMill's multi-axis CNC and robot capabilities to create additive toolpaths with detailed process parameter control.
- These process parameters enable you to finely control the operations of deposition at a toolpath point level”.
- Despite packages, AM's software hierarchy has major flaws. Lack of intelligence and process-based recipes is a problem. ★



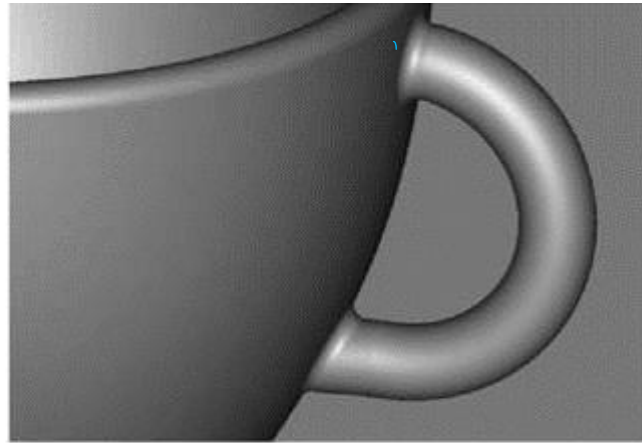
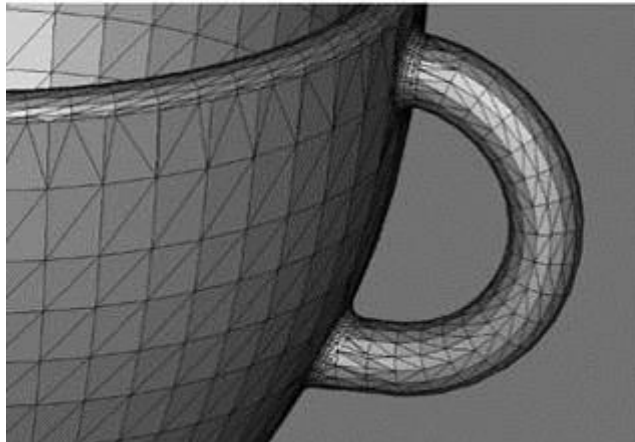
MODELING FOR PRINTING PART



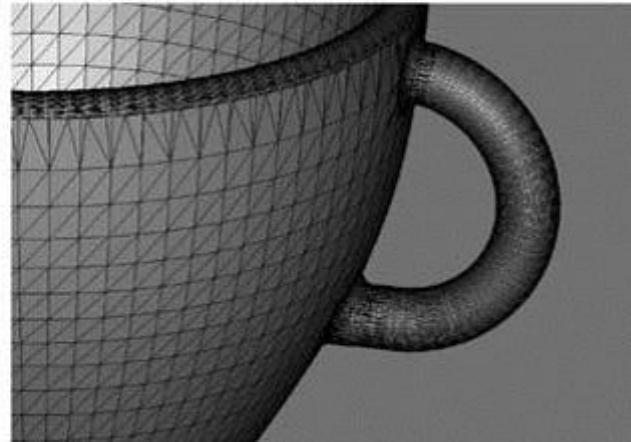
DATA PROCESSING IN AM SYSTEM



TESSELLATION IN CAD MODEL



Large STL files



Small STL file



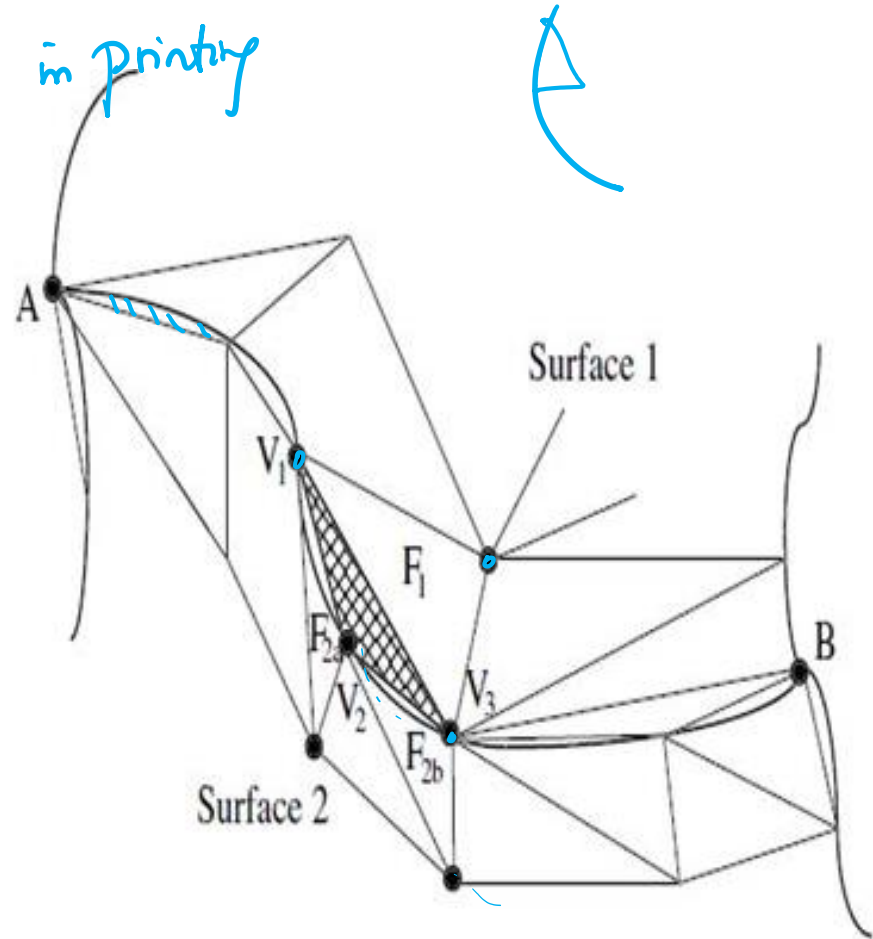
COMMON ISSUES WITH STL FILE FORMAT.

→ error in printing

A

GAPS OR MISSING FACETS:

- During tessellation of surfaces having large curvatures, gaps or holes can be generated at the intersection of these surfaces.
- This results in errors at these intersections which leave gaps and holes along the edges as shown in fig.



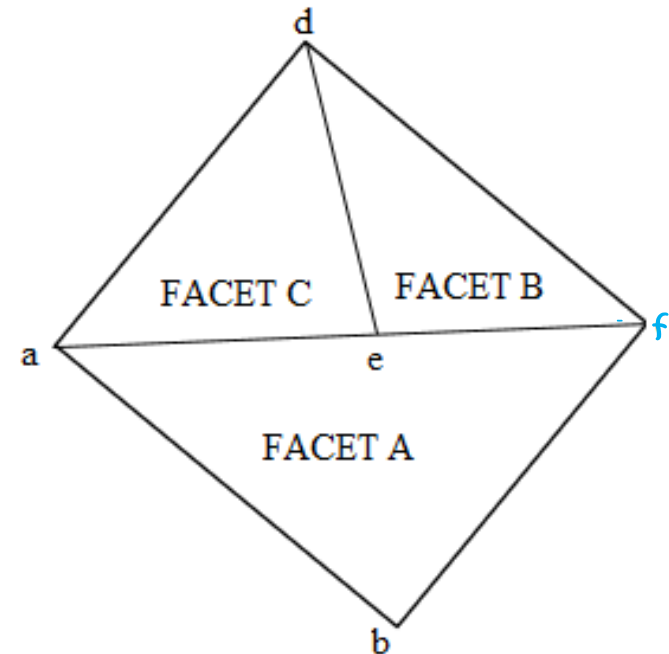
Gaps or missing facets



COMMON ISSUES WITH STL FILE FORMAT.

DEGENERATE FACETS:

- During tessellation, open spaces are created due to unequal tessellation of two adjacent surface patches along a common mating curve.
- The stitching of these open spaces is carried by STL file correction software's resulting in geometrical degeneracies.
- This is particularly when all edges of the facet are collinear, but vertices are distinctly shown in fig.



Degenerate facets.



COMMON ISSUES WITH STL FILE FORMAT.



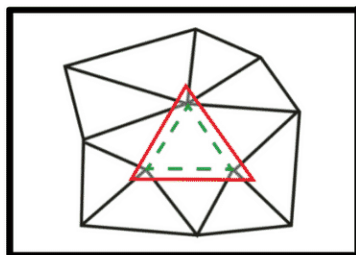
- Degenerate facets provide essential topological information (indicating mating of two surfaces).
- Even though it does not contain valid surface normal.
- This vital information is stored before neglecting the degenerate facet.



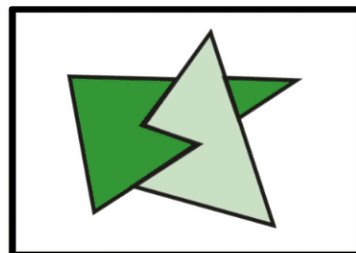
COMMON ISSUES WITH STL FILE FORMAT.

OVERLAPPING FACETS:

- In STL file Vertices are denoted as floating numbers resulting in a



OVERLAPPING
FACETS



OVERLAPPING
TRIANGLES

General ASCII format for defining a facet

Solid **name**

Facet normal ***ni nj nk***

Outer loop

Vertex ***v1 v1 v1***

Vertex ***v2 v2 v2***

Vertex ***v3 v3 v3***

end loop

endfacet

endsolid **name**



MANIFOLD GEOMETRY

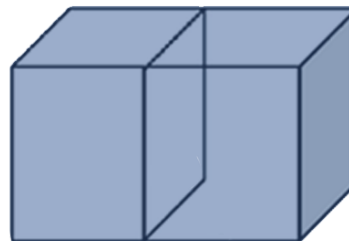
Manifold
non-manifold

Manifold 3D Model



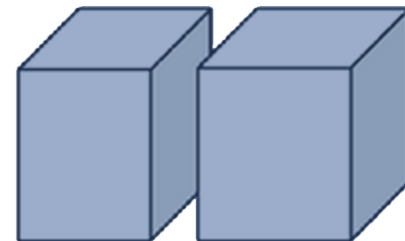
(a)

Non-Manifold



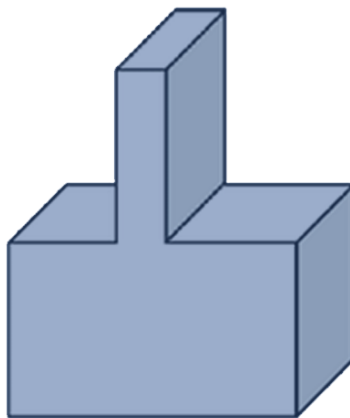
(b)

Manifold 3D Model



(c)

Manifold
3D Model

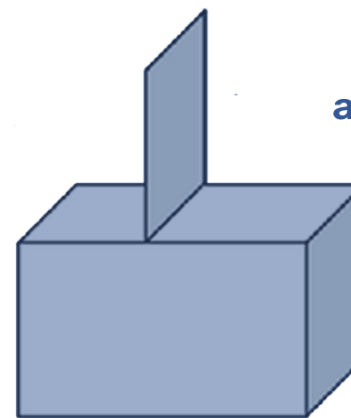


(d)

Manifold
3D Model



Idealization
of the top part



(e)

2D Face
associated with
3D Model

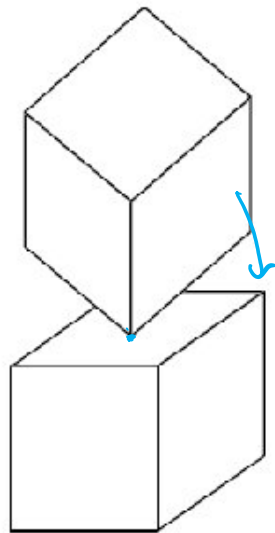
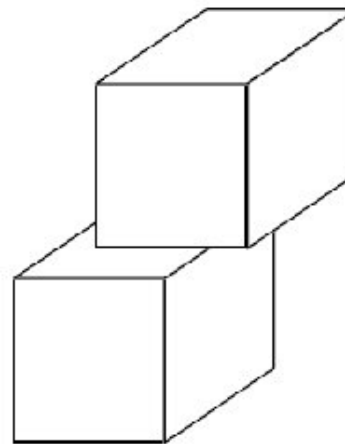
Non-Manifold
3D Model



COMMON ISSUES WITH STL FILE FORMAT

NON-MANIFOLD GEOMETRIES:

- Non-manifold geometries are geometric topology terms that allow all disjoint lumps to existing in their own logical body. It can be simply understood with manufacturability.
- These are mainly generated due to a round of errors during the tessellation of thin features.



BASIC STRUCTURE OF THE ADDITIVE MANUFACTURING FILE FORMAT

Name	Information included
<object >	Each file must contain at least one object element to describe the object
<material >	Define single or multiple material IDs for printing
<texture >	Define single or multiple texture mapping
<constellation >	Define displacement parameters, rotation parameters, which are collections of instances
<metadata >	Specify additional information about the objects and elements contained in the file



COMMONLY USED CAD FILE FORMAT IN ADDITIVE MANUFACTURING

	FILE FORMAT		
	STL format	OBJ format	PLY format
Development company	3D Systems	Wavefront Technologies	Stanford Graphics Lab
Description	Triangular patch, vertex color value	Straight lines, polygons, free-form curves	Vertices, faces, related data, groups
A face that supports more than three vertices	No	Yes	No
The compression ratio of PNG pictures	44.7:1	32.2:1	87.9:1



ADDITIVE MANUFACTURING FILE FORMAT

TECHNOLOGY INDEPENDENCE:

- AMF files use XML structure to describe the information of model objects in a general way.
- It can be not only processed by computers but also understandable by humans
- The new standard not only records a single material, but also assigns different materials to different parts, and can change the proportion of the two materials in stages.
- It is possible to specify an image to be printed on the surface of the model, and it is also possible to specify the most efficient print path for 3d printing
- Raw data such as the author's name, model name, etc. Can be recorded.



ADDITIVE MANUFACTURING FILE FORMAT

① **SIMPLICITY:**

- For ease of understanding and application, the file format should be able to read and edit in a simple text viewer, and the same information should not be stored in multiple places in the file.

■ **EXTENSIBILITY:**

- ② ■ As the complexity and size of components increase, it can be expanded with the increasing resolution and accuracy of manufacturing equipment, including large arrays capable of handling the same objects, complex repetitive internal features (for example, a grid), a smooth surface with fine print resolution, and many components for printing that are placed in the ideal fill material package



ADDITIVE MANUFACTURING FILE FORMAT

HIGH PERFORMANCE:

- It allocates reasonable duration (interaction time) for reading and writing and uses reasonable file size for typical large volume objects.

STRONG COMPATIBILITY:

- AMF format is not only backward compatible, but also compatible with existing STL and PLY file formats and can be adapted to future developmental needs to achieve forward compatibility.



COMPARISON OF COMMON 3D MODEL FILE FORMATS

File format	STL	OBJ	PLY	AMF	3MF
Description	Triangular patch	Straight lines, polygons, surfaces, free-form curves.	Fixed points, facets, related data, groups	Geometric information, colors, materials, author information, etc., can be expanded.	Geometric information, colors, materials, textures, etc.
Whether it contains color information	No	No	Yes	Yes	Yes
Whether it contains material information	No	No	No	Yes	Yes
Company	3D	Wavefront	Stanford	ASTM committee	3D manufacturing



MODEL SLICING

- The processing of geometric data for additive manufacturing mainly compromises two stages.



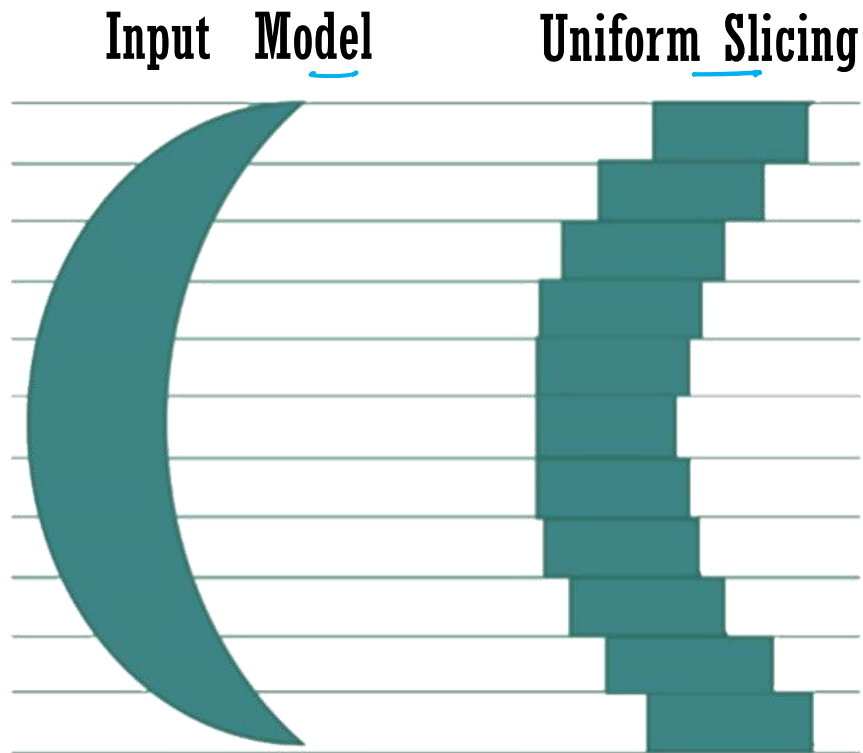
1. Slicing the information into layers for path generation.
2. Generating process-specific rastering patterns for each layer.

- There are a number of slicing methodologies that are being used by various software. These can be basically classified into two generic methodologies

1. Uniform life
2. Adaptive slicing



MODEL SLICING



Adaptive Slicing

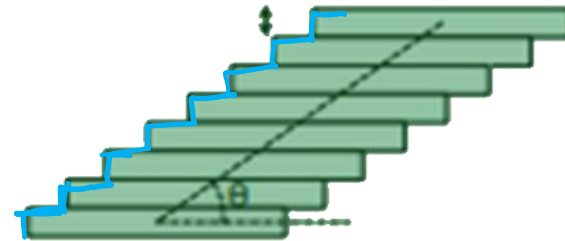


DESIGN CONSIDERATION IN AM

- **COMMON ISSUES:**
 - Feature resolution — PBF / DED / metal extrusion.
 - Surface finish — Selective sintering / melting
 - Geometrical accuracy.
- **'STAIRCASE EFFECT'** in angled features.



(a) Vertical Features



(b) Angled Features



(c) Angled Feature – Material extrusion



(d) Angled Feature – Material Stereolithography



(e) Angled Feature – Powder Bed Fusion

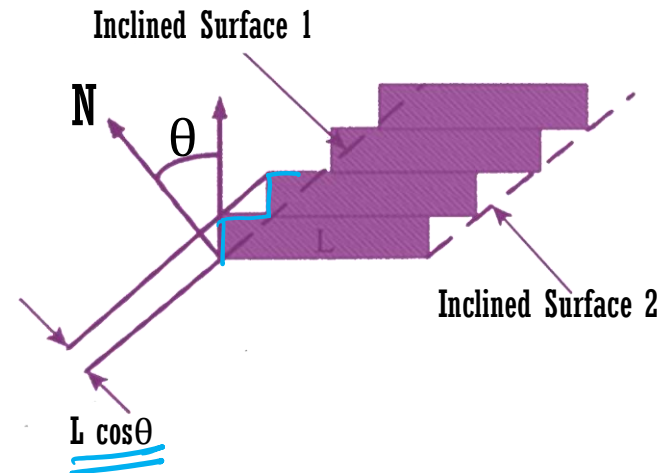


MINIMUM STAIR STEPPING ERROR MODEL

- Consider a planner volume. The stair stepping volume is the sum of each stair step (V_{step}) which is a function of the surface area and inclination angle that the surface makes with the build plane.

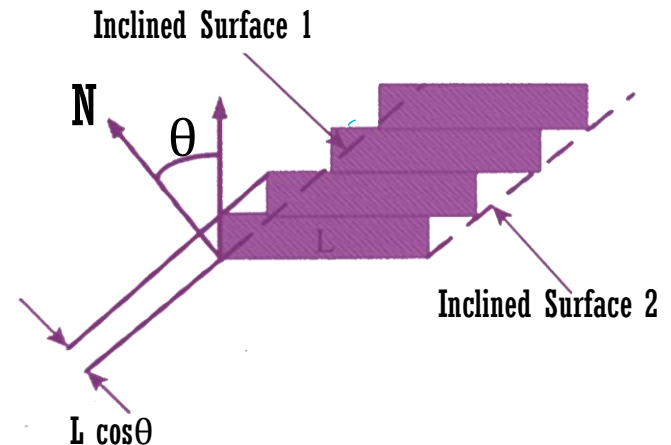
$$V_{\text{step}} = \frac{A_i L \cos(\theta)}{2}$$

Where, A_i , L , and θ are planners surface area, layer thickness, and angle between normal vector of plane and building directional vector respectively.



MINIMUM STAIR STEPPING ERROR MODEL

- If only one feature is present in the component it is preferred to have $\theta=0$.
- If more number of features are present it is the designer's responsibility to select between features and decide the optimal orientation.



DESIGN CONSIDERATION IN AM

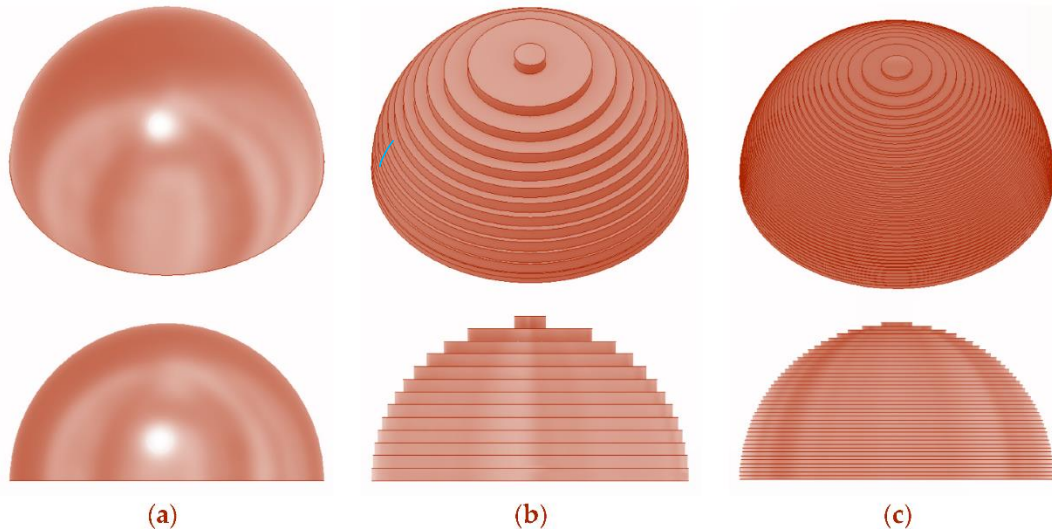
■ **LAYER HEIGHT:**

- Simplest parameter to influence printed part.
- With a decrease in height, finer details with high accuracy and surface finish can be printed.
- Most 3d printers have default layer height.

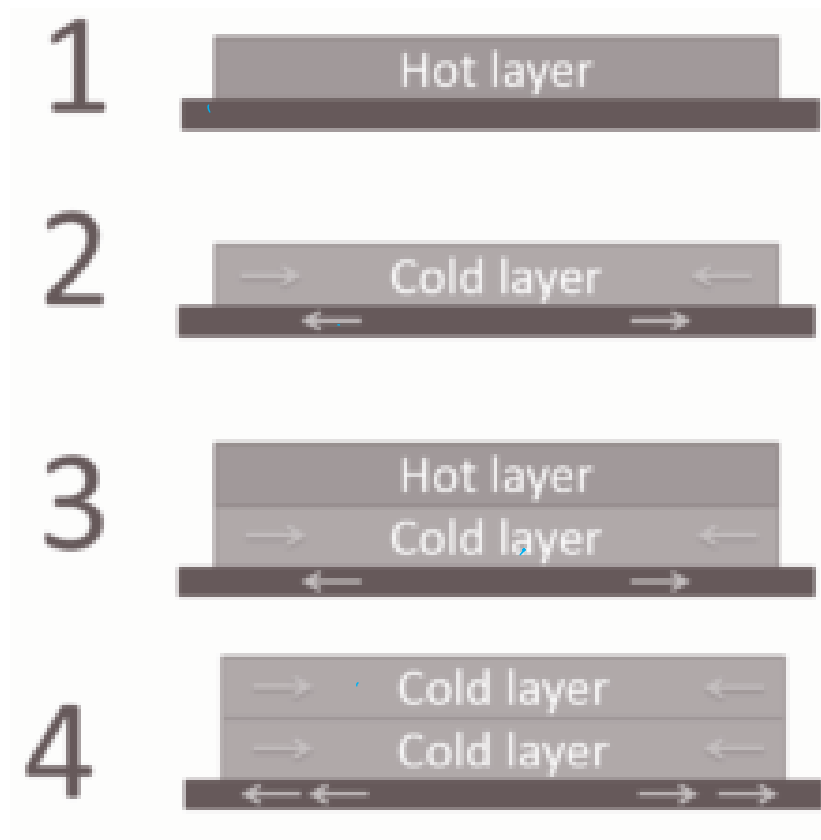
(a) An ideal sphere

(b) Sphere sliced at 0.8
mm layer height

(c) Sphere sliced at 0.25
mm layer height



RESIDUAL STRESS IN ADDITIVE MANUFACTURING



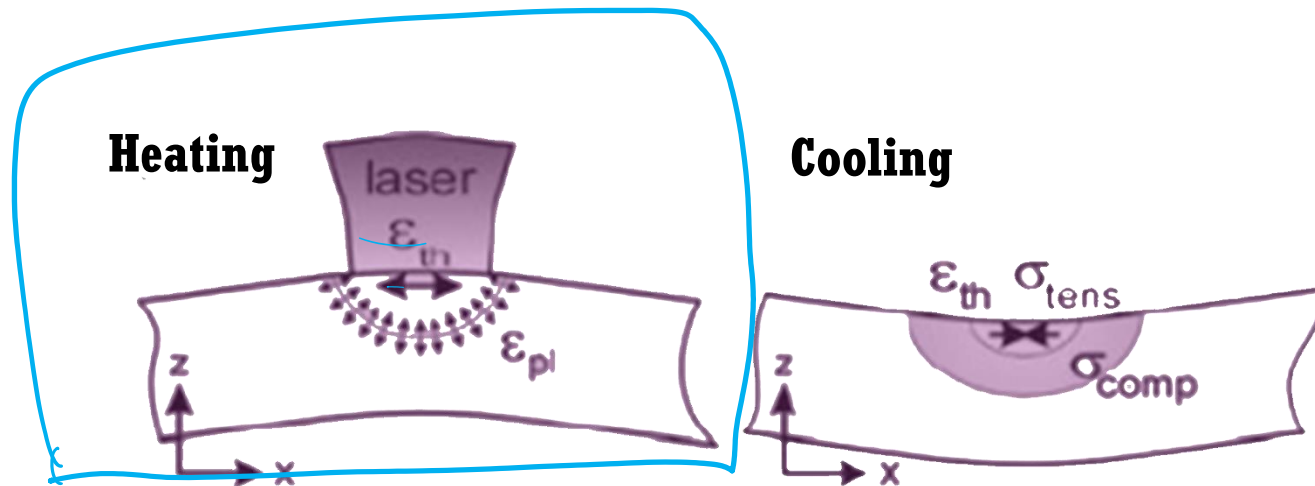
**Thermal stress resisted by
Build plate (no contraction)**

**Explained layer placed
On stressed expanded layer**

**Additional layers add more
Stress but it is uniformly distributed
(no wrapping)**



RESIDUAL STRESS IN ADDITIVE MANUFACTURING



Solution: By controlling the in-situ surface temperature of the material.



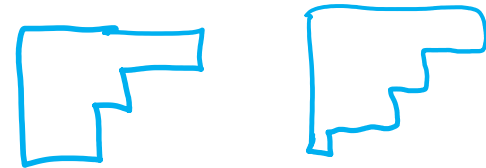
DESIGN CONSIDERATIONS IN ADDITIVE MANUFACTURING

SHRINKAGE AND WARPING

- Associated with Temperature and curing.
 - **Temperature-** thermal stresses and residual stresses cause shrinkage and warping.
 - **Curing-** As the layer of photopolymers is cured shrinkage and warping occur.
 - **Mitigating shrinkage and warping**- Printing in a temperature-controlled build environment, avoiding large flat surfaces, and providing supports.



DESIGN CONSIDERATIONS IN ADDITIVE MANUFACTURING



■ **FILLETS:**

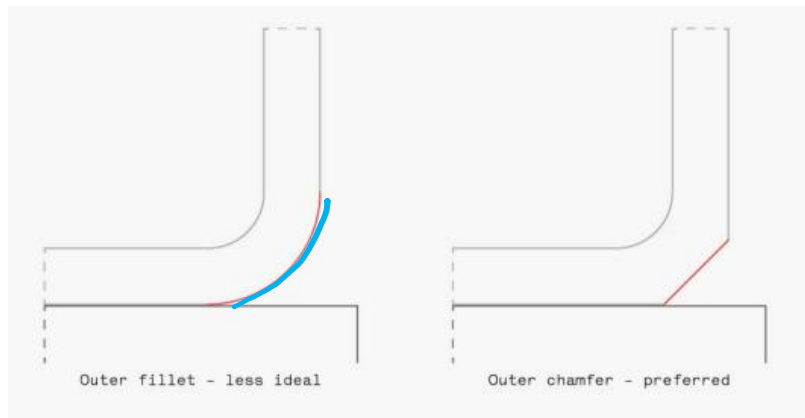
- Helps to reduce stress concentration at corners or edges.
- It also helps in assisting the removal of parts from the built platform.
- Should be included in 3D design of printed parts wherever possible.
- Most technology produces “natural fillet” on edges and corners.

■ **SUPPORT STRUCTURES.**

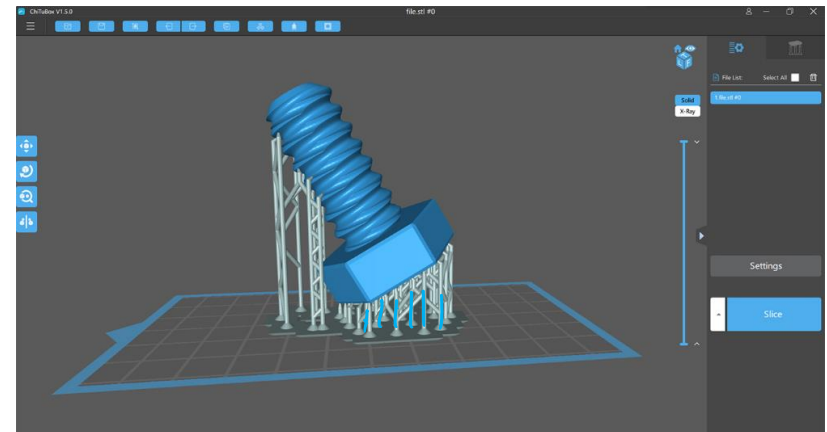
- Need for support structures as each layer requires a build platform.
- Most support structures have a negative effect on the printed part.
- Some process (like FFF and material jetting) offer dissolvable support while some process (like Powder or Sand based) doesn't require support.



DESIGN CONSIDERATIONS IN ADDITIVE MANUFACTURING



Fillet compared with a chamfer at edges in contact with the built plate



Support generation for a bolt to be printed.





COMMERCIALLY AVAILABLE SOFTWARE FOR SIMULATION

1. Digimat-RP
2. RP-Photonics
3. AdditiveLab
4. Procast
5. Arena
6. Automode
7. SimProcess





STEPS FOR BUILD FILE PREPARATION

1. Checking the geometry input as per standard file format. Checking for file errors and rectifying the errors, if any.
2. Checking part orientation considering build time, support requirements, stair stepping error, etc.
3. Addition of support structures in automatic/semi-automatic mode by providing the support type, criteria for support generation, type of support, etc. as input.
4. Nesting of the same or multiple components as per the requirements.
5. Slicing the part and support geometry by providing layer thickness as input.
6. Generation of tool path and selection of scanning strategies.
7. Input the process parameters specific to the process. Generally, separate process parameters are provided for the support structure to allow easy removal.
8. Rapidly review the geometry and laser tool path slice by slice.



MACHINE SETUP

- The quality of the additive manufactured products also depends on various parameters which are not part of pre-processing.
- These parameters are machine, material, and application-specific, and their due consideration is required to achieve desired results.
- The machine setup primary includes the following
 1. Build plate preparation
 2. Feedstock preparation
 3. Built environment preparation

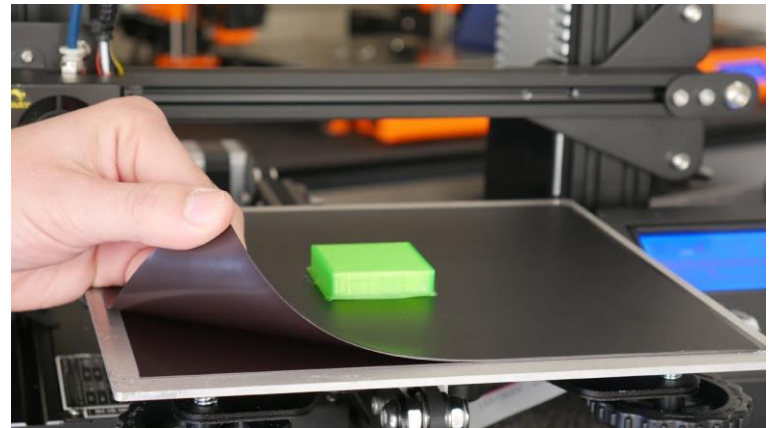


MACHINE SETUP

1. BUILD PLATE PREPARATION:

It is the base for fabricating the components and the preparation of the build plate is important to obtain high-quality components. some important considerations during build plate preparation are

- Selection of build plate material
- Preparation of build plate
- Levelling of the build plate. ★



MACHINE SETUP

2. FEEDSTOCK PREPARATION :

- Many feedstock materials tend to absorb moisture from the atmosphere.
- During handling, inappropriate storage, and manual sieving/recycling moisture, there are chances to pick up moisture.
- These moisture pickup can result in poor oxide formation in the additive manufacturing build component.
- The moisture also affects the fluidity of the powder and yields agglomeration and nonuniform spreading during additive manufacturing.
- Preheating of the powder is required to remove the moisture.



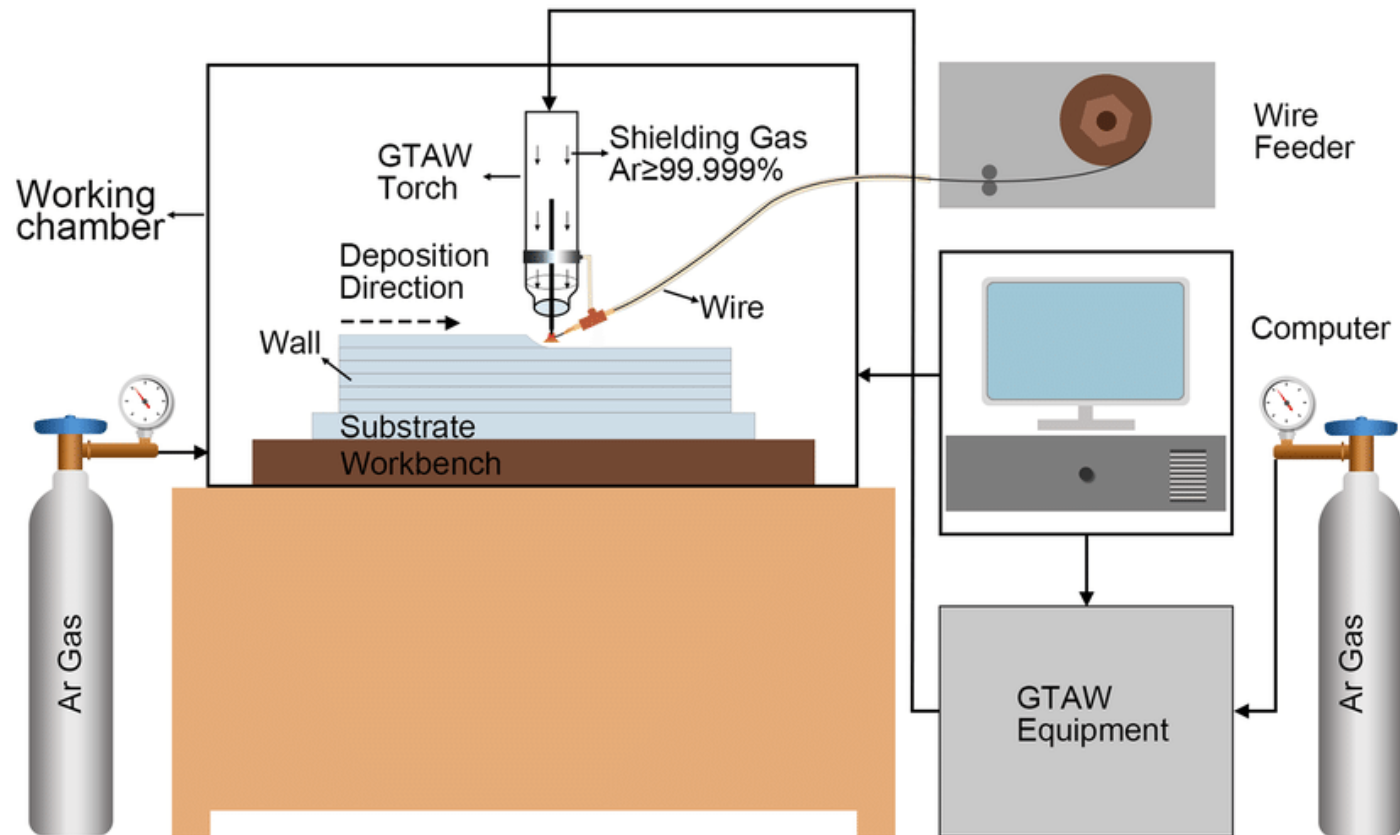
MACHINE SETUP

3. BUILD ENVIRONMENT

- The component is generally a built-in controlled atmosphere to prevent oxidation of the melt pool.
- Argon is generally used for highly sensitive materials like aluminum and titanium while nitrogen is used for processing other metals and alloys.
- In the case of polymer-based additive manufacturing the melting environment provides uniform temperature to the build component during the process



MACHINE SETUP



POINTS TO PONDER

- Different file formats used for AM.
- Errors associated with STL file format.
- Slicing and Design consideration for modeling
- Steps for file preparation for printing
- Machine set-up





ASSIGNMENT

- Make a flow chart for preparing CAD files for printing.
- Think and list some of the errors that can occur while machine set up.





THANK YOU

