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▶ BY GREG LANDGRAF, ASSOCIATE EDITOR

With the development of new, less expensive systems, rapid prototyping makes its move to the masses.

Layer by Layer

It takes a while to get used to the idea of rapid prototyping (RP). It's not natural to see a spool of plastic filament, a box of powder or a tub of goo and envision turning those raw materials into fully shaped prototypes that look—and in some cases, act—like finished parts.

RP systems turn those raw materials into prototypes through an additive process, building pieces layer by layer. While RP systems have been commercially available since the 1980s, the industry has remained in its infancy until recently. The high cost, complexity and potentially harmful materials of additive manufacturing equipment has kept RP locked in a niche.

In the past couple years, however, new additive technologies have been developed and old ones have been upgraded. Although some machines still cost about $1 million, two RP systems can now be purchased for less than $30,000, and several others are available for less than $100,000. Many are safe and quiet enough to be used in an office environment.

Z Corp.

Stratasys

Stratasys

Rapid prototyping can build complicated patterns layer by layer from a CAD drawing, often requiring much less time than it would to devise necessary toolpaths for traditional manufacturing. This article is illustrated with sample parts made by a variety of RP systems.

Low Prices Lead to Takeoff

The economic recovery is part of the reason more manufacturers are investing in RP equipment. Probably even more important, however, is the availability of lower-cost systems.

"For the first time, we've seen some competitive pressures," said Terry Wohlers, president of Wohlers Associates Inc., an industry consulting firm in Fort Collins, Colo. "Until [2003], there hadn't been much incentive to lower prices."

Z Corp., Burlington, Mass., and Stratasys Inc., Eden Prairie, Minn., are two companies offering more affordable RP systems. Both offer models as low as $29,900.

"For many, especially in schools, RP technology was relatively unknown before Stratasys and Z Corp. introduced their low-cost machines," Wohlers said. "Stratasys sold an estimated 300 of its low-end Dimension machines last year—that's unprecedented."

Part of the lower cost is the result of new technology. "The machines that are dropping in price are not the ones that are historically expensive," Wohlers said. "Stereolithography (SLA) and selective laser sintering (SLS) machines are still relatively expensive."

Most low-cost machines take a dif-

Stratasys

Rapid Prototype

Z Corp.

A rapid recap

Rapid prototyping systems are additive technologies that build prototypes layer by layer. Beyond that, however, different systems use different approaches, each with its own benefits and weaknesses. Here's an overview of four common types.

Stereolithography: The abbreviation "SLA" stands for "stereolithography apparatus," but it is commonly used for the process as well. SLA creates prototypes in a tub of liquid resin. A laser traces each layer's pattern, and the points touched by the laser solidify. After each layer is hardened, a platform lowers the prototype 0.001" to 0.005". After building is completed, the prototype must be cleaned with solvent and post-cured with ultraviolet or infrared lights.

Selective laser sintering: SLS is similar to SLA in that a laser traces one layer at a time, and a platform lowers the prototype after each layer. Instead of solidifying liquid resin, however, the laser heats grains of powder, causing them to bond with nearby grains. After the platform lowers, a roller spreads a new layer of powder across the top of the prototype. In theory, the powder can be any powdered metal or plastic material that melts under a laser's heat.

Fused deposition modeling: FDM builds prototypes by extruding a thin bead of semimelted plastic onto a surface. Because the prototype is not suspended in resin or powder, a support material may also be extruded if the prototype has overhanging sections. FDM can produce prototypes out of engineering-grade plastics, like acrylonitrile-butadiene-styrene or polycarbonate, so finished prototypes are strong and durable. Machines are inexpensive and safe to use in an office environment. FDM prototypes, however, have a rough, ribbed surface finish.

3-D printing: Like SLS, 3DP machines incorporate a roller that spreads powder across a platform that lowers after each layer. Instead of plastic or metal, however, this approach builds prototypes out of an inexpensive starch-based powder. The powder is joined together by a liquid binder dispensed from standard inkjet printer heads. The binder is "printed" in a raster, or back-and-forth, pattern, rather than point by point. As a result, 3DP builds prototypes fast. Like FDM machines, 3DP machines are inexpensive and safe to use in an office. In addition, prototypes can be made in multiple colors by mixing different inks with the binder. The 3DP process is not capable of building protytypes to tight tolerances, however, and prototypes are fragile unless treated with some form of infiltrant. The process is often used early in the design process for testing design concepts.

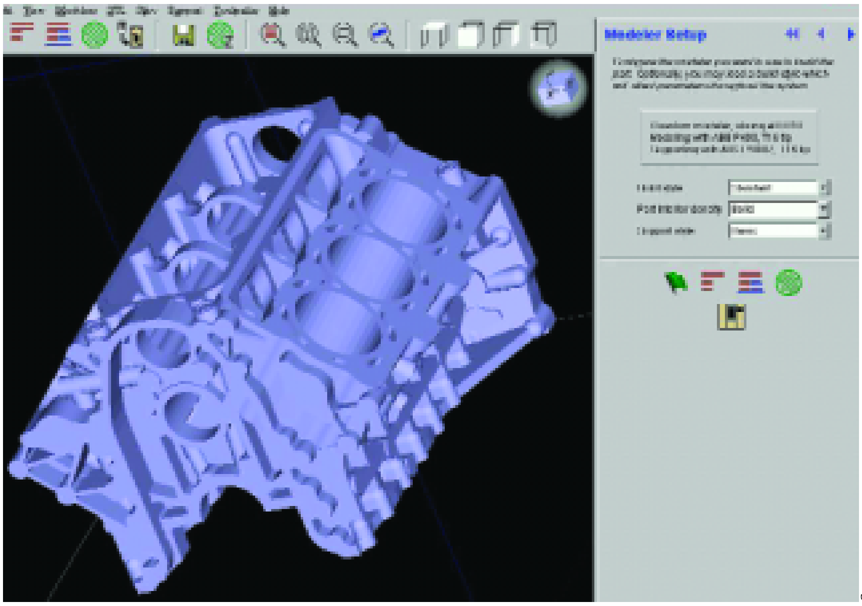
—G. Landgraf

ferent approach. Stratasys machines use a process the company developed called fused deposition modeling (FDM). Z Corp. commercialized the 3-D printing (3DP) process invented at the Massachussets Institute of Technology. (See sidebar, page 48, for more information on the types of RP systems.)

Competition and new technologies are part of what's driving prices down, but they don't account for the entire cost reduction.

Marina Hatsopolous, president of Z Corp., said her company lowered production costs by simplifying machine design. "When we originally launched the technology, we wanted a really reliable machine and probably overdesigned it," she said, adding that the simplified design can maintain reliability less expensively.

"I think it's like any evolving technology," said Bruce Lustig, marketing manager for Solidscape Inc., Merrimack, N.H., which offers a machine for $49,900. "When [a technology] first arrives, it's expensive and there's lots of R&D. Then the product becomes more manufacturable, and companies find less expensive options to reach the broader market." For example, Solidscape developed a smaller, less expensive machine that meets the needs of customers in urban areas where space is



Stratasys

For RP, CAD programs must translate data into STL, or stereolithography, format, which slices the design into buildable layers.

at a premium.

The final part of the equation is the "chicken-and-egg," efficiencies-of-scale effect of any maturing market. Lower prices make it possible for more companies to buy machines, while higher volume lets equipment makers produce machines at lower prices.

Specialized Approaches

The promise of rapid prototyping is that for some complex applications, a prototype can be built faster than it can be machined.

"If customers need a model or functional part quickly, we can often provide it in 24 hours," said Don Bailey, CEO of Rapid Prototype Co., an Auburn Hills, Mich., prototyping service bureau.

"Manufacturers realize that RP gets products to market quicker, which is

State of the rapid prototyping industry

While revenues in most segments of the rapid prototyping (RP) industry dropped in 2002, machine sales worldwide increased from 489 in 2001 to 656 in 2002, according to the 2003 edition of the *Wohlers Report*, an annual report from industry consultant Wohlers Associates that was published in May 2003. Faring especially well in 2002 were sales of 3-D printers. With the exception of a slight drop in 2001, unit sales have grown every year since 1996, when 105 machines were sold.

The most common RP application is making functional models, followed by visual aids for engineering and fit/assembly tests. Many RP models are used for multiple applications.

U.S. companies purchased 40.9 percent of all RP systems in 2002, followed by Japan with 14.6 percent, China with 10.8 percent and Germany with 8.1 percent. 2002 was the first time China purchased more RP machines than Germany. U.S. market share is expected to decline as other countries embrace RP technologies.

The number of RP-related patents, reflecting R&D efforts, has grown steadily since 1996. An estimated 212 were granted in 2003, up from 188 granted in 2002. The dominant research trends for the past few years have been improving existing RP processes and combining aspects of multiple technologies, rather than developing new technologies.

Rapid manufacturing—strictly speaking, the direct production of finished goods from an RP device—is a small but exciting segment of the industry. While RP systems are successfully being used for rapid manufacturing applications, there are not yet any systems specifically for rapid manufacturing. In the future, there likely will be.

—G. Landgraf

All information for this sidebar came from the executive summary of Wohlers Report 2003, *released in May 2003. The report is published annually, and the full report is available from Wohlers Associates, (970) 225-0086, www.wohlersassociates.com.*

very important when you've got millions of dollars tied up in development," said Scott Crump, CEO of Stratasys.

Each RP process fills a certain niche. That's a natural consequence of differences in speed, accuracy, finish, machine and material cost, and physical properties of the build materials.

The following companies contributed to this report:

Rapid Prototype Co.
(248) 391-6600
www.rpparts.com

Solidscape Inc.
(603) 429-9700
www.solid-scape.com

Stratasys Inc.
(888) 480-3548
www.stratasys.com

Wohlers Associates Inc.
(970) 225-0086
www.wohlersassociates.com

Z Corp.
(781) 852-5005
www.zcorp.com

3DP, for example, builds prototypes within a few hours, and is suitable for concept modeling, form-and-fit testing and producing functional prototypes.

Hatsopolous said Z Corp. machines have made prototype car mirrors for aerodynamics testing, as well as large ducting works to test an automotive air-conditioning system.

FDM can produce prototypes from production plastics, so its products are often used for functional testing. Crump described a prototyping project for a vacuum-cleaner manufacturer that built a working vacuum with 31 RP plastic parts. The plant manager said that the product was the first one he'd seen where every part in the production pilot run fit together properly.

Solidscape

Solidscape's Lustig said his company's machines often make tooling-grade masters for investment casting.

What about the older, more expensive, laser-based techniques? Stereolithography is known for its accuracy, smooth finishes and the ability to make relatively large prototypes. In addition, Wohlers said many stereolithography materials have been developed since SLA was first offered in 1987.

Meanwhile, "selective laser sintering makes strong parts, so it's useful when strength for testing is an issue," Wohlers said.

Rapid Prototype Co. uses SLA and SLS to make its prototypes, many of which are used for functional testing in the automotive, appliance, medical and aerospace industries. "We originally chose SLS because of the tremendous variety of [usable build] materials, from glass-reinforced nylon to metals," Bailey said. While the 3DP process can help engineers visualize their designs quickly, Bailey added, it "doesn't have the same accuracy and ability to make functional parts."

Wohlers noted, however, that the newer FDM and 3DP machines are improving and taking some of that advantage away. "With these technologies, you've got to wonder if the laser-based systems will be around in 7 to 10 years."

Getting Simple

An additional effect of the lower-cost RP systems is that prototyping is shifting from being a manufacturing function to a design one. "We're seeing more and more in-the-office prototyping," Wohlers said. "It's especially good for smaller companies without distinct prototyping departments."

The change in raw materials allowed the move. "Nonoffice printers use toxic materials or require ventilation," explained Hatsopolous. "Parts also require extensive post-processing." Uncured SLA resins can cause allergic reactions, and post-processing requires cleaning with solvents.

The move into the office has been accompanied by the systems becoming easier to use. "Our low-priced model was designed so a user with no experience can follow the prompts on the display panel to get started," Crump said. "One user reported being up and running in 45 minutes."

"It's not much more complicated than printing a word-processing file," Hatsopolous noted.

Dropping prices and greater usability have suppliers believing they are at the start of a period of explosive growth that will broadly change the way designing is done. Said Crump: "Some day every CAD system may come with an RP device."