ADDITIVE MANUFACTURING

UNIT-1

DEFINITION OF A PROTOTYPE

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version.
e.g.: A prototype supersonic aircraft.

(OR)

An approximation of a product (or system) or its components in some form for a definite purpose in its implementation.

TYPES OF PROTOTYPES

The general definition of the prototype contains three aspects of interests:

1) The implementation of the prototype- from the entire product (or system) itself to its sub-assemblies and components,
2) The form of the prototype; from a virtual prototype to a physical prototype, and
3) The degree of the approximation of the prototype; from a very rough representation to an exact replication of the product.

1) The implementation of the prototype

The implementation aspect of the prototype covers the range of prototyping the complete product (or system) to prototyping part of, or a sub-assembly or a component of the product.

- One example of such prototype is one that is given to a group of carefully selected people with special interest, often called a focus group, to examine and identify outstanding problems before the product is committed to its final design.
- On the other hand, there are prototypes that are needed to study or investigate special problems associated with one component, sub-assemblies or simply a particular concept of the product that requires close attention. An example of such prototype is a test platform that is used to find the comfortable rest angles of an office chair that will reduce the risk of spinal injuries after prolonged sitting on such a chair.

2) The form of the prototype

The second aspect of the form of the prototype takes into account how the prototype is being implemented. On one end, virtual prototypes that refers to prototypes that are nontangible, usually represented in some form other than physical.

- An example is the visualization of airflow over an aircraft wing to ascertain lift and drag on the wing during supersonic flight. Such prototype is often used when either the physical prototype is too large and therefore takes too long to build, or the building of such a prototype is exorbitantly expensive.

- The main drawback of these kinds of prototypes is that they are based on current understanding and thus they will not be able to predict any unexpected phenomenon.

3) The degree of the approximation of the prototype

- The third aspect covers the degree of approximation or representativeness of the prototype. On one hand, the model can be a very rough representation of the intended product, like a foam model, used primarily to study the general form and enveloping dimensions of the product in its initial stage of development. Some rough prototypes may not even look like the final product, but are used to test and study certain problems of the product development.
- An example of this is the building of catches with different material to find the right "clicking" sound for a cassette player door.

ROLES OF THE PROTOTYPES

The roles that prototypes play in the product development process are several. They include the following:

(1) Experimentation and learning
(2) Testing and proofing
(3) Communication and interaction
(4) Synthesis and integration
(5) Scheduling and markers

(1) Experimentation and learning

To the product development team, prototypes can be used to help the thinking, planning, experimenting and learning processes while designing the product. Questions and doubts regarding certain issues of the design can be addressed by building and studying the prototype.

- For example, in designing the appropriate elbow-support of an office chair, several physical prototypes of such elbow supports can be built to learn about the "feel" of the elbow support when performing typical tasks on the office chair.

(2) Testing and proofing

Prototypes can also be used for testing and proofing of ideas and concepts relating to the development of the product.

- For example, in the early design of folding reading glasses for the elderly, concepts and ideas of folding mechanism can be tested by building rough physical prototypes to test and prove these ideas to see if they work as intended.

(3) Communication and interaction

The prototype also serves the purpose of communicating information and demonstrating ideas, not just within the product development team, but also to management and client.

- Nothing is clearer for explanation or communication of an idea than a physical prototype where the intended audience can have the full experience of the visual and tactile feel of the product.
- A three-dimensional representation is often more superior than that of a two-dimensional sketch of the product.
- For example, a physical prototype of a cellular phone can be presented to carefully selected customers. Customers can handle and experiment with the phone and give

feedback to the development team on the features of and interactions with the phone, thus providing valuable information for the team to improve its design.

(4) Synthesis and integration

A prototype can also be used to synthesize the entire product concept by bringing the various components and sub-assemblies together to ensure that they will work together.

- When putting the prototype together, all aspects of the design, including manufacturing and assembly issues will have to be addressed, thus enabling the different functional members of the product development team to understand the various problems associated with putting the product together.

(5) Scheduling and markers

Prototyping also serves to help in the scheduling of the product development process and is usually used as markers for the end or start of the various phases of the development effort. Each prototype usually
marks a completion of a particular development phase, and with proper planning.

HISTORICAL DEVELOPMENT OF RAPID PROTOTYPING

The development of Rapid Prototyping is closely tied in with the development of applications of computers in the industry. The declining cost of computers, especially of personal and mini computers, has changed the way a factory works. The increase in the use of computers has spurred the advancement in many computer-related areas including Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Computer Numerical Control (CNC) machine tools. In particular,
the emergence of RP systems could not have been possible without the existence of CAD.

Year of Inception	Technology
1770	Mechanization [4]
1946	First Computer
1952	First Numerical Control (NC) Machine Tool
1960	First commercial Laser [5]
1961	First commercial Robot
1963	First Interactive Graphics System (early version of Computer-Aided Design) [6]
1988	First commercial Rapid Prototyping System

What are the three phases of prototyping? Contrasting these with those of geometric modeling, what similarities can be drawn.

Three Phases of Development Leading to Rapid Prototyping

Geometric Modeling	Prototyping

❶ **First Phase: 2D Wireframe**
• Started in mid-1960s
• Few straight lines on display may be:
  • circuit path on a PCB
  • plan view of a mechanical component
• "Natural" drafting technique
	❶ **First Phase: Manual Prototyping**
	• Traditional practice for many centuries
	• Prototyping as a skilled crafts is:
	  • traditional and manual
	  • based on material of prototype
	• "Natural" prototyping technique

❷ **Second Phase: 3D Curve and Surface Modeling** • Mid-1970s • Increasing complexity • Representing more information about precise shape, size and surface contour of parts	❷ **Second Phase: Soft or Virtual Prototyping** • Mid-1970s • Increasing complexity • Virtual prototype can be stressed, simulated and tested, with exact mechanical and other properties
❸ **Third Phase: Solid Modeling** • Early 1980s • Edges, surfaces and holes are knitted together to form a cohesive whole • Computer can determine the inside of an object from the outside. Perhaps, more importantly, it can trace across the object and readily find all intersecting surfaces and edges • No longer ambiguous but exact	❸ **Third Phase: Rapid Prototyping** • Mid-1980s • Benefit of a hard prototype made in a very short turnaround time is its main strong point (relies on CAD modeling) • Hard prototype can also be used for limited testing • Prototype can also assist in the manufacturing of the products

FUNDAMENTALS OF RAPID PROTOTYPING

Common to all the different techniques of RP is the basic approach they adopt, which can be described as follows:

1. A model or component is modeled on a Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system. The model which represents the physical part to be built must be represented as closed surfaces which unambiguously define an enclosed volume.
2. The solid or surface model to be built is next converted into a format dubbed the "STL" (STereoLithography) file format which originates from 3D Systems. The STL file format approximates the surfaces of the model by polygons. Highly curved surfaces must employ many polygons, which means that STL files for curved parts can be very large. However, there are some rapid prototyping systems which also accept IGES (Initial Graphics Exchange Specifications) format.
3. A computer program analyzes a STL file that defines the model to be fabricated and "slices" the model into cross sections. The cross sections are systematically recreated through the solidification of either liquids or powders and then combined to form a 3D model.

With a neat sketch explain Additive Manufacturing(AM) i.e., RP Wheel OR
Name the important elements of RP wheel? OR
Write short notes on RP wheel?

RP WHEEL

Fundamentally, the development of RP can be seen in four primary areas. The below mentioned Rapid Prototyping Wheel depicts these four key aspects of Rapid Prototyping. They are: Input, Method, Material and Applications.

Input

Input refers to the electronic information required to describe thephysical object with 3D data. There are two possible starting points —

- computer model
- physical model.

The computer model created by a CAD system can be either a surface model or a solid model.

On the other hand, 3D data from the physical model is not at all straightforward. It requires data acquisition through a method known as reverse engineering. In reverse engineering, a wide range of equipment can be used, such as CMM (coordinate measuring machine) or a laser digitizer, to capture data points of the physical model and "reconstruct" it in a CAD system.

Material

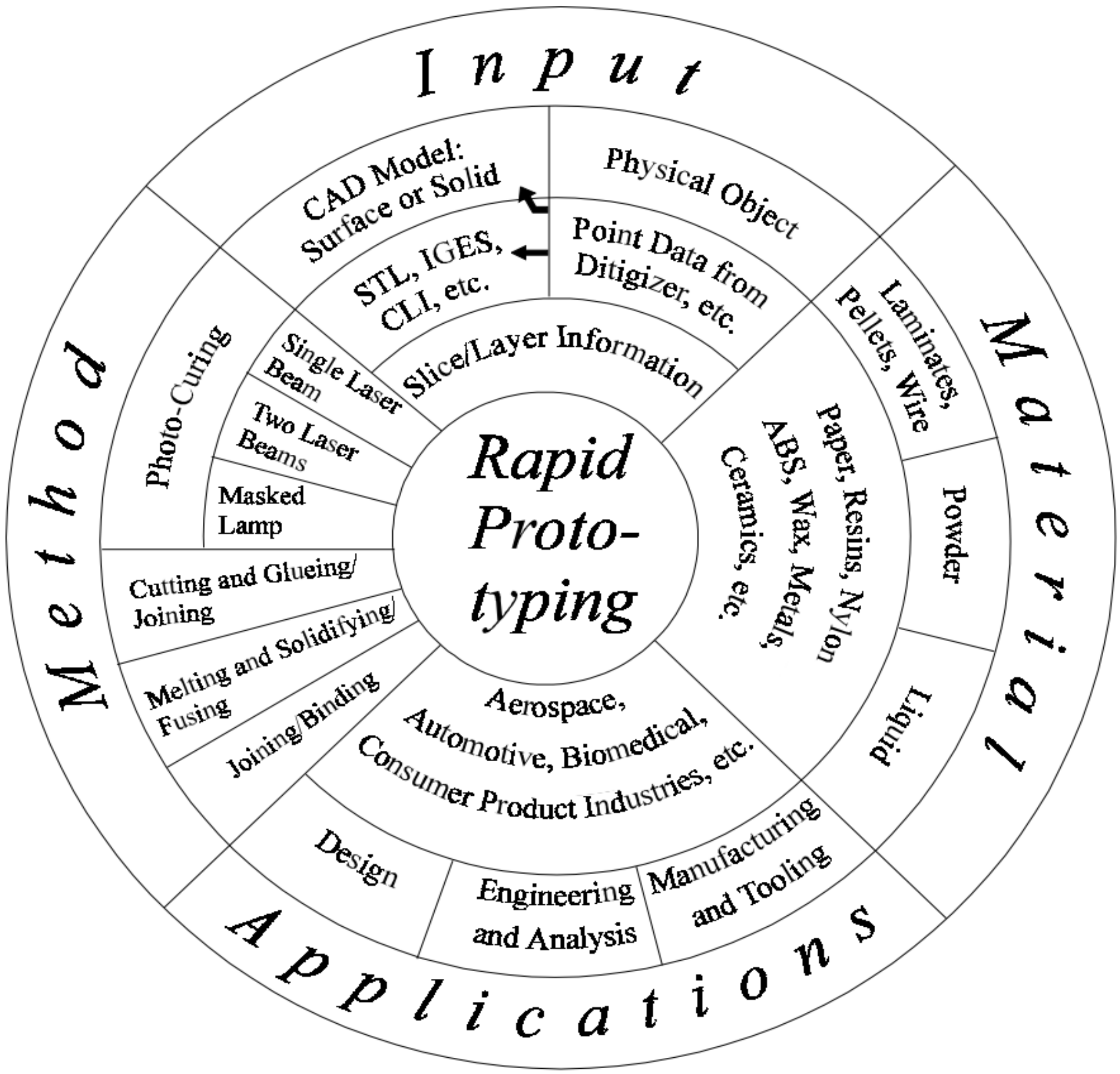
The initial state of material can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. The current range materials include paper, nylon, wax, resins, metals and ceramics.

Method

Presently there are more than 20 vendors for RP systems, the method employed by each vendor can be generally classified into the following categories: photo-curing, cutting and glueing/joining, melting and solidifying/fusing and joining/binding. Photo-curing can be further divided into categories of single laser beam, double laser beams and masked lamp.

Applications

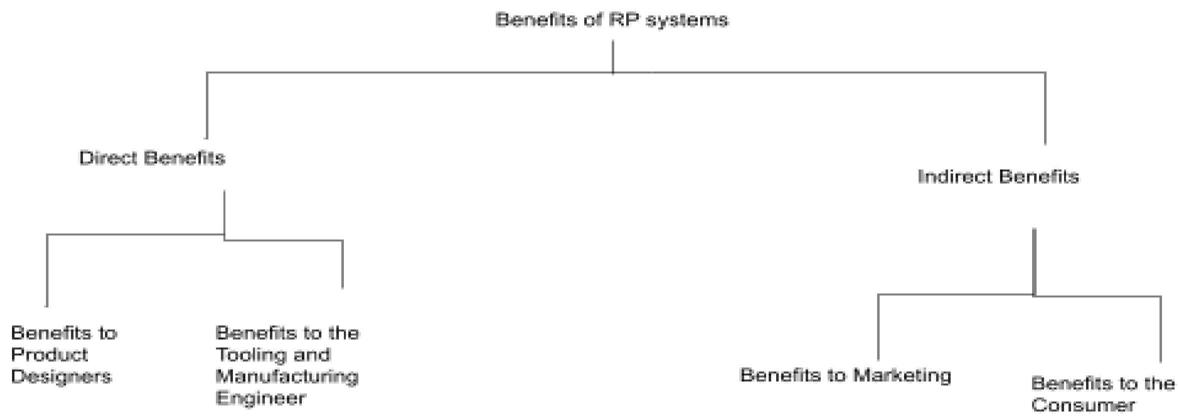
Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into
(1) Design
(2) Engineering, Analysis, and Planning and
(3) Tooling and Manufacturing.
A wide range of industries can benefit from RP and these include, but are not limited to, aerospace, automotive, biomedical, consumer, electrical and electronics products.



ADVANTAGES OF RAPID PROTOTYPING

- Today's automated, toolless, patternless RP systems can directly produce functional parts in small production quantities.
- Parts produced in this way usually have an accuracy and surface finish inferior to those made by machining.

The benefits of RP systems are can be categorized into direct and indirect benefits.



DIRECT BENEFITS

Benefits to Product Designers

- The product designers can increase part complexity with little significant effects on lead time and cost.
- They can optimize part design to meet customer requirements.
- They can reduce parts count by combining features in single-piece parts that are previously made from several manufacturing process.
- With fewer parts, time spent on tolerance analysis, selecting fasteners, detailing screw holes and assembly drawings is greatly reduced.

Benefits to the Tooling and Manufacturing Engineer

- The manufacturing engineer can minimize design, manufacturing and verification of tooling.
- He can realize profits earlier on new products, since fixed costs are lower.
- The manufacturer can reduce the labor content of manufacturing.
- Reducing material waste, waste disposal costs, material transportation costs, inventory cost for raw stock etc.

INDIRECT BENEFITS

Benefits to Marketing

- It presents new capabilities and opportunities.
- It can greatly reduce time-to-market.
- products offering the price/performance of the latest technology.

Benefits to the Consumer

- The consumer can buy products which meet more closely individual needs.

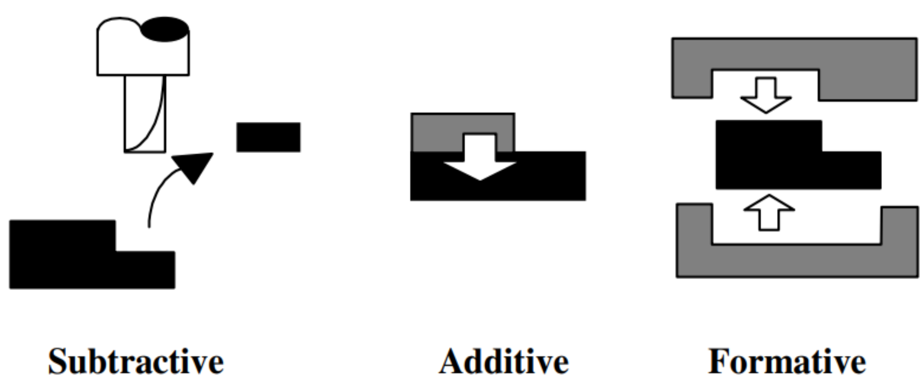
COMMONLY USED TERMS RAPID PROTOTYPING:

The following terms emphasizes on the unique characteristic of RP — layer by layer addition as opposed to traditional manufacturing methods such as machining which is material removal from a block. This group includes Layer Manufacturing, Material Deposit Manufacturing and Material Addition Manufacturing.

There is yet another group which chooses to focus on the words “solid” and “freeform” — Solid Freeform Manufacturing and Solid Freeform Fabrication. Solid is used because while the initial state may be liquid, powder, individual pellets or laminates, the end result is a solid, 3D object, while freeform stresses on the ability of RP to build complex shapes with little constraint.

FUNDAMENTAL AUTOMATED PROCESSES

There are three fundamental fabrication processes as shown in the below Figure They are Subtractive, Additive and Formative processes.



Three types of fundamental fabrication processes

In the subtractive process, one starts with a single block of solid material larger than the final size of the desired object and material is removed until the desired shape is reached.

In contrast, an additive process is the exact reverse in that the end product is much larger than the material when it started. A material is manipulated so that successive portions of it combine to form the desired object.

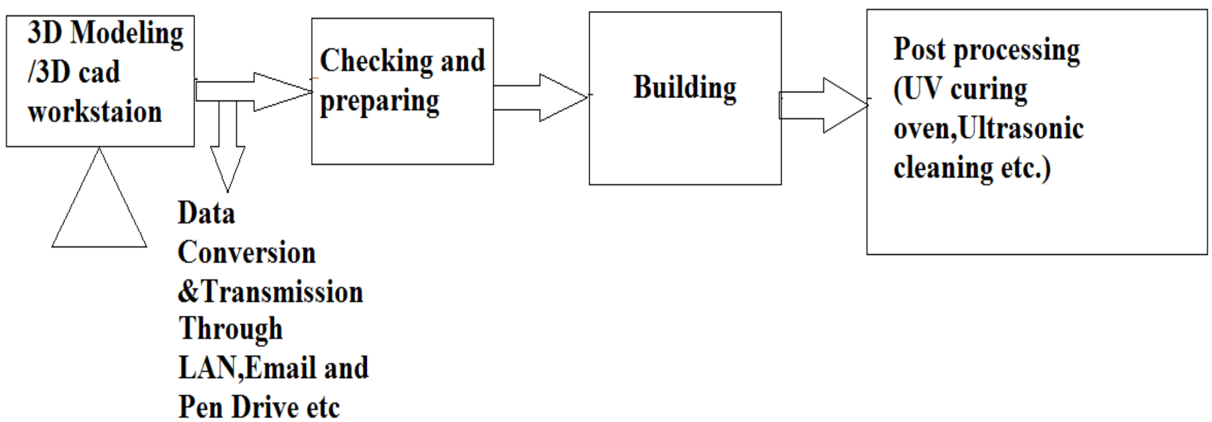
Lastly, the formative process is one where mechanical forces are applied on a material so as to form it into the desired shape.

There are many examples for each of these fundamental fabrication processes. Subtractive fabrication processes include most forms of machining processes — CNC or otherwise. These include milling, turning, drilling, planning, sawing, grinding, EDM, laser cutting, water jet cutting etc.

Most forms of rapid prototyping processes such as Stereolithography and Selective Laser Sintering fall into the additive fabrication processes category.

Examples of formative fabrication processes are: Bending, forging, electromagnetic forming and plastic injection molding.

PROCESS CHAIN OF RAPID PROTOTYPING:



3D MODELING

- Advanced 3D CAD modeling is a general prerequisite in RP processes and, usually is the most time-consuming part of the entire process chain.
- It is most important that such 3D geometric models can be shared by the entire design team for many different purposes, such as interference studies, stress analyses, FEM analysis, detail design and drafting, planning for manufacturing.

DATA CONVERSION AND TRANSMISSION

The solid or surface model to be built is next converted into a format dubbed the STL file format. This format originates from 3D Systems which pioneers the STereoLithography system.

The STL file format approximates the surfaces of the model using tiny triangles. Highly curved surfaces must employ many more triangles, which mean that STL files for curved parts can be very large.

CHECKING AND PREPARING

- first time users are frustrated at this step to discover that their STL files are faulty.
- However, more often than not, it is due to both the errors of CAD models and the non robustness of the CAD-STL interface.
- At present, the CAD model errors are corrected by human operators assisted by specialized software such as MAGICS.
- Once the STL files are verified to be error-free, the RP system's computer analyzes the STL files that define the model to be fabricated and slices the model into cross-sections.

BUILDING

- For most RP systems, this step is fully automated.
- Thus, it is usual for operators to leave the machine on to build a part overnight.
- The building process may take up to several hours to build depending on the size and number of parts required.

POST PROCESSING

- The final task in the process chain is the postprocessing task. At this stage, generally some manual operations are necessary.
- As a result, the danger of damaging a part is particularly high.
- The necessary postprocessing tasks for some major RP systems are shown in below table.

Essential postprocessing tasks for different RP processes
(✓ = is required; ✘ = not required)

Postprocessing Tasks	Rapid Prototyping Technologies			
	SLS	**SLA**	**FDM**	**LOM**
1. Cleaning	✓	✓	✘	✓
2. Postcuring	✘	✓	✘	✘
3. Finishing	✓	✓	✓	✓

SLS — Selective Laser Sintering
SLA — Stereolithography Apparatus
FDM — Fused Deposition Modeling
LOM — Layered Object Manufacturing

Cleaning:

- The cleaning task refers to the removal of excess parts which may have remained on the part.
- Parts are typically cleaned with solvent to remove unreacted photosensitive resin.
- With newer cleaning solvents, like TPM (tripropylene glycol monomethyl ether) introduced by 3D Systems, part damage due to the cleaning solvent can be reduced or even eliminated.

Postcuring:

SLA parts are built with pockets of liquid embedded within the part. Therefore, postcuring is required. All other nonliquid RP methods do not undergo this task.

Finishing:

Finishing refers to secondary processes such as sanding and painting used primarily to improve the surface finish or aesthetic appearance of the part /product.

ADVANTAGES AND DISADVANTAGES OF AM PROCESS

The advantages of AM process

1. Freedom of design and innovative
2. Support of green manufacturing
3. Bottom line improvements through factory physics
4. Get parts –fast
5. Less wastage in this process
6. Complexity is free
7. No need assembly
8. Little lead time
9. Little skill-manufacturing

DISADVANTAGES

1. Slow build rates
2. High production costs
3. Discontinuous production process
4. Poor mechanical properties
5. Considerable effort in application design and setting process parameters
6. Not suitable for mass production
7. Limited working materials

Applications of AM process

1. Industrial model fabrication
2. Making jewellery
3. Medical and dental elements
4. Making the food items

MEDICINE

So much So much more is known about the human body than in the past, but the ability to create tissue and organs has always been elusive. This ability to artificially regenerate is something which is highly prized by medical scientists, having the potential to cure or at least overcome the ravages of, disease, illness and injury

INDUSTRIAL USES

There's a vast number of industries which have made use of the technology such as aerospace, defense, industry and automotive, and each of these has found certain key elements particularly beneficial. Tooling is used in all of these industries and has a broad number of applications, and this is one area which can be significantly improved with the use of additive manufacturing.

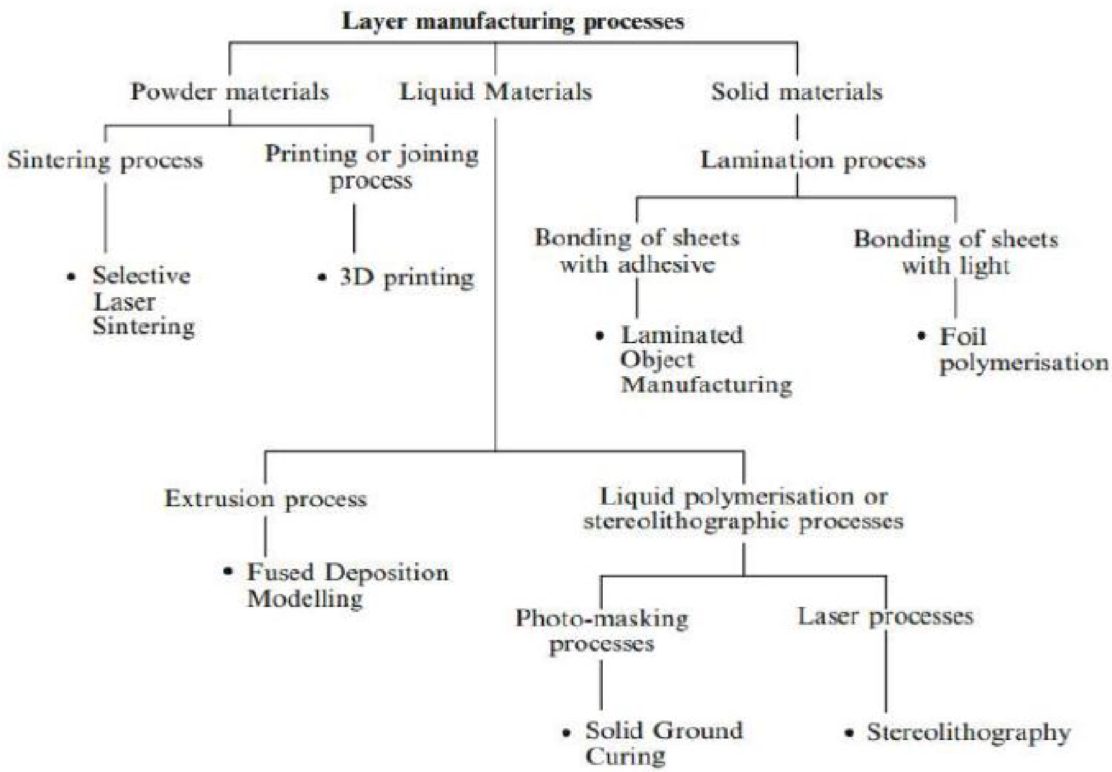
Difference between Additive Manufacturing and Subtractive Manufacturing processes

Additive Manufacturing	Subtractive Manufacturing
Involves adding layers of material to create an object	Removes material from an object
Processes include 3D printing, direct digital manufacturing, rapid prototyping or additive and layered fabrication	The process is either by: manual removal, traditional machining or CNC machining
Uses computers and specialist 3D printing equipment to create products or prototypes	Uses computers and robotics to assist standard machining processes, e.g., turning, drilling or milling
The layering often leaves a slightly 'stepped' or rough surface which needs to be finished post-printing by sanding or blowing	A variety of surface finishes can be machined, including smooth, stepped, mottled, etc.
Intricate and hollow objects can easily be built up in layers	Milling undercuts and intricate shapes can be difficult
Best suited for smaller items or parts, especially in plastic	Best suited for manufacturing voluminous items and parts, especially in metal
Depending on the size of the object, 3D printing can be a slow process	Relatively fast process
Software is available to directly link the design to a 3D printer, so a machine operator isn't necessary	A CNC machinist is required to operate the mill or machine and oversee the production. However, new automated software means that programming machine-executable code is no longer needed
Overall, 3D printing is a fairly cheap process	Generally, more expensive than additive manufacturing

List various types of Additive Manufacturing Processes?

The Better way is to classify Additive Manufacturing systems broadly by the initial form of its material, all AM Systems can be easily categorised into:

Liquid Based, Solid Based and Powder Based



Liquid based: Stereolithography Apparatus(SLA), PolyJet 3D printing, Multijet Printing(MJP), Solid Object Ultravoilet-Laser Printer(SOUP), Rapid Freeze Prototyping.
Solid based: Fused deposition modeling (FDM), Selective Deposition Lamination (SDL), Laminated Object Manufacturing (LOM), Ultrasonic Consolidation.
Powder based: Selective Laser Sintering(SLS), ColorJet Printing(CJP), Laser Engineered Net Shaping (LENS), Electron Beam Melting(EBM) etc.

List the different types of Liquid based RP systems?

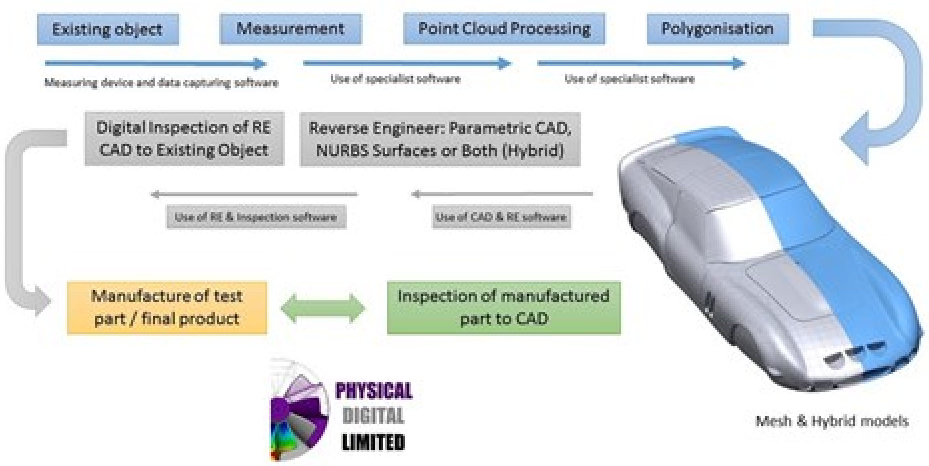
Most liquid-based rapid prototyping systems build parts in a vat of photo-curable liquid resin, an organic resin that cures or solidifies under the effect of exposure to laser radiation, usually in the UV range.The laser cures the resin near the surface, forming a hardened layer. When a layer of the part is formed, it is lowered by an elevation control system to allow the next layer of resin to be similarly formed over it. This continues until the entire part is completed.

1. Stereolithography Apparatus (SLA)
2. Solid Ground Curing (SGC)
3. Solid Creation System (SCS)
4. Solidform System.

Mention the role of reverse engineering in additive manufacturing process?

In Mechanical Engineering, the term Reverse Engineering (often abbreviated to RE) is used to summarise the process of reconstructing an already existing object. In Reverse Engineering, the design engineer starts with the final product and works through the design process in the opposite direction to arrive at the product design specification.

The usual starting point of the process of Reverse Engineering is by gaining dimensional information of the model, whether it is a mechanical component, a consumer product or an ancient artefact. This is done with the use of a 3D scanner, such as Physical Digital's highly accurate, GOM ATOS systems.



Why is Reverse Engineering used?

Reverse Engineering enables the duplication of an existing part by capturing the component's physical dimensions, features, and material properties. There are a wide range of reasons for reverse engineering an object, including:

Legacy Components – For many components that were designed and manufactured years ago, there are no existing 2D drawings or 3D CAD data from which to reproduce the object. Here, Reverse Engineering is a vital means to gain the information to recreate the product.

Original Equipment Manufacturer (OEM) issues – If the OEM is no longer trading or has lost design measurements then Reverse Engineering will supply the vital product information for manufacturing.

Design Development, Part Testing & Analysis – Through Reverse Engineering, a 3D product can be quickly captured in digital form and remodelled or analysed in order to achieve improved design iterations.

Competitor Analysis – Any organisation can analyse competitor products through Reverse Engineering.

Modern manufacturing methods such as Additive Manufacturing rely on Reverse Engineering.