Rapid prototyping is the automatic construction of physical objects using additive manufacturing technology. The first techniques for rapid prototyping became available in the late 1980s and were used to produce models and prototype parts. Today, they are used for a much wider range of applications and are even used to manufacture production-quality parts in relatively small numbers. Some sculptors use the technology to produce complex shapes for fine arts exhibitions.

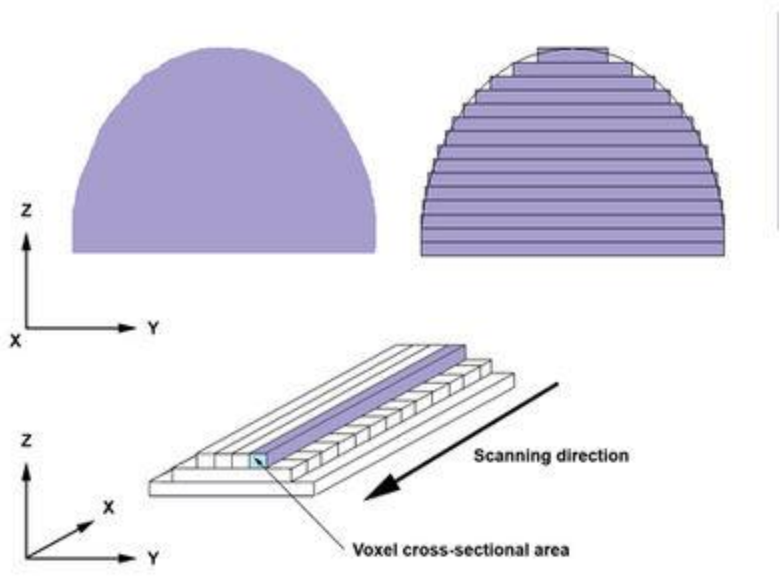
Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereolithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available.

Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, **RP models can be used for testing**, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber molds and investment casts. *In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough.* When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced.

Introduction

The use of additive manufacturing for rapid prototyping **takes virtual designs** from computer aided design (CAD) or animation modeling software, **transforms them** into thin, virtual, horizontal cross-sections and then **creates successive layers** until the model is complete.

With additive manufacturing, the machine reads in data from a CAD drawing and lays down successive layers of liquid, powder, or sheet material, and in this way **builds up the model from a series of cross sections.** These layers, which correspond to the virtual cross section from the CAD model, are joined together or fused automatically to create the final shape. **The primary advantage to additive fabrication is its ability to create almost any shape or geometric feature.**



The standard data interface between CAD software and the machines is the STL file format. An STL file approximates the shape of a part or assembly using triangular facets. Smaller facets produce a higher quality surface.

The word "rapid" is relative: construction of a model with contemporary methods can take from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems for rapid prototyping can typically produce models in a few hours, although it can vary widely depending on the type of machine being used and the size and number of models being produced simultaneously.

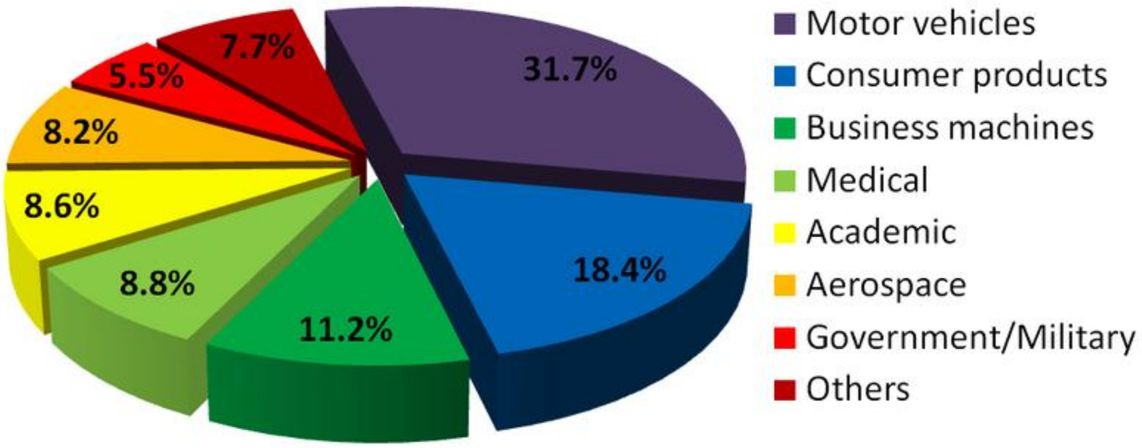
Some solid freeform fabrication techniques use two materials in the course of constructing parts. The first material is the part material and the second is the support material (to support overhanging features during construction). The support material is later removed by heat or dissolved away with a solvent or water.

Traditional injection molding can be less expensive for manufacturing polymer products in high quantities, but additive fabrication can be faster and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams the ability to produce parts and concept models using a desktop size printer.

Rapid prototyping is now entering the field of rapid manufacturing and it is believed by many experts that this is a "next level" technology

Technologies

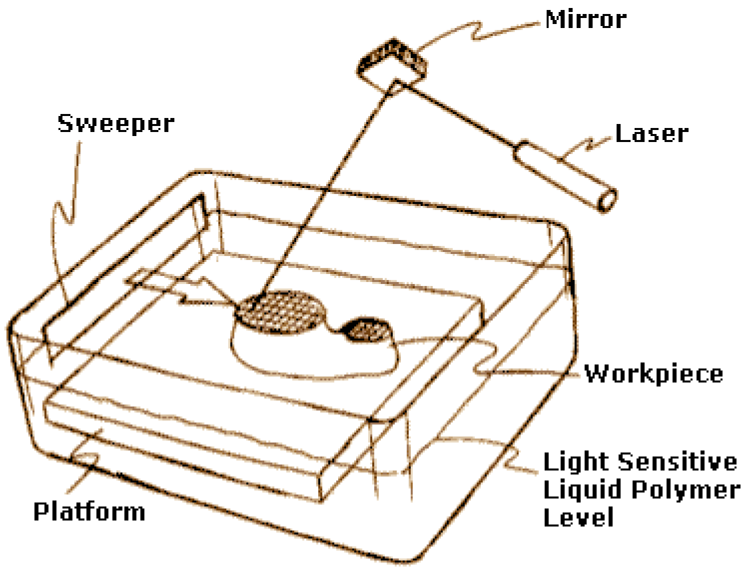
A large number of competing technologies are available in the marketplace. As all are additive technologies, their main differences are found in the way layers are built to create parts. Some are melting or softening material to produce the layers (SLS, FDM) where others are laying liquid materials thermosets that are cured with different technologies. In the case of lamination systems, thin layers are cut to shape and joined together.



Stereolithography

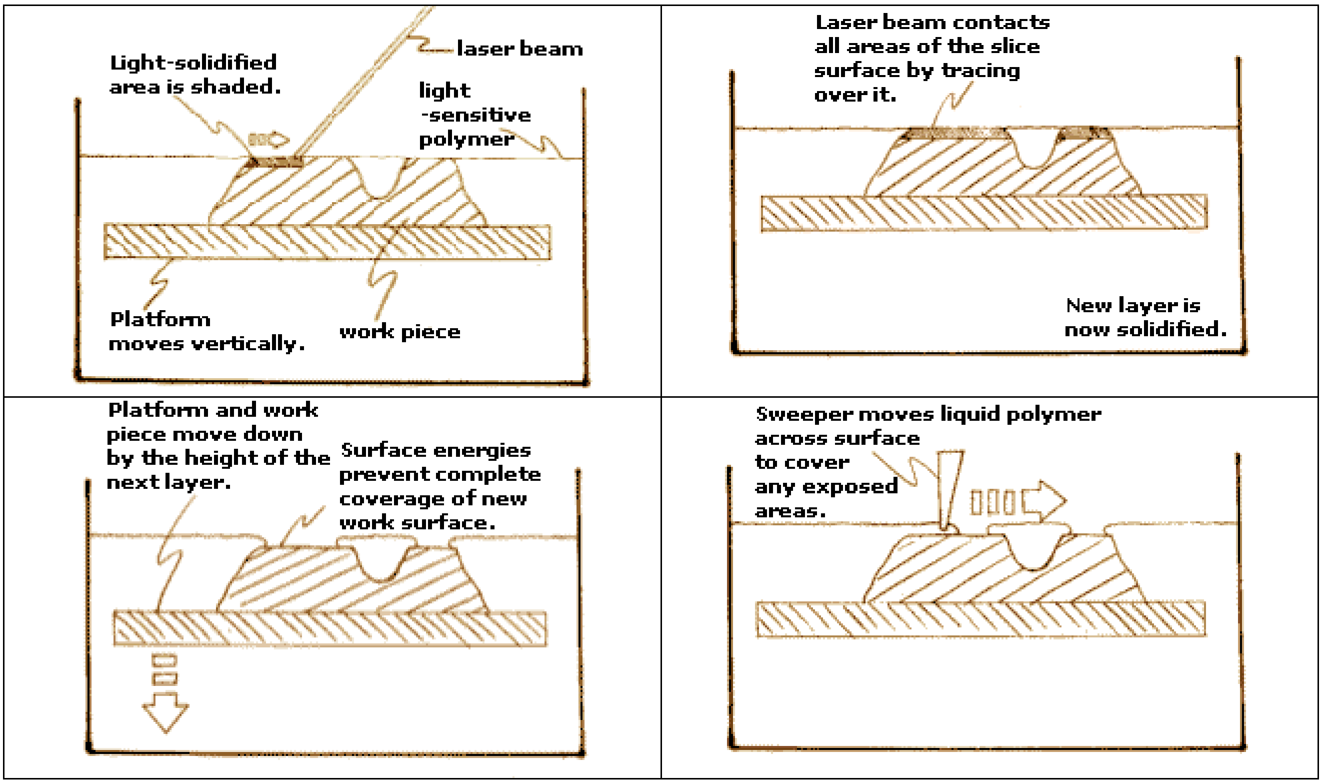
Stereolithography (SLA), the first Rapid Prototyping process, was developed by 3D Systems of Valencia, California, USA, founded in 1986. A photosensitive resin contains a vertically-moving platform. The part under construction is supported by the platform that moves downward by a layer thickness (typically about 0.1 mm) for each layer. A laser beam traces out the shape of each layer and hardens the *photosensitive resin*.

The Stereolithography (SLA) System overall arrangement:



Stereolithography Process

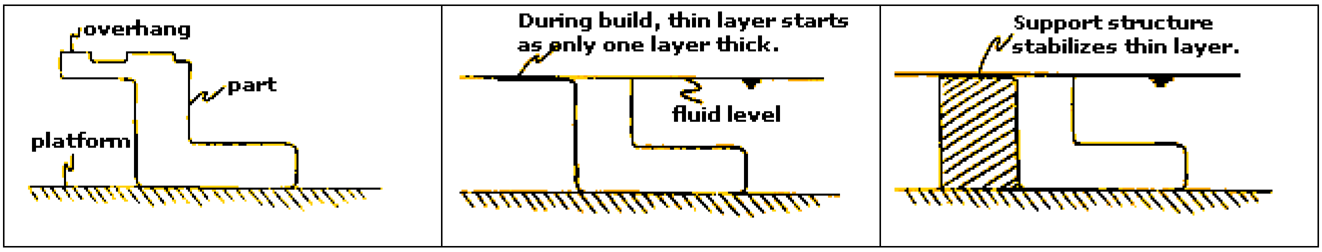
The sequence of steps for producing a Stereolithography (SLA) layer is shown in the following figures:



COMPLETED PART

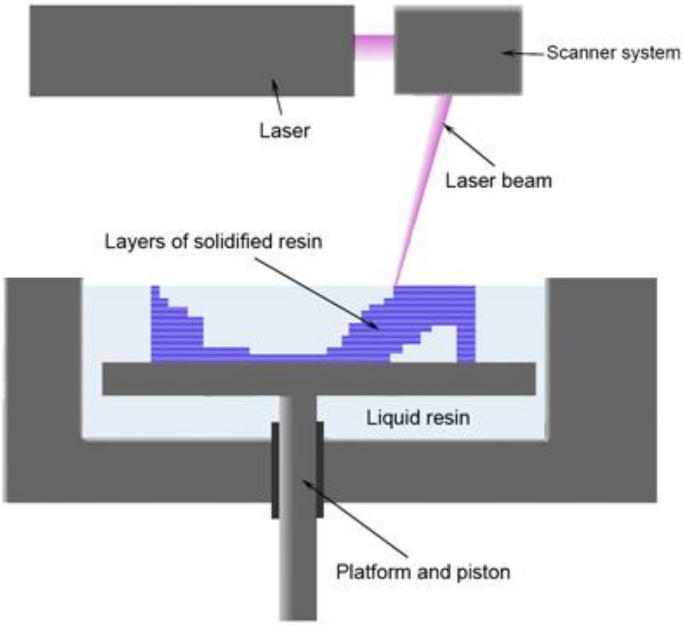
Uncured resin is removed and the model is post-cured to fully cure the resin. Because of the layered process, the model has a surface composed of stair steps. Sanding can remove the stair steps for a cosmetic finish. Model build orientation is important for stair stepping and build time.

During fabrication, if extremities of the part become too weak, it may be necessary to use supports to prop up the model. The supports can be generated by the program that creates the slices, and the supports are only used for fabrication. The following three figures show why supports are necessary:



Stereolithography is an additive manufacturing process using liquid UV-curable photopolymer "resin" and a UV laser to build parts a layer at a time. On each layer, the laser beam traces a part cross-section pattern on the surface of the liquid resin. Exposure to the UV laser light cures, solidifies the pattern traced on the resin and adheres it to the layer below.

After a pattern has been traced, the SLA's elevator platform descends by a single layer thickness, typically 0.05 mm to 0.15 mm. Then, a resin-filled blade sweeps across the part cross section, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, adhering to the previous layer. A complete 3-D part is formed by this process. After building, parts are cleaned of excess resin by immersion in a chemical bath and then cured in a UV oven.

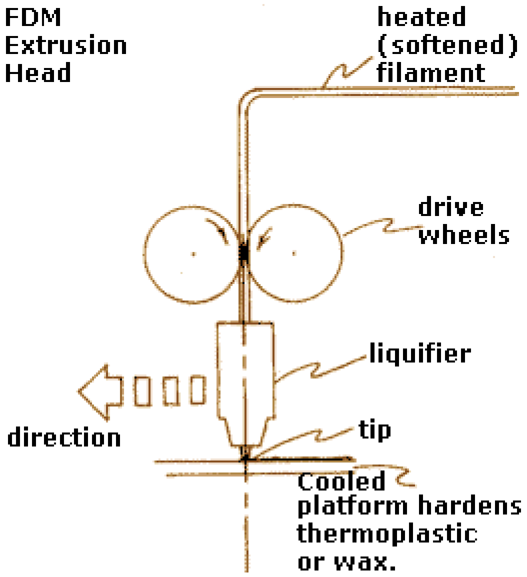


Stereolithography requires the use of support structures to attach the part to the elevator platform and to prevent certain geometry from not only deflecting due to gravity, but to also accurately hold the 2-D cross sections in place such that they resist lateral pressure from the re-coater blade. Supports are generated automatically during the preparation of 3-D CAD models for use on the Stereolithography machine, although they may be manipulated manually. Supports must be removed from the finished product manually; this is not true for all rapid prototyping technologies.

A stereolithography machine

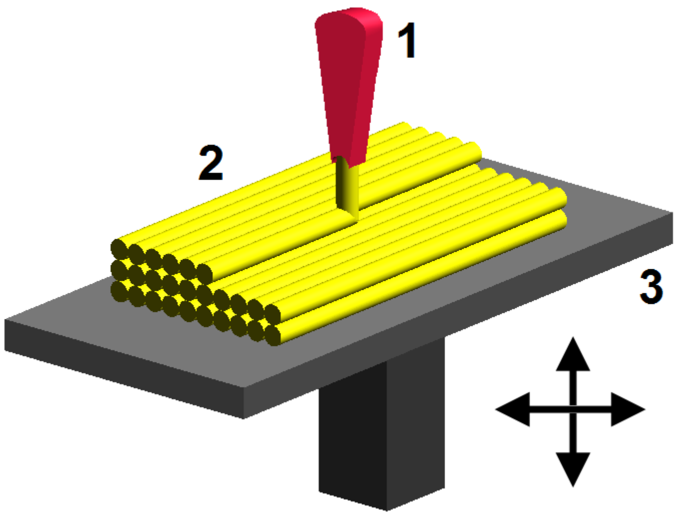
Fused Deposition Modeling [FDM]

Stratasys of Eden Prairie makes Fused Deposition Modeling (FDM) machines. The fundamental process **involves heating a filament of thermoplastic polymer and squeezing it out like toothpaste from a tube to form the RP layers.** The machines range from fast concept modelers to slower, high-precision machines. The materials include polyester, ABS, elastomers, and investment casting wax. The overall arrangement is illustrated below:



Fused deposition modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990.

FDM works on an "additive" principle by laying down material in layers. <u>A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package.</u> The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle.



Fused deposition modeling: 1 - nozzle ejecting molten plastic, 2 - deposited material (modeled part), 3 – controlled moving table.

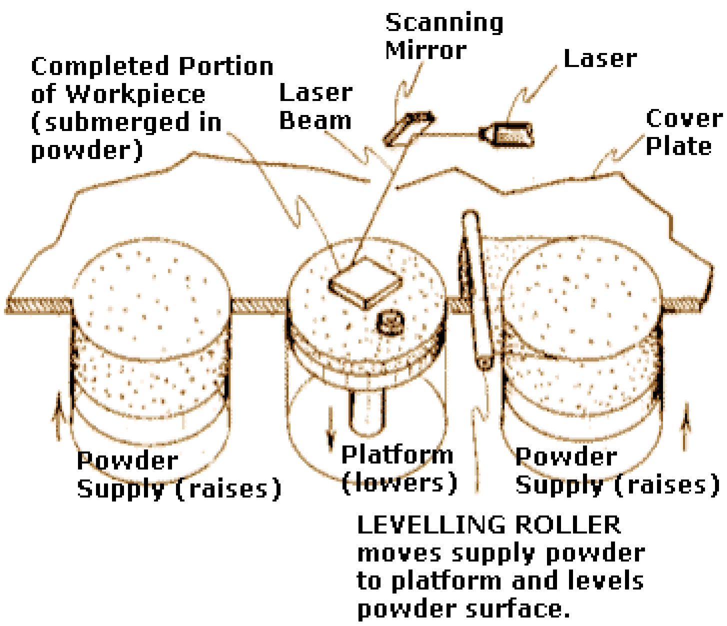
Several materials are available with different trade-offs between strength and temperature properties. As well as acrylonitrile butadiene styrene (ABS) polymer, polycarbonates, polycaprolactone, polyphenylsulfones and waxes. A "water-soluble" material can be used for making temporary supports while manufacturing is in progress, this soluble support material is quickly dissolved with specialized mechanical agitation equipment utilizing a precisely heated sodium hydroxide solution.

The term **Fused deposition modeling** and its abbreviation to **FDM** are trademarked by Stratasys Inc. The exactly equivalent term is called **Fused Filament Fabrication** or **FFF**.

Selective Laser Sintering

Selective Laser Sintering is a process that was patented in 1989 by Carl Deckard, a University of Texas graduate student. Its chief advantages over Stereolithography (SLA) revolve **around material properties. Many varying materials are possible and these materials can approximate the properties of thermoplastics such as polycarbonate, nylon, or glass-filled nylon.**

As the figure below shows, a SLS machine consists of two powder magazines on either side of the work area. The leveling roller moves powder over from one magazine, crossing over the work area to the other magazine. The laser then traces out the layer. The work platform moves down by the thickness of one layer and the roller then moves in the opposite direction. The process repeats until the part is complete.



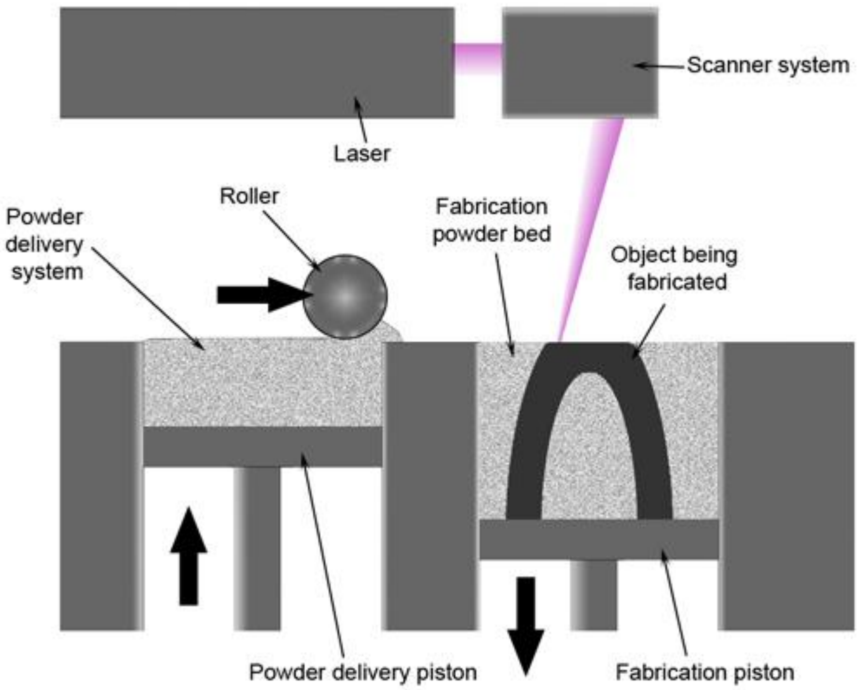
Selective laser sintering (**SLS**) is an additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (Direct Metal Laser Sintering), ceramic, or glass powders into a mass that has a desired 3-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

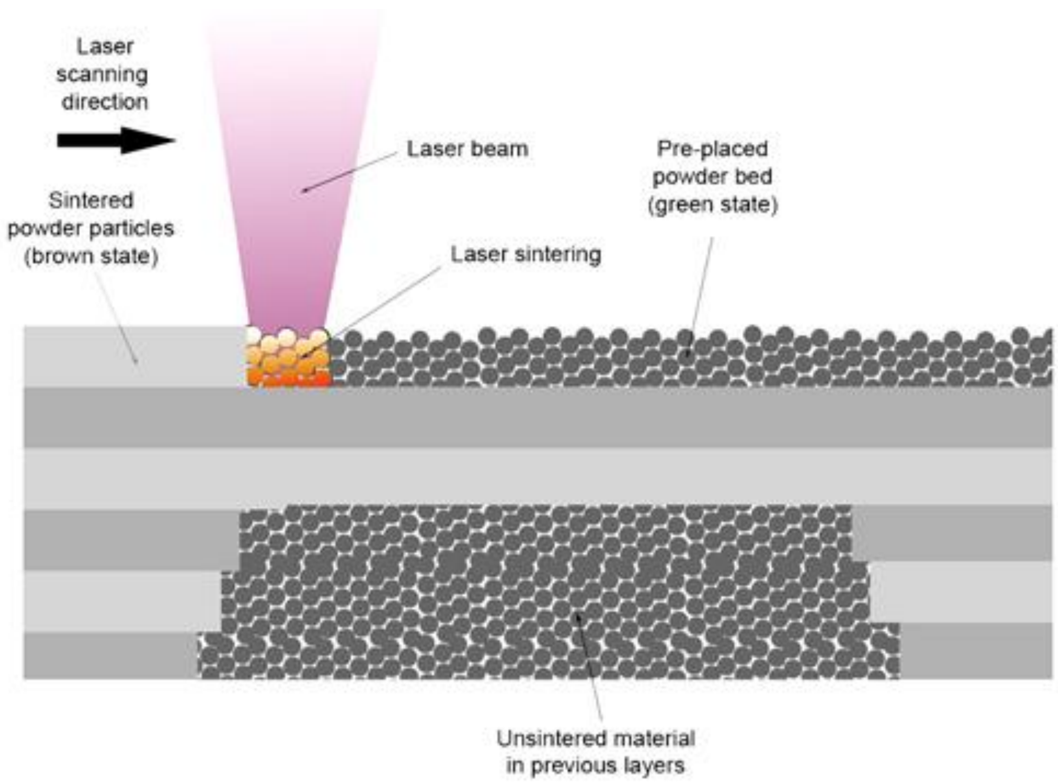
Because finished part density depends on peak laser power, rather than laser duration, a SLS machine typically uses a pulsed laser. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point.

Some SLS machines use single-component powder, such as direct metal laser sintering. However, most SLS machines use two-component powders, typically either **coated powder** or a **powder mixture**. In single-component powders, the laser melts only the outer surface of the particles (surface melting), fusing the solid non-melted cores to each other and to the previous layer.

Compared to other methods of additive manufacturing, SLS can produce parts from a relatively wide range of commercially available powder materials. These include polymers such as nylon, (neat, glass-filled or with other fillers) or polystyrene, metals including steel, titanium, alloy mixtures, and composites and green sand. The physical process can be full melting, partial melting, or liquid-phase sintering. And, depending on the material, up to 100% density can be achieved with

material properties comparable to those from conventional manufacturing methods. In many cases large numbers of parts can be packed within the powder bed, allowing very high productivity.





SLS is performed by machines called SLS systems. SLS technology is in wide use around the world due to its ability to easily make very complex geometries directly from digital CAD data. While it

began as a way to build prototype parts early in the design cycle, it is increasingly being used in limited-run manufacturing to produce end-use parts. One less expected and rapidly growing application of SLS is its use in art.

SLS was developed and patented by Dr. Carl Deckard at the University of Texas at Austin in the mid-1980s, under sponsorship of DARPA. A similar process was patented without being commercialized by R.F. Housholder in 1979.