

2. Rapid Prototyping Technology Overview

Rapid prototyping is still the most common name given to numerous related additive fabrication technologies that are used to make physical objects directly from CAD data sources. These methods are generally similar to each other in that they add and bond materials in layerwise-fashion to form objects. This is directly the opposite of what classical methods such as milling or turning do. Objects are formed in those processes by mechanically removing material. Rapid prototyping is also known by the names of three dimensional printing, 3D printing, freeform fabrication (FFF), layered manufacturing, automated fabrication and other variants. Sometimes the names of the specific processes themselves are also used synonymously to denote the field as a whole. (See the Appendix article “What’s all this name stuff anyway?” for a thorough discussion of terminology.)

While additive fabrication seems like a new idea, it isn’t. The underpinnings of the technology date back to at least the eighteenth century. Dr. Joseph Beaman has written a fascinating account of RP’s early history [1]. His paper includes information about early patents which should be of continuing interest to system developers today. The thrust for much of this seminal work was to develop an automated form of representational sculpture, a subject still much under discussion, but as yet economically unfulfilled.

Rapid prototyping isn’t necessarily very rapid and doesn’t necessarily have to do with prototypes, either. Speed is relative: The processes can shave weeks to months off a design cycle, but still may require many hours to fabricate a single object. Prototypes for design evaluation are often made using these processes, but the technology also is beginning to address the direct production of final useful parts and assemblies, and injection molding and other types of tools.

Rapid prototyping isn’t a solution to every part fabrication problem. After all, CNC technology is economical, widely understood and available, offers wide material selection and excellent accuracy. However, if the requirement involves producing a part or object of even moderately complex geometry, and doing so quickly - RP has the advantage. It’s very easy to look at extreme cases and make a determination of which technology route to pursue, CNC or RP. For many other less extreme cases the selection crossover line is hazy, moves all the time, and depends on a number of variably-weighted, case-dependent factors. While the accuracy of rapid prototyping isn’t generally as good as CNC, it’s adequate today for a wide range of exacting applications.

The materials used in rapid prototyping are limited and dependent on the method chosen. However, the range and properties available are growing quickly. Numerous plastics, ceramics, metals ranging from stainless steel to titanium, and wood-like paper are available. At any rate, numerous secondary processes are available to convert patterns made in a rapid prototyping process to final materials or tools.

Additive fabrication technologies have been based on every form of matter known to man. Liquids that change into solids with application of light (photopolymers) formed the first generation of practical machines (stereolithography). Quick to follow were methods based on bonding powders (selective laser sintering), extrusion of thermoplastics (fused deposition modeling), stacking of web materials (laminated object manufacturing) and many others. Even gases have been used as a starting point to form small objects. Some idea of the wide variety of approaches that have been utilized can be found on Henri Koukka’s *Whole RP Family Tree* web page [2].

Object sizes currently addressed by these technologies range from microscopic to entire buildings. Materials range from paper and plastics, to metals and ceramics. Applications range from toys to aerospace and advanced medicine.

There are about fifty companies worldwide that produce rapid prototyping systems. Many of these companies have close relationships with RP material suppliers, and about fourteen of them make systems that are based on some variation of the stereolithography process.

The technologies described in this chapter are just a few of the scores of technologies either commercially available or described in the academic and patent literature. However, these are today's economically most important ones, and nearly all of the others can be thought of as variations on one or more of these schemes.

As the systems evolve further and the materials they use become able to accommodate a wider range of desirable mechanical properties, the term, rapid prototyping will become even more of a misnomer. This technology really represents the nascent state of computationally-based manufacturing. Rapid prototyping is the link between Moore's Law and the real world.

Stereolithography

The implementation shown in Fig. 2.1 is used by 3D Systems and some manufacturers outside the US. A moveable table, or elevator (A), initially is placed at a position just below the surface of a vat (B) filled with liquid photopolymer resin (C). This material has the property that when light of the correct color strikes it, it turns from a liquid to a solid. The most common photopolymer materials used require an ultraviolet light, but resins that work with visible light are also utilized. The system is sealed to prevent the escape of fumes from the resin.

A laser beam is moved over the surface of the liquid photopolymer to trace the geometry of the cross-section of the object. This causes the liquid to harden in areas where the laser strikes. The laser beam is moved in the X-Y directions by a scanner system (D). These are fast and highly controllable motors which drive mirrors and are guided by information from the CAD data.

The exact pattern that the laser traces is a combination of the information contained in the CAD system that describes the geometry of the object, and information from the rapid prototyping application software that optimizes the faithfulness of the fabricated object. Of course, application software for every method of rapid prototyping modifies the CAD data in one way or another to provide for operation of the machinery and to compensate for shortcomings.

After the layer is completely traced and for the most part hardened by the laser beam, the table is lowered into the vat a distance equal to the thickness of a layer. The resin is generally quite viscous, however. To speed this process of recoating, early stereolithography systems drew a knife edge (E) over the surface to smooth it. More recently pump-driven recoating systems have been utilized. The tracing and recoating steps are repeated until the object is completely fabricated and sits on the table within the vat.

Some geometries of objects have overhangs or undercuts. These must be supported during the fabrication process. The support structures are either manually or automatically designed.

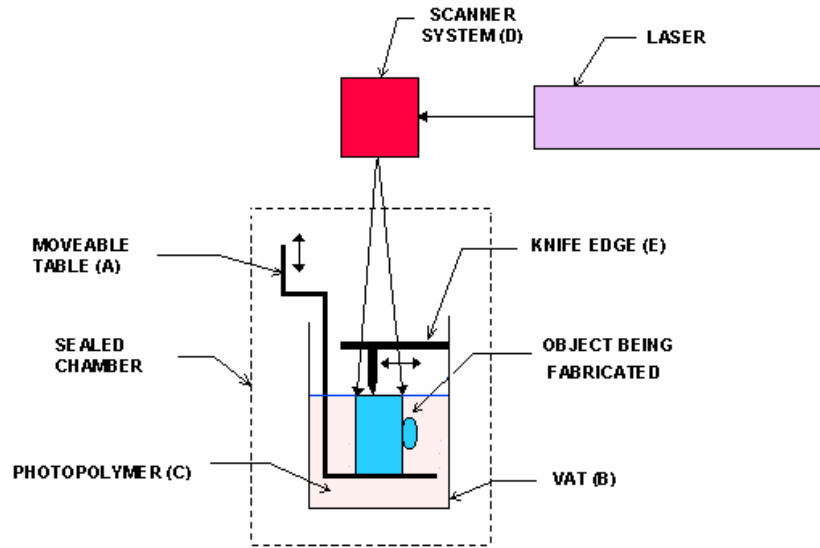


Fig. 2.1. Stereolithography

Upon completion of the fabrication process, the object is elevated from the vat and allowed to drain. Excess resin is swabbed manually from the surfaces. The object is often given a final cure by bathing it in intense light in a box resembling an oven called a Post-Curing Apparatus (PCA). Some resins and types of stereolithography or other photopolymer-based equipment don't require this operation, however.

After final cure, supports are cut off the object and surfaces are sanded or otherwise finished.

Stereolithography generally is considered to provide the greatest accuracy and best surface finish of any rapid prototyping technology. Work continues to provide materials that have wider and more directly useable mechanical properties. Materials are available that simulate the properties of engineering plastics such as ABS and polypropylene, as well as provide a limited range of special properties like flexibility and flame retardancy.

Inkjet technology has been also extended to operation with photopolymers resulting in systems that have both fast operation and good accuracy. See the section on inkjets. Photopolymer-based systems also exist that use means other than a laser for exposure. The Perfactory™ series from Envisiontec GmbH (Germany) and V-Flash™ both use a deformable mirror device manufactured by Texas Instruments Inc. to expose an entire layer of a part at one time. The systems are consequently faster than vector-based systems, but the materials available for these machines are more limited still.

Selective Laser Sintering

The process is somewhat similar to stereolithography in principle as can be seen from Fig. 2.2. In this case, however, a laser beam is traced over the surface of a tightly compacted powder made of thermoplastic material (A). The powder is spread by a roller (B) over the surface of a build cylinder (C). A piston (D) moves down one object layer thickness to accommodate the layer of powder.