Rapid Prototyping

Additive Technologies That Will Reshape Design & Manufacturing

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Whether invoked in the creation of works of fine art or products for mass consumption, the process of design is a cycle of activity that remains the same—even as new technologies and tools continue to emerge. Each design cycle can spawn dozens of sketches, all competing for the designer's attention and approval. Like a gardener or animal breeder, the designer selects the best specimens from one design cycle, then transforms and combines them to create even stronger designs among the progeny. And so it goes, over and over again, until the final design is completed.

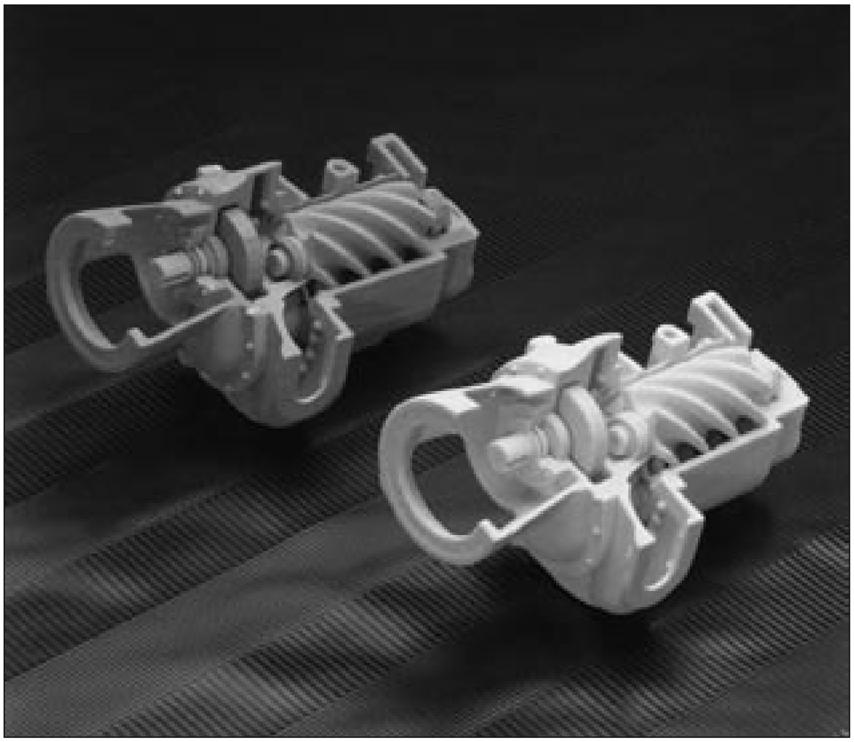
When designing objects, as opposed to flat images, there is a need to create 'three dimensional sketches' in the form of physical prototypes. As models, prototypes provide the real world sensory feedback needed to make aesthetic judgments. Prototypes can also aid in the functional verification of a design, enable an ergonomic evaluation, or simply serve as tools of persuasion in a presentation. And for some, especially fine artists, the last prototype may not be a prototype at all, but rather the actual final object.

However, the traditional creation of prototypes, whether from simple hand sketches or finely drafted plans, is both expensive and time-consuming. In practice, the designer often cannot afford the time or expense to create frequent prototypes, and thus many design cycles pass between physical models. Rapid prototyping technology offers the 3D designer a solution to this problem.

Simply stated, rapid prototyping uses automated technologies to provide substantial improvements in the speed and cost of prototype creation. Rapid prototyping does not represent a break with the tradition of cyclical design by incremental improvement or successive approximation; rather, it speeds the design cycle and increases the use of prototypes to an extent that new ideas, new results, and new techniques become possible. It's also worth noting that in a commercial setting, rapid prototyping can often provide a significant and demonstrable return on investment.

In many ways, rapid prototyping is the natural result of two earlier, converging technologies. For the past several decades, Computer Assisted Design (CAD) software has provided designers with computer-based tools for drafting, mechanical drawing, architectural blueprints, and so on, offering advantages similar to those available to 2D designers using desktop publishing tools. Over the same period of time, machine shops have used Numerical Control (NC) computers with milling machines, allowing the automation of their operation, and thus the creation of parts at lower expense and greater precision.

The ZPrinter 406 rapid prototyping system.



Sample objects created by a Z Corp. ZPrinter.

Rapid prototyping in a sense marries these two technologies by allowing designers to create plans for real world objects in the virtual world of the computer, and then in a single step to create a physical object directly from those plans.

However, there is an important difference between CAD-driven NC milling and rapid prototyping. Traditional shop techniques, whether manual or numerically controlled, are a subtractive process. They start with a block, sheet, or tube of raw material and then, by drilling, cutting, lathing, and grinding, material is removed, yielding the desired object or product. Rapid prototyping, on the other hand, is an additive process: the desired object is built from bottom to top in very thin layers.

Whereas subtractive techniques require hard-earned craft skills for the complicated and unique setups that vary with each job, additive techniques require no special knowledge on the part of the prototype fabricator. In fact, some rapid prototyping systems are called “3D Printers” because it is as easy to send a model to such a prototyping system as it is to send a document to a networked printer. Even complicated mechanisms with moving parts, multiple enclosed parts, or trapped volumes, bearing assemblies, and so on can be “printed” directly, without the need for further assembly.

This fundamental change from subtractive to additive methods has important implications for the future of robotic manufacturing. It will allow, for example, the mass production of unique objects, a subject that will be touched upon towards the end of this article.

Rapid prototyping is important to artists because it allows them to directly translate ideas into physical objects. It contributes to the trend in the digital arts of moving away from purely virtual creations and reconnecting with the physical world by using “high-tech” tools. A sampling of currently available devices is described below.

Z Corp. ZPrinter System

http://zcorp.com/

The ZPrinter 310 System is one of the most popular rapid prototyping systems in the university sector, due to its ease of use, versatility, relatively low cost, and office-friendly operation. Like the larger systems from Z Corporation, the ZPrinter 310 uses a starch- or plaster-based powder and a binding agent applied by an inkjet-like mechanism.

The mechanism passes over a bin with a thin layer of powder, applying the binding agent only where the resulting object is intended to be solid. Then, a fresh layer of powder is added to the top of the bin, and the mechanism selectively applies another layer of binding agent. This is repeated many times until the entire object has been built up out of many thousands of layers.

The completed object is then removed from the bin and any excess unbound powder is blown off with compressed air. As an option, the prototype can then be immersed in liquid infiltrants, which saturate the object and have a lasting effect upon drying. Some infiltrants will harden and toughen the relatively brittle ZPrinter prototypes, while others will result in a flexible or rubbery material.

The ZPrinter 406 System operates in a similar manner, but along with the binding agent the inkjet mechanism also acts like a traditional color printer, and applies the four CMYK pigments that combine to produce virtually any color (see the example on the front cover of this magazine). The resulting object can have any number of arbitrarily colored sections, and the color permeates the object, allowing for sanding of the surface, if desired.

Recently, Z Corporation introduced the Zcast process for the direct production of molds that can be used to cast aluminum or other non-ferrous metals. An artist with a metal sculpture in mind can create the (positive) model in a 3D package such as Autocad or Maya, directly create a (negative) mold in a single step on a ZPrinter 310 or 406, then bring that mold to the sculpture studio and create a direct cast—all without the use of intermediates. The Zcast process can be used with a ZPrinter 310 or 406 and does not require additional special hardware.

While the Z Corp. systems seem to be leading the pack, especially in the university sector, there are some tradeoffs. Starting at about $30,000, the cost is relatively low and competitive, but the maximum size of the resulting object is modest, with a so-called "build envelope" of 8" x 10" x 8".

Each layer is only about .003" to .010" thick, but some competing devices allow for even greater laminar resolution. The surface texture is also a bit rough relative to other processes. Finally, the material is somewhat brittle in its untreated form, and some feel that the need to use infiltrants as a final step is an unwanted hassle, while others prefer the options various infiltrants offer.

Stratasys Prodigy Plus

http://www.stratasys.com/NA/

The Stratasys Prodigy Plus is about as easy to use as the Z Corp. systems, but it exploits an entirely different mechanism and material. Utilizing a fused disposition modeling process, the Prodigy Plus creates prototypes out of durable ABS plastic. Tiny dots of ABS plastic are deposited and fused in very thin layers, creating a plastic object that is as strong as an industrially manufactured part.

Trailing the Z Corp. systems a bit, Prodigy Plus layers can be from .007" to .013" thick, and parts can be only a single color (the color of the plastic used). The maximum size of a Stratasys object is slightly larger than is possible with Z Corp. systems, with a build envelope of 8" x 8" x 12".

As rapid prototyping literally reshapes our homes and even our bodies, it will become a basic technology of interest to all.

One interesting problem any rapid prototyping system must solve is the support of the object it is building while it builds it. For example, imagine a model of a tree being constructed from the bottom up—any downward hanging branches would initially have to float in mid-air until the connection to the trunk was completed in upper layers.

In the Z Corporation system, this problem is solved by the excess, unbound powder that surrounds the object and supports any unattached parts. Other systems have to create temporary supports that are cut away once the prototype is completed. The Stratasys uses the unique WaterWorks system that creates supports out of a second, water-soluble material that can be washed away once the object is finished.

The primary advantage of the Prodigy Plus is the strength of the ABS plastic material it uses and, relative to some systems, the WaterWorks removable support system.

The Solidscape T66

http://solid-scape.com/t66.html

The Solidscape T66 is a specialized rapid prototyping device that excels at the creation of small parts with very fine details. These parts can be used as "investment casts" in a lost wax process for casting metal such as jewelry.

The T66 allows a small build envelope of 6" x 6" x 6", and uses only a single, somewhat soft, waxy, thermoplastic material. This material, however, holds fine detail, resists thermal expansion or other distortion, and, when removed in mold-making, leaves behind virtually no ash or residue.

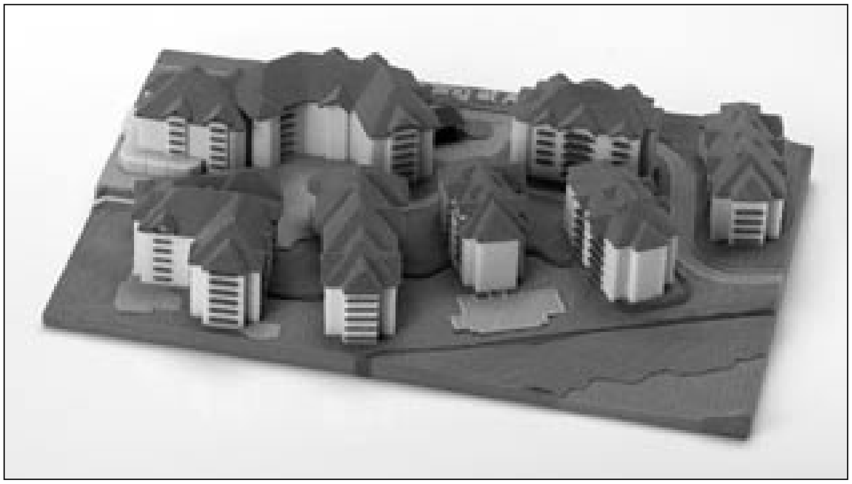
The T66 offers very high resolution, with layers from .0005" to .003", and the ability to produce features as small as .01". What the Solidscape T66 lacks in generality, it makes up for in resolution. For those working with jewelry or the casting of other very fine parts, it is a uniquely powerful tool.

Other Systems

The systems noted above are among those most often used by artists, but there are many others:

- Industrial systems are available at greater expense from Z Corporation and Stratasys with build envelopes of nearly two feet on each side.

- An older rapid prototyping technology called stereolithography uses a vat of photoreactive liquid that solidifies at the surface when struck by a



A sample prototype produced by a ZPrinter.

relatively cool scanning laser. A system such as the 3D Systems SLA 7000 offers high resolution layers from .001” to .005” with a 20” x 20” x 23” build envelope and very smooth surface textures. The resulting objects are relatively strong, but can also be used as patterns for investment casting. (See *http://www.3dsystems.com/products/sla/sla7000/*.)

- A large class of rapid prototyping machines use powdered metal to create metal objects. Selective Laser Sintering (SLS) machines build up layers of powdered metal that are fused into a solid object by a hot scanning laser. SLS parts can serve as prototypes, but are also directly used as short run products in industries such as aerospace. The 3D Systems Vanguard, for example, can create arbitrary metal objects within a build envelope of 14.5” x 12.5” x 17.5”, with features as small as .02”. (See *http://www. 3dsystems.com/products/sls/vanguard/*.)

- Metal objects can also be created by a Direct Material Deposition process where tiny amounts of metal powder are applied and immediately fused to the part by a highly accurate tool—integrating the powder delivery system and a laser. Such systems can dynamically mix different metal powders creating objects made of alloys that vary in composition across the object in a highly controlled manner. AeroMet, perhaps the largest of these systems, can create objects out of the usually difficult-to-machine Titanium, in a build envelope of 10’ x 10’ x 4’. (See *http://www.aerometcorp.com/theMachine.htm*.)

The Future State of the Art

The current buzz among rapid prototyping experts is the paradigm shift from rapid prototyping to additive manufacture. Most objects now created by rapid prototyping systems are stand-ins for something that will later be manufactured by other means. But that practice is changing.

Some futurists imagine rapid prototyping-inspired additive manufacturing factories that can laminate all manner of materials, creating finished products in a single pass, allowing for personalization and customization with each item, and providing the ability to build all sorts of different products without having to reconfigure a production line. For example, imagine an integrated car dashboard built as a single piece on a single machine, including all the needed switches, displays, and mechanical indicators, or, for that matter, imagine an entire car built this way.

The future, in fact, may not be so far away. University of Southern California Engineer Behrokh Khoshnevis hopes to create a robotic “house printer” that can custom-pour arbitrary cement structures as soon as 2005. Integrated with a design system to drive the process, one could custom-specify any number of house designs, including curving and irregular walls that would be difficult to build any other way, and then simply “print” them out on-site. (See *http://www.newscientist.com/news/news.jsp?id=ns99994764*.)

Medical applications represent a burgeoning market for rapid prototyping and additive manufacturing, and some products are already available. An alternative to braces, the Invisalign product allows dentists to send traditional x-rays and casts to the company’s 3D computer imaging facility.

Invisalign then uses the derived data to drive a rapid prototyping facility, which creates a series of custom removable aligners made from clear plastic. Each uniquely fits the given person’s mouth, and, over a period of months, the patient’s teeth are slowly moved into alignment. (A streaming video about the product is available at *http://www.invisalign.com/US/html/explore/MFGVideo.jsp*.)

Envisiontec's Bioplotter applies rapid prototyping technology to grow living tissue for implantation into patient-specific shapes (e.g., an ear). In the future, shape information will be extracted from MRI, CAT, or ultrasound scans, and then used to drive the Bioplotter, which will build replacement skin, cartilage, or bone from biodegradable scaffold materials and cell cultures from the patient. Because the cells come from the patient, replacement tissues created via rapid prototyping will be immune to rejection. (See *http://envisiontec.de/03hbiopa.htm* and *http://www.e4engineering.com/item.asp?id=48516*.)

In the near term, rapid prototyping offers artists and designers an extremely powerful tool. But, as rapid prototyping literally reshapes our homes and even our bodies, it will become a basic technology of interest to all.

For more information about rapid prototyping, please see the corresponding project page at the Arts Technology Group website: *http://www.nyu.edu/its/atg/pages/projects/rp/*.

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Laser Cutting and Etching for Artists at NYU

This spring, a new device was added to the Arts Technology Studio at the ITS Multimedia Lab located at 35 W. 4th Street. While not, strictly speaking, a rapid prototyping device, the Universal Laser Systems X2-660 does allow artists to easily cut and etch flat materials from digital plans. Just about any flat material up to 32" x 18" other than metal can be cut or etched, including plexiglass, acrylic plastic, vinyl, paper, matte board, cardboard, cork, fabric, leather, rubber, and wood. Glass, stone, and treated metal can be etched but not cut.

The Universal X2-660

Plans can be prepared using popular design packages such as Adobe Illustrator or CorelDraw, as well as CAD-oriented packages such as AutoCAD. The designer simply draws lines or text with the standard tools, and uses colors to code which lines are intended as cuts and which are intended as etched lines. In addition, pixel-based graphics such as JPEGs or Adobe Photoshop files can be burned into a surface as a duotone or grayscale image. The system uses an extremely thin laser beam and highly accurate X/Y plotter mechanism allowing, for example, the creation of interlocking pieces or inlay materials.

Jeff Bary of the ITS Arts Technology Group, operating the new laser system.

For more information about accessing this device, please send e-mail to the author at *galanter@nyu.edu*.