RAPID PROTOTYPING

Introduction:

'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.'

Today, prototypes are often created with additive layer manufacturing technology, also known as 3-D printing.

'**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. Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology.'

History of RP system:

Manual prototyping by a skilled craftsman has been an age old practice for many centuries. Second phase of prototyping started around mid-1970s, when a soft prototype modeled by 3D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties. Third and the latest trend of prototyping, i.e., Rapid Prototyping (RP) by layer-by-layer material deposition, started during early 1980s with the enormous growth in Computer Aided Design and Manufacturing (CAD/CAM) technologies when almost unambiguous solid models with knitted information of edges and surfaces could define a product and also manufacture it by CNC machining. The historical development of RP and related technologies is presented below:

Year of inception Technology

1770 Mechanization

1946 First computer

1952 First Numerical Control (NC) machine tool

1960 First commercial laser

1961 First commercial Robot

1963 First interactive graphics system (early version of ComputerAided Design)

1988 First commercial Rapid Prototyping system

Brief history of RP Technology

1986: First Patent on Stereo lithography By Charles Hull, Founder of STRATASYS.

1989: Patent on Selective Laser Sintering By Carl Deckard

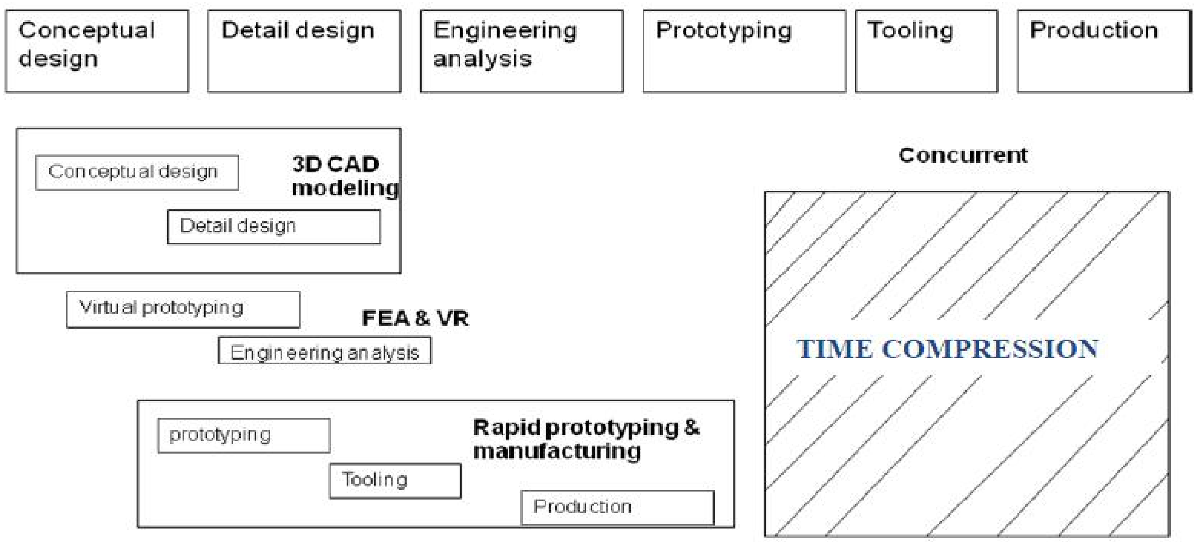
1992: Fused Deposition Modelling Patent Acquired By STRATYSYS.

2004: Dr Boyers Introduced Open Source REPRAP

2008: Direct Digital Manufacturing and 3D Printing

Need for compression in Product development:

Any new product development has to go through various design and testing phases so that it can become 100% successful in market and remain competitive and sustainable. This is time consuming and hence need is felt in time compression in product development, which is very well done by using Rapid prototyping techniques. The Time Compression in Product is well shown below:



In time compression in Product development Conceptual Design, Detail design, Engineering Analysis Tooling, Production stages has been modified with use of Rapid Prototyping and Direct Digital Manufacturing Techniques thus substantially compressing the product development time, and thus making companies product quality and competitive in today's ever changing business environment.

Growth of RP Industry:

-The RP industry has enjoyed tremendous growth since the first system was introduced in 1988. The rate of growth has also been significant.

-Right up to 1999, the industry was enjoying two-digit growth rate annually.

-In 2001, the RP industry continued to expand, though not at the same rate anywhere near as before. More systems were installed, more materials for these systems used and more applications for the technology were uncovered.

- The rate of growth has tapered off significantly since 2000. The events and economic conditions of 2001 did not help to improve the situation.

-Then in 2003, the RP industry took a turn and revenues returned to levels of the past.

-The growth of RP industry once again leaped upwards in 2004. There has been no sign of slowing down in the RP industry growth since then.

-Observation made on four leading RP companies in 2006 revealed an approximate of 15% sale increases compared to 2005. 3D systems still remains as the leading company in the RP industry with revenue of $135 million in 2006.

-With the introduction of the only high definition colour 3D printer in the market, Z corporation enjoyed 50% revenue growth. EOS GmbH(Germany), the leading company for sintering systems, reported an approximately $68 million in revenue during the fiscal year ending September 2006.

Classification of RP system:

The professional literature in RP contains different ways of classifying RP processes. However, one representation based on German standard of production processes classifies RP processes according to state of aggregation of their original material and is given in figure:

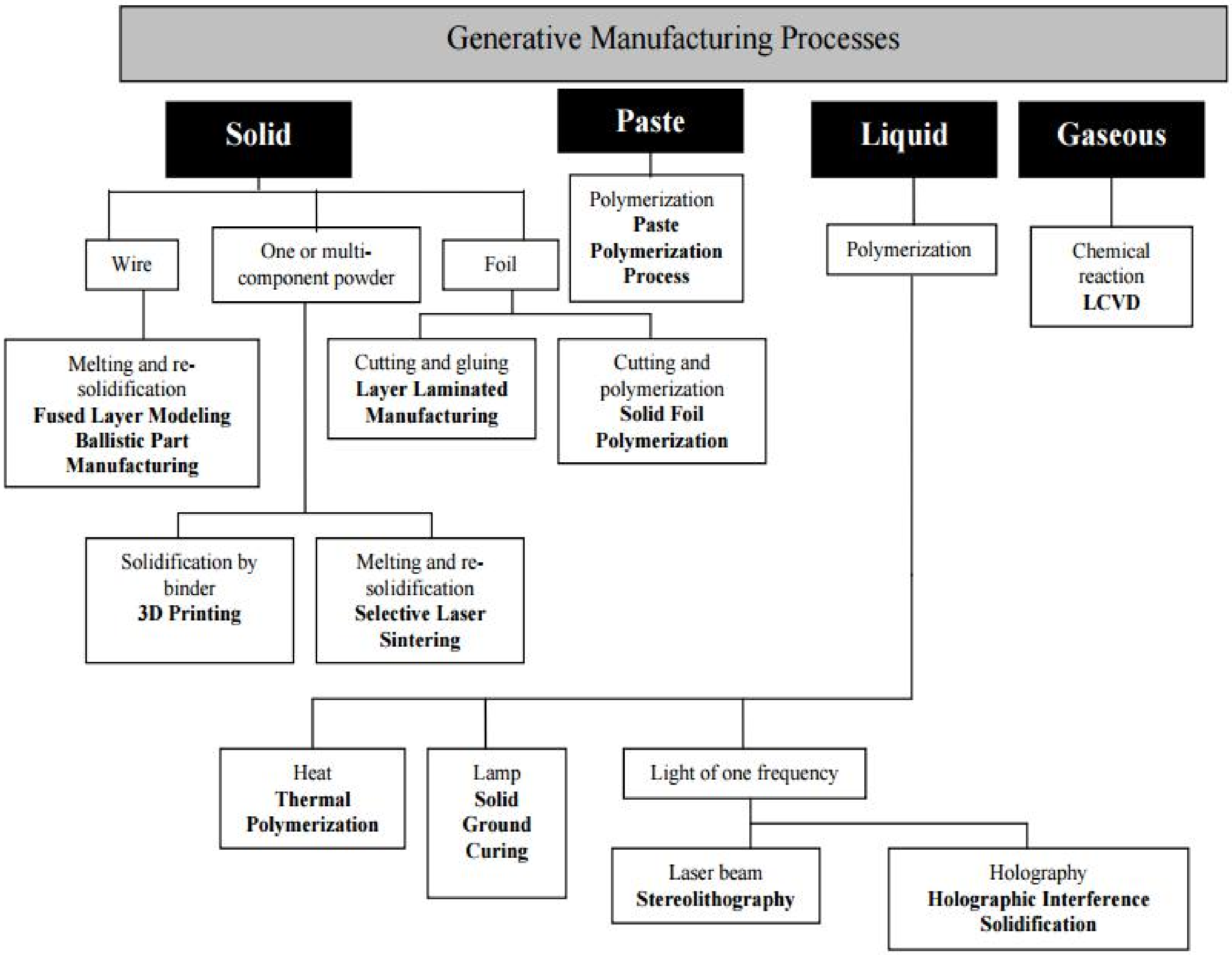


Fig:Classification of RP processes (after Gebhardt, 2003)

Stereolithography Process

A Basic Stereo lithography System is Composed of

1. Solid State Laser Device

2. A Scanner System

3. An Elevator Platform

4. A Liquid Resin VAT.

5. Computer Hardware and Software

Principle:

The SLA process is based fundamentally on the following principles [3]:

(1) Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photopolymerization process) which scans across the surface of the resin.

(2) The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

In this process photosensitive liquid resin which forms a solid polymer when exposed to ultraviolet light is used as a fundamental concept. Due to the absorption and scattering of beam, the reaction only takes place near the surface and voxels of solid polymeric resin are formed. A SL machine consists of a build platform (substrate), which is mounted in a vat of resin and a UV Helium-Cadmium or Argon ion laser. The laser scans the first layer and platform is then lowered equal to one slice thickness and left for short time (dip-delay) so that liquid polymer settles to a flat and even surface and inhibit bubble formation. The new slice is then scanned. In new SL systems, a blade spreads resin on the part as the blade traverses the vat. This ensures smoother surface and reduced recoating time. It also reduces trapped volumes which are sometimes formed due to excessive polymerization at the ends of the slices and

an island of liquid resin having thickness more than slice thickness is formed. Once the complete part is deposited, it is removed from the vat and then excess resin is drained. It may take long time due to high viscosity of liquid resin. The green part is then post-cured in an UV oven after removing support structures.

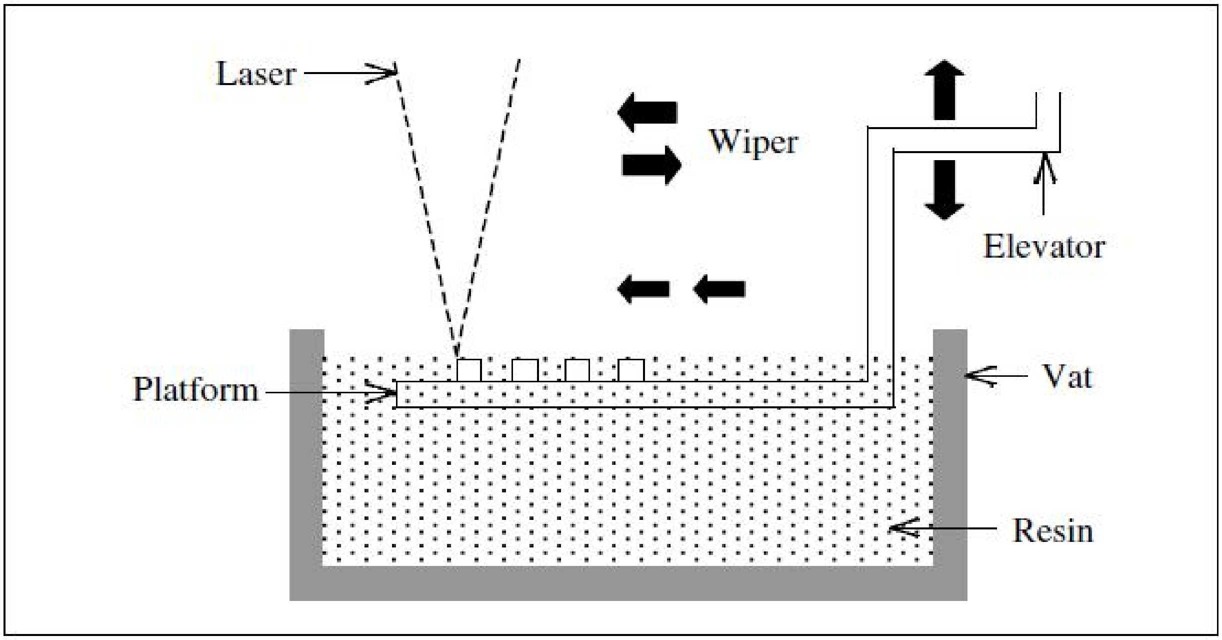


Figure : Schematic of SLA process

Commonly made Components are Prototypes for concept models , Form-fit for assembly tests and process planning , Models for investment casting, replacement of the wax pattern Patterns for metal spraying, epoxy molding and other soft tooling , and Micro parts. Schematic diagram of a typical Stereolithography apparatus is shown in figure.

Process Parameter

Various Process parameters for a SLA Process are

1. Laser type, wavelength

2. Power

3. Layer thickness

4. Drawing speed

5. Max part weight

6. Elevator resolution

7. Repeatability

8. Vat capacity

9. Max build envelop

10. Operating system

Advantages and Disadvantages

The main advantages of using SLA are:

(1) *Round the clock operation.* The SLA can be used continuously and unattended round the clock.

(2) *Good user support.* The computerized process serves as a good user support.

(3) *Build volumes.* The different SLA machines have build volumes ranging from small to large to suit the needs of different users.

(4) *Good accuracy.* The SLA has good accuracy and can thus be used for many application areas.

(5) *Surface finish.* The SLA can obtain one of the best surface finishes amongst RP technologies.

(6) *Wide range of materials.* There is a wide range of materials, from general-purpose materials to specialty materials for specific applications.

The main disadvantages of using SLA are:

(1) *Requires support structures.* Structures that have overhangs and undercuts must have supports that are designed and fabricated together with the main structure.

(2) *Requires post-processing.* Post-processing includes removal of supports and other unwanted materials, which is tedious, time consuming and can damage the model.

(3) *Requires post-curing.* Post-curing may be needed to cure the object completely and ensure the integrity of the structure

Note:

Stair Stepping Effect

RP process belong to the generative (or additive) production processes unlike subtractive or forming processes such as lathing, milling, grinding or coining etc. in which form is shaped by material removal or plastic deformation. In all commercial RP processes, the part is fabricated by deposition of layers contoured in a (x-y) plane two dimensionally. The third dimension (z) results from single layers being stacked up on top of each other, but not as a continuous z-coordinate. Therefore, the prototypes are very exact on the x-y plane but have stair-stepping effect in z-direction. If model is deposited with very fine layers, i.e., smaller z-stepping, model looks like original. RP can be classified into two fundamental process steps namely generation of mathematical layer information and generation of physical layer model.

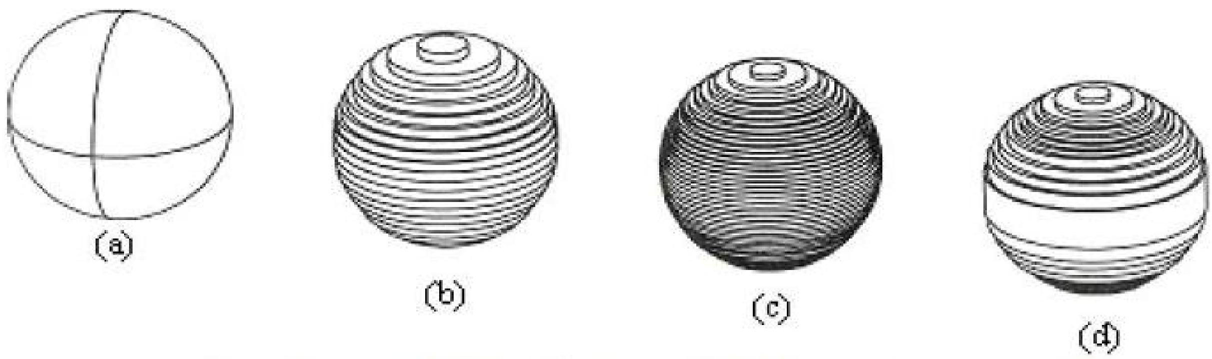


Figure : Slicing of a ball, (a) No slicing (b) Thick slicing (c) Thin slicing

Real error on slice plane is much more than that is felt, as shown in figure (a). For a spherical model Pham and Demov (2001) proposed that error due to the replacement of a circular arc with stair-steps can be defined as radius of the arc minus length up to the corresponding corner of the staircase, i.e., cusp height (figure (b)). Thus maximum error (cusp height) results along z direction and is equal to slice thickness. Therefore, cusp height approaches to maximum for surfaces, which are almost parallel with the x-y plane. Maximum value of cusp height is equal to slice thickness and can be reduced by reducing it; however this results in drastic improvement in part building time. Therefore, by using slices of variable thicknesses (popularly known as adaptive slicing, as shown in figure), cusp height can be controlled below a certain value.

Data preparation& Data flow

• A CAD model is constructed, and then it is converted to STL format. The resolution of the process should be set to minimize stair stepping.

• The RP machines then processes the .STL file by taking it as input and create sliced layers of the model as output.

• The first layer of the physical model is created and then the model is lowered by the thickness of the next layer, and the process is repeated until completion of the model.

• Finally the model and any other supports are removed and the surface of the model is then finished and cleaned.

Generally the data flow and process of RP can be understood by the process flow chart given by Gebhardt

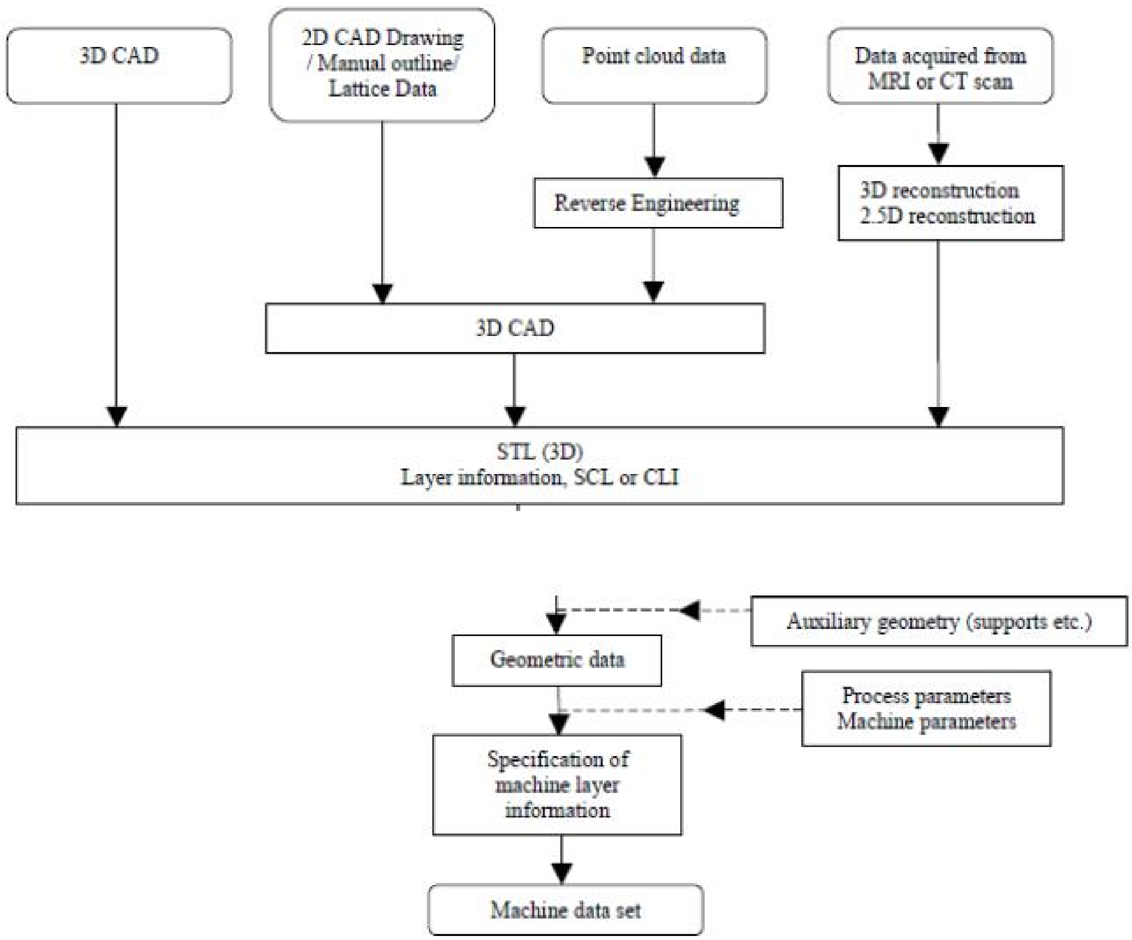


Fig: Flow chart CAD data flow in a RP System

<u>Data files</u>

STL FORMAT

Representation methods used to describe CAD geometry vary from one system to another. A standard interface is needed to convey geometric descriptions from various CAD packages to rapid prototyping systems.The

STL (**ST**ereo**L**ithography) file, as the *de facto* standard, has been used in many, if not all, rapid prototyping systems.

The STL file , conceived by the 3D Systems, USA, is created from the CAD database via an interface on the CAD system. This file consists of an unordered list of triangular facets representing the outside skin of an object. There are two formats to the STL file. One is the ASCII format and the other is the binary format. The size of the ASCII STL file is larger than that of the binary format but is human readable.

In a STL file, triangular facets are described by a set of *X*, *Y* and *Z* coordinates for each of the three vertices and a unit normal vector with *X*, *Y* and *Z* to indicate which side of facet is an object.

Nevertheless, there are several advantages of the STL file. First, it provides a simple method of representing 3D CAD data. Second, it is already a *de facto* standard and has been used by most CAD systems and rapid prototyping systems. Finally, it can provide small and accurate files for data transfer for certain shapes.

On the other hand, several disadvantages of the STL file exist. First, the STL file is many times larger than the original CAD data file for a given accuracy parameter. The STL file carries much redundancy information such as duplicate vertices and edges.

Machine Details

The machine has four important parts:

- A tank filled with several gallons of liquid photopolymer. The photopolymer is a clear, liquid plastic.
- A perforated platform immersed in the tank. The platform can move up and down in the tank as the printing process proceeds.
- An ultraviolet laser
- A computer that drives the laser and the platform

Applications for Stereolithography

- Visual prototypes for photo shoots and market testing.
- "Show and tell" parts with smooth surfaces and fine details.
- Prototypes for limited functional testing.
- Masters for copying techniques such as Vacuum Casting.
- Alternatives for sheet metal prototypes when coated with a metal plating process.
- Patterns for investment casting.
- Low-volume production of complex geometries.

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