Chapter 2 - CAD for Additive Manufacturing

Define CAD.

Computer-aided design (CAD) is the use of computers (or workstations) to aid in the creation, modification, analysis, or optimization of a design. This software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

CAD Data formats:

CAD formats are divided into

1. Native CAD formats
2. Neutral 3D formats
3. Specialized formats

1. **Native CAD formats :** Most popular 3D CAD file formats are native CAD formats. That's because native formats create and let you access the most information possible about your 3D CAD file.
   Following are some of the types of Native CAD formats.

- **AutoCAD (.dwg):** This is the most popular 3D CAD file format because, it's the original. It's the native file format for Autodesk's AutoCAD program, the first widespread CAD program in the field. The extension is short for "drawing" and is a compact binary format.
- **Blender (.blend):** Blend files are special beasts. They're a scene description format from the 3D modeling and animation software Blender.
- **Parasolid (.x_t):** Parasolid is a geometric modeling program, and its file extension contains 3D CAD file information like geometry, topology, and color from your drawing.
- **SolidWorks (.sldprt and .sldasm):** These two file extensions, coming from SolidWorks, are short for "SolidWorks Part" and "SolidWorks Assembly". .sldprt provides details on specific parts within an entire system, allowing a comprehensive study that can then be reassessed with an overview of how it fits into the rest of the 3D CAD file.

- **Inventor (.ipt and .iam):** Much like SolidWorks, Autodesk Inventor has complementary formats for parts and assemblies. .ipt represents a single item of design, like one ball bearing in a wheel setting, while .iam is meant for assemblies, or files with more than one interacting part, like a screw going through a latch.
- **SketchUp (.skp)**: Originally developed by @Last Software, SketchUp and its 3D CAD file format was bought by Google in 2006 and by Trimble in 2012.

2. **Neutral 3D formats** are useful for sharing between different CAD programs. These 3D CAD file formats don't inherently collect as much metadata as native CAD files, so there's some level of fine detail loss when using them, but they're great for collaborative work.
   Following are some of the types of Neutral 3D formats.

- **Stereolithography or "Standard Tessellation Language" (.stl):** The STL file format uses rough triangles to describe the surface shape and area of your 3D CAD design.
- **Additive Manufacturing (.amf):** This is an open standard for describing objects within additive manufacturing and is most commonly used in 3D printing. It's a 3D CAD file format based on XML, which allows any CAD program to describe any 3D object to build on any 3D printer.
- **STEP (.stp and .step):** STEP stands for Standard for the Exchange of Product model data, and it stores 3D images in an ASCII format.
- **Wavefront (.obj):** First developed by Wavefront for its own Advanced Visualizer animation software, the OBJ file format has been adapted by scores of other 3D graphics software.
- **3D Manufacturing Format (.3mf):** Recently developed by the 3MF Consortium, 3MF is an open-source file format striving to become a standard in the additive manufacturing world.
- **Initial Graphics Exchange Specification (.iges):** Invented by the US Air Force as a national standard CAD file format, IGES lets users exchange circuit diagrams, wireframe, freeform surface, or solid modeling representations of product models.

3. **Specialized Formats :** 3D CAD work encompasses a lot of industries and types of projects, from machine part modeling to video game character building. This variety creates an ever-expanding need for new types of 3D CAD file formats that can handle the viewing and manipulation of unique data.

   Following are some of the types of Specilized formats.

- **Autodesk (.3ds):** The 3DS format specializes in importing and exporting your drafting files. It's designed to facilitate easy model moving between CAD software, which means it only stores essential geometry, texture, and lighting data.
- **Collada (.dae):** Sony originally created this format as a way to share 3D graphical files over a wide range of software.
- **X3D**: This 3D CAD file format is the improved successor of VRML. X3D is based on XML and is a royalty-free standard for declaratively representing 3D graphics.

Basic Principles of Additive Manufacturing Process

- All additive manufacturing (AM) models are built by joining single layers of equal thickness.
- The layer is shaped (contoured) in an x-y plane two dimensionally. The third dimension results from single layers being stacked up on top of each other, but not as a continuous z coordinate.
- The models are therefore three-dimensional forms that are very exact on the building plane (x-y direction) and owing to the described procedure are then stepped in the z direction, whereby the smaller the z step is, the more the model looks like the original.
- The stair-step effect is a typical characteristic of the additive manufacturing process that can never be entirely eliminated but can be reduced by decreasing the layer thickness.
- A larger layer thickness, up to around 0.2 mm, is most oftenused for fabbers or for reducing the building time on other additive manufacturing machines.

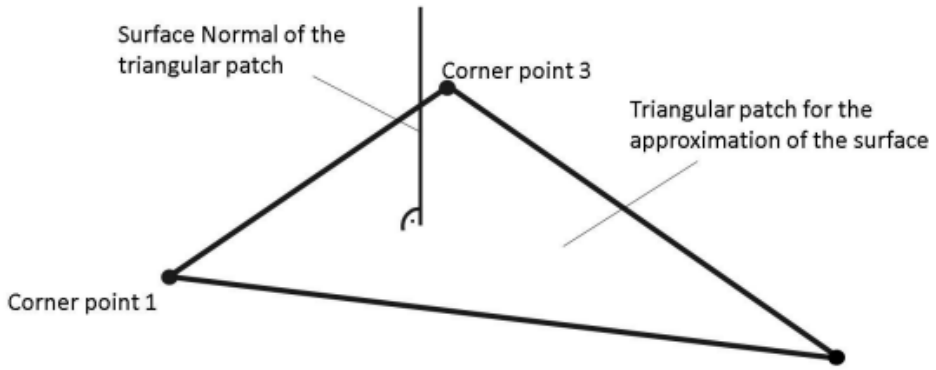
- Depending on the type of contouring (scanning, plotting, and so on) and the chosen AM process, the object is contoured continuously in the building plane (x-y plane).

Need of STL format

- STL is a file format native to the stereolithography CAD software created by 3D Systems.
- STL has several backronyms such as "Standard Triangle Language" and "Standard Tessellation Language".
- This file format is supported by many other software packages; it is widely used for rapid prototyping, 3D printing and computer-aided manufacturing.
- STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact.
- An STL file describes a raw, unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system.
- In the original specification, all STL coordinates were required to be positive numbers, but this restriction is no longer enforced and negative coordinates are commonly encountered in STL files today. STL files contain no scale information, and the units are arbitrary.

STL Format

- In order to obtain an STL data set of the part, the surfaces of the part are approximated by triangles.




```
FACET NORMAL 0.000000e+00 0.000000e+00 -
 OUTER LOOP
  VERTEX 9.999990e+00 9.999990e+00
  VERTEX 9.999990e+00 1.100001e+01
  VERTEX 1.100001e+01 9.999990e+00
 ENDLOOP
ENDFACET
```

```
Surface Normal of the triangular patch 1
 Start of the point data
  Triangular facet 1; corner point 1
  Triangular facet 1; corner point 1
  Triangular facet 1; corner point 1
 End of the point data
End of facet description for facet 1
```

- Volume elements exhibit at least two surfaces, the inner and outer surfaces. Both of them differ only by the normal vectors.
- The definition of the surface by triangles is called triangulation or tessellation. This leads to the so- called STL data. It is regarded as a de facto industry standard for AM processes, but it is actually nowhere standardized.
- This contributed to the fact that this process, long before it was discovered for additive manufacturing, was used for shading and thus for the visualization of three-dimensional CAD lattice models.
- Decisive for the establishment of the STL format as an interface for additive manufacturing was the early publication of the interface formulation.
- The STL interface, which has been known since then as the stereolithography interface, could be used by both machine manufacturers and free software businesses.
- This was especially beneficial to the development of special software that is offered by independent developers and made a lasting contribution to the user-friendliness of additive manufacturing systems.

- The STL data contains the normal vector as shown in Figure (positive direction outward, away from the volume) and the coordinates of the three vertices of each triangle. An ASCII or binary file can be created.
- The amount of data is much lower for binary files, but ASCII files are comparatively easy to read and control in the source code.

Data loss/ Errors

- During the transformation of the CAD internal geometry data into STL files, different errors can occur that affect the quality of the physical component. The errors are categorized by Hoffmann as
    - construction errors,
    - transforming errors, and
    - description errors.

Construction errors

- Construction errors are based on unnecessary data inside the component that are the result of combining the single elements incorrectly in the CAD system
- These errors are problematic for the AM process. For example, LLM processes include unnecessary cuts because of these errors. The consequences range from additional expenses during the building process to the total loss of thepart.
- The consequences range from additional expenses during the building process to the total loss of the part.
- Construction errors do not affect components that are produced by polymerization and sintering processes.

Transforming errors

- Transforming errors exist when the convergence of the mathematically exact con-tour by triangles is inaccurate and the number of transforming errors is larger the lower the number of triangles chosen.
- With the increased accuracy in defining the surface made possible by increasing the number of triangles, the amount of data increases enormously.

- In practical terms, the fineness of the triangulation is not problematic if approved settings are used.

Description errors

- Description errors are primarily attributable to three causes:
    - Gaps between triangle patches (boundary error),
    - double triangle patches (overlap),and
    - incorrect orientation of individual patches (disorientation).
- Gaps (and double triangle patches as a special form of gaps) are the result of inaccurate boundaries that border on each other.
- The existence of differing resolution densities of geometries can cause boundary errors on the edge on the opposite side. These are called “naked edges.”
- Such defects are irrelevant for visualization and also for processing with cutter diameters in the range of millimeters. In applications with lasers that exhibit a beam diameter of 0.1 mm, such defects have a negative effect.
- When the surface is oriented incorrectly, the normal vector points to the inside of the model. In general, the human eye can assign such surfaces correctly, but for generating machine data these results are problematic. The result is that the inner and outer sides cannot be separated.
- When the machine-specific layer information is generated, all gaps have to be closed. This process is called the repair of the data set. Normally, special modules of front-end software do this automatically. While repairing semi automatically, manual intervention leads to faster and better results.

Need of Slicing in 3D printing

- 3D models are sliced into instructions for 3D printers by the process known as slicing. It essentially "slices" the 3D model into thin layers and then determines the path for each layer to be printed to get the best strength, shortest printing time, etc.
- A 3D CAD model, often an STL format file, is converted into Gcode, which the printer may use. The three main categories of parameters that can be adjusted in a slicer program are as follows:
    - Layer heights
    - Shells

    - Infill percentages, and
    - 3D print speeds.
- Print bed settings, filament diameter, extrusion multiplier, and extruder temperature are included in filament settings. A printer's settings include the diameter of the nozzle, the shape of the print bed (L x W), and the Z offset.

Advantages of CAD

- **Increases Productivity**
  CAD software allows designers to lower production costs, work faster and smarter, and ultimately leads to quicker project completion.
- **Higher Quality Designs**
  The use of CAD allows design teams to control the quality of the final engineered product. It's easy to investigate an error, diagnose the problem, and solve it all using the software before any prototypes are made. This not only saves time, but also money.
- **Reuse and Easily Change Designs**
  Fashion design is one industry that uses CAD often. It allows designers to create clothes and see how they would fit on virtual models, all without spending a dime on manufacturing.
- **Easier to Read**
  CAD drawings are easily read, as they're standardized and organized. Legibility is increased, and there are no issues with reading the drawings.
- **Simplified Sharing**
  CAD makes collaborating easy, even for remote teams.
- **Documenting the Design**
  CAD software is excellent at documenting all aspects of a design. The measurements, angles, and dimensions of a product are all conveniently recorded and saved for future use.

Limitation of CAD

- Skill of the Designer
  CAD (and CAM, its counterpart) are tools for a designer to use to create a design. Like all tools, they are only as useful as the one handling them. While a computer can tell you what a design will look like when you use

either steel or wood, the user is the one who makes the decision, which inevitably affects function. CAD software also can't tell you which design is more aesthetically pleasing, and in some industries, that overrides function.

- Designing Physical Objects in a Virtual Workspace
  Designing virtually allows the user to create perfection without concerning themselves with real-world constraints.

Questions

- *Explain different errors in STL files.*
- *Explain the file formats in CAD and their types.*
- *Define CAD.*
- *Explain the basic Principles of Additive Manufacturing Process.*
- *Write the short notes on*
  i) Advantages of CAD. ii.Applications of CAD packages.
- *State the need of STL model.*
- *Explain STL model.*
- *State the need of STL model.*
- *Define Material Extrusion.*