

# PHYSICAL AND DIGITAL PROTOTYPING **BELONG TOGETHER**

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Z CORPORATION®

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**About the author**

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## PROTOTYPES ARE RAPIDLY EVOLVING

Makers of 3D CAD software for digital prototyping sometimes claim that their systems eliminate the need for physical prototypes. In fact, physical prototypes are much in use today because they are essential to creating great designs. Thanks to the speed of 3D printing systems, innovative product developers use more physical prototypes than they did when each prototype was hand crafted, and combine them with digital prototypes to accelerate design. This paper explores how digital and physical prototypes complement each other and provides guidance on what to look for when choosing where and when to use each type.

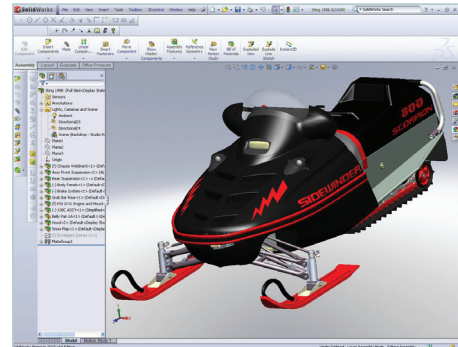
Prototypes are models of new products.<sup>1</sup> Designers have used prototypes or models of designs since people began planning the things they were going to make instead of crafting them individually.

For thousands of years, prototypes have been physical objects. By the late 20th century, however, engineers developed three-dimensional computer-aided design (CAD) software that enables digital prototypes to be created in a computer's memory and shown on a graphics display.

Until 1987, physical prototypes had to be hand-crafted from wood or metal using shop machinery such as lathes and mills.<sup>2</sup> Prototype builders frequently worked from two-dimensional engineering drawings. Intricate parts required multiple setups in a variety of tools. Numerically controlled machine tools had to be programmed in arcane computer languages.

The advent of digital prototyping also led to the development of systems that could automatically make intricate physical prototypes from digital models. Today these additive manufacturing systems are exemplified by products such as Z Corporation's ZPrinter® and ZBuilder™ Ultra systems that fabricate complex products by laying down thin layers of material. Parts are fabricated directly from 3D computer models without the need to draft or read engineering drawings.

The process of product development typically begins with simple prototypes, continues with development of more detailed visual prototypes, and culminates with the testing of working prototypes. Let's examine how the needs for digital and physical prototypes evolve within the context of each stage of the design process.



**Figure 1.** Example of a 3D CAD model of a snowmobile designed with Dassault Systèmes SolidWorks®.



**Figure 2.** Z Corporation's ZPrinter 650 builds parts at the rate of 1.1 vertical inches (28 mm) per hour with length and width as large as 10 x 15 inches (254 x 381 mm).

<sup>1</sup> Merriam-Webster's Third Unabridged Dictionary.

<sup>2</sup> "From the editor," Rapid Prototyping Report, Vol. 1, No. 1, June 1991, p 2.

## FORM STUDIES

Most design concepts begin with sketches. As soon as an attractive sketch is finished, designers begin modeling in 3D CAD.

Conceptual prototypes lack the detail of a finished design but enable designers to explore the basic size, look, and feel of a product idea early in the design process. Digital conceptual models are easy to make with CAD software because they require only a few features. CAD concepts enable designers to evaluate their ideas from any angle and make changes instantly.

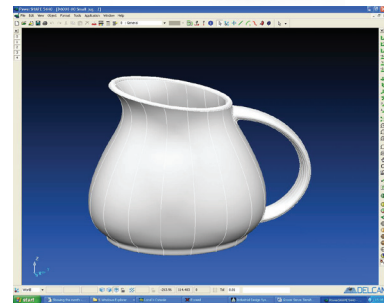
Through the magic of computer graphics, CAD models appear to exist in a 3D space behind a computer display. People can't touch or feel digital prototypes. Often they can't get a physical sense of the scale of CAD models because they can be shown at any scale. Consequently, computer images alone are not adequate for evaluating many types of designs.

Customers, executives, sales and service people, as well as designers, need to touch, hold, and feel physical conceptual models to better understand each design. People react emotionally to physical prototypes the way they would to the actual product. And unless CAD engineers expend great effort creating virtual environments, computer models don't allow people to see what the product will look like in the actual setting where it will be used.

For example, Cisco's Consumer Business Group makes wireless routers, switches, and wireless audio components that are used in homes and offices. These electronic devices need to look attractive in the settings where they will be used.

Eskild Hansen, Head of Cisco's European Design Centre says his group's ZPrinter 450 makes 10 rapid prototypes per week for design reviews. Hansen believes it's essential for designers to pass around physical models and mark on them with pencil before continuing development with their CAD software.<sup>3</sup>

For conceptual prototypes, speed is essential. The useful life of a conceptual prototype may be only a few hours. Conceptual models should be produced in or near the design studio. Consequently systems that use hazardous materials, require special ventilation, or employ support structures that must be removed with special tools are less than ideal for conceptual models. Conceptual modelers should employ low-cost materials because many models are required.



**Figure 3.** The design of a Denby Pottery pitcher proceeds from a rough sketch, to a 3D CAD model, to a physical prototype made with a Z Corporation ZPrinter.



**Figure 4.** Using a fast and economical ZPrinter, Cisco makes prototypes frequently to evaluate design concepts.

<sup>3</sup> "Cisco Uses 3D Printing Technology to Help Uphold Scandinavian Design Tradition," Z Corporation, 2009.

## VISUAL PROTOTYPES

Visual prototypes accurately reflect the appearance of a product in every detail without performing its function. Visual prototypes can serve a variety of product-development purposes.

### Product engineering

The process in which all the engineering details necessary to define products for production begins after initial concepts have been approved. This work is typically done with 3D CAD software. 3D CAD software designs product geometry and validates form, fit, and manufacturing tolerances. CAD not only produces mathematical models for manufacturing, but it also automates production drafting and generates bills of material used by manufacturing planners and purchasing agents.

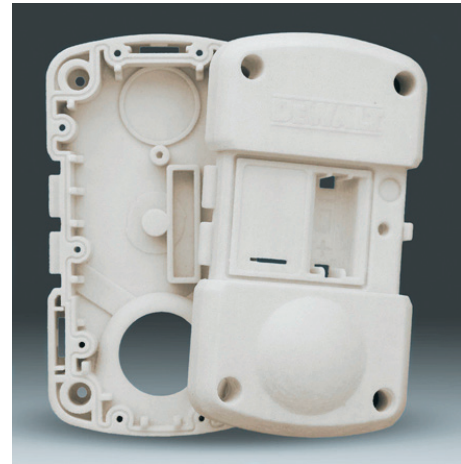
Modern products must satisfy many requirements: aesthetic appeal, safety, ergonomics, reliability, and low cost. Digital prototypes alone are not sufficient to assure that all these demands have been met. Most manufacturers insist that a product's final appearance be approved in a physical prototype before costly production tools are procured. Defects in visual appeal or ergonomics that may go unnoticed in digital models are often spotted in reviews of physical prototypes. Service technicians must check that products can be disassembled for repairs and that parts are easily accessible to reduce labor costs.

### Manufacturing engineering

Design of mass production tools and processes often costs more than development of the manufactured product. Manufacturing engineering activities include design of production facilities, assembly lines, jigs, fixtures, and gauges; process planning; writing assembly instructions; numerically controlled mill programming and validation; scheduling, and manufacturing-resource planning.

Until the 1990s, manufacturing engineering typically followed detailed product engineering. Manufacturers often discovered that although their products worked as intended, they cost too much to make.

Farsighted companies realized that manufacturing engineering needed to begin before product designs were finalized. Minor refinements in the product design could yield huge manufacturing cost savings, making products more competitive in their markets. Today most successful manufacturers involve manufacturing engineers — including the engineers of suppliers — in the product development process.



**Figure 5.** An engineering model of a Black & Decker Job Site Security Sensor produced with Z Corporation's ZPrinter shows internal details needed for manufacturing.

Designing products to be assembled quickly and economically is a key task for engineers early in a product's development. Makers of digital prototyping software sell applications that simulate material-handling and assembly operations. Building and programming digitally simulated 3D production systems are difficult tasks requiring specialized skills. Unless products are large and heavy, such as trucks or aircraft, it is often more cost effective to print 3D physical prototypes for planning and verifying assembly procedures before production parts are available.

Physical prototypes also can help manufacturing engineers design and check jigs, fixtures, and gauges used in assembly processes before stamped, cast, or molded production parts are available. And when tools, fixtures, and gauges are themselves designed with 3D CAD, rapid prototypes can be generated quickly to evaluate their proper functioning and assembly. For example, Hydroforming Design Light AB of Vansbro, Sweden uses models made on its ZPrinter to check the fit of complex prototype parts in fixtures.<sup>4</sup>

### Marketing and sales

Sales and marketing people can no longer wait for product designers to finish their work before they start selling. Consumer products for peak seasons must be ordered many months earlier, and buyers of innovative new products want to see what they're ordering.

Marketing people also must begin planning advertising campaigns and ad layouts before photographs of production products are ready. They also want to gauge reactions of customers to new product designs before costly tools are ordered. Did the engineers design something people want to buy? Or will customers be indifferent toward it?

Digital prototyping software can produce photo-quality images of product designs from CAD models. In some cases, computer rendering is not sufficient. Frequently people must be photographed holding or using the product. Visual physical prototypes of final or near-final designs enable customers to obtain samples that can be photographed before first-article samples are available from manufacturers.

Marketing people also want to take physical prototypes, not just computer images, to trade shows and focus groups to gauge customer reactions. Retail buyers may wish to see and experience prototypes before committing to purchase in volume. For example, sales people for Timberland, a maker of outdoor and casual footwear, bring prototypes to sales calls with major retail chains.<sup>5</sup>



**Figure 6.** Realistic rendering of the Devon Tread 1 watch made with Bunkspeed SHOT™, an application that renders realistic images of 3D CAD models using the iray® physically accurate rendering software from mental images, a Nvidia subsidiary.



**Figure 7.** Prototypes of Timberland Company footwear made on Z Corporation's color ZPrinter appear remarkably lifelike.

<sup>4</sup> "Hydroforming Design Light AB Seizes Power of Water, Color and 3D Printing to Improve Business Performance," Z Corporation, 2007.

<sup>5</sup> "Timberland Saves Time and Money, Finds the Right Style with 3D Printing," Z Corporation, 2005.

Systems for making visual prototypes have capabilities in common with those used for form studies. They must be fast because visual prototypes are needed quickly. 3D printers must also be economical to operate because many prototypes are needed.

Visual prototyping systems that print in multiple colors simultaneously eliminate the need to paint models after fabrication. And visual prototyping systems must be sufficiently accurate to evaluate fit between parts.

## WORKING PROTOTYPES

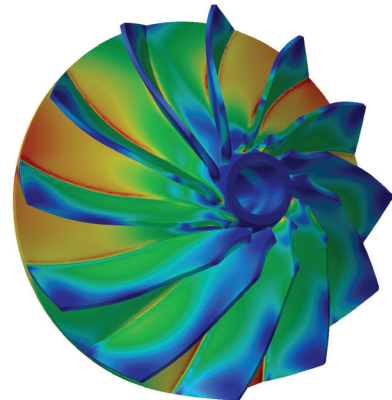
Functional prototypes embody both the form and function of a product.<sup>6</sup> Digital prototypes can validate many aspects of a product's physical performance. For example, CAD software can be used for kinematic studies. Dynamic analysis software can estimate loads on components. Finite element analysis (FEA) can help visualize stresses, temperatures, and magnetic fields. Computational fluid dynamics can illustrate fluid flows and estimate pressure on solid objects.

Digital prototyping software can help reduce the number of working prototypes made for a given product, but it can't entirely eliminate them. Given the wrong loads or boundary conditions, analytical software can produce wrong answers. Results of physical testing of prototypes must be compared with analytical results to assure product reliability and safety.

Some aspects of physical performance can be evaluated more cost effectively with tests than by computer analysis. For example, Steeda Autosports mounts ZPrinter models of its cold-air intake kits to Ford engines and measures the actual air flow and pressure drop.<sup>7</sup>

Checking snap and press fits with computer models is time consuming and requires highly skilled analysts. Fabricating prototypes with systems such as the ZBuilder Ultra allows designers to evaluate interference fits by testing them. The ZBuilder Ultra employs flexible materials that behave similarly to molded plastics.

Functional testing of prototypes before committing products to mass production is essential. Marketing people also need to assess consumer acceptance of design features before costly investments in tooling. And of course regulatory agencies require products to be tested for safety.



**Figure 8.** Plot of stresses produced by centripetal forces in a turbine impeller generated by Dassault Systèmes Abaqus software.



**Figure 9.** Example of a working prototype of a Steeda Autosports air inlet (in white) fabricated for testing with a ZPrinter.

<sup>6</sup> Basic prototype categories, Wikipedia, October 2010.

<sup>7</sup> "ZPrinting Revs Up Steeda Autosports' R&D," Z Corporation, 2010.

Working prototypes must be made from materials that have physical properties and surface finishes similar to those of the production product. In other words, parts that are metal in the production product also must be metal in the prototype. Polymeric material must have the strength and stiffness of molded plastics.

Today's additive manufacturing systems don't offer the range of material properties found in mass production. However, some systems come close. Z Corporation's ZBuilder Ultra employs a photopolymeric material with a tensile strength in excess of 6,000 psi.

Parts made with 3D printing can also facilitate production of metal investment castings. For instance, Spirax Sarco uses its ZPrinter to make burnout patterns instead of sending CAD models to a tooling contractor. This technique saves three to four weeks and avoids a \$3,000 to \$5,000 (USD) tooling charge. The pattern costs about \$8 (USD).<sup>8</sup>

Complete working prototypes can be fabricated from a mix of parts created with rapid prototyping systems, fabricated by traditional methods, or purchased. For example, parts made with a ZBuilder Ultra could be combined with parts made from glass and sheet metal and electrical components purchased from a catalog.

## MAKING THE RIGHT CHOICES

Physical and digital prototyping complement one another. Both should become an integral part of your product-development processes.

Digital prototyping tools allow detailed 3D models to be conceived and changed quickly. But computer graphics is no substitute for reality. When combined with additive manufacturing technologies, physical prototypes can be made from digital models quickly and with much less labor than was traditionally required.

Deciding when and how to use physical prototypes in addition to digital prototypes requires knowledge of both digital and physical prototyping methods. Engineering executives and managers need not become additive manufacturing experts. However, they or their designated staff members should familiarize themselves with the various physical prototyping system capabilities, materials, costs, building speeds, and accuracies. With this information, managers will have rational bases for deciding if and when making a physical prototype is more cost effective than analyzing or simulating product behavior with digital prototypes.



**Figure 10.** Z Corporation's ZBuilder Ultra produces parts with smooth surface finish, sharp details, and mechanical properties similar to ABS plastic.

<sup>8</sup> "Steam Expertise and Enterprise 3D Printing Make Powerful Combination for Spirax Sarco Inc.," Z Corporation, 2008.

Whether you are evaluating physical prototyping technologies in order to purchase a system for your company or employ a service, keep these points in mind:

1. Faster systems that produce multiple models simultaneously are desirable for iterative, conceptual prototypes or visual prototypes that support detailed design, manufacturing engineering, or marketing.
2. If you plan to make many prototypes, low material costs may be more important than buying a low-priced system.
3. Color systems eliminate the need for painting and finishing.
4. Strong but flexible materials may be needed for evaluating snap fits.
5. Some technologies are well suited to making patterns for metal castings while others are not.
6. Higher-strength materials may be necessary for physical testing.
7. Systems with fine surface finish may be required for working prototypes or final advertising shots, but can take longer to produce.

Companies that make wise choices about both digital and physical prototyping technologies will have competitive advantages compared with companies that don't. The effective combination of both CAD and engineering software with 3D printing and rapid prototyping assures that your company will deliver products that are desirable, affordable, reliable, and safe.

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### **About Z Corporation**

Z Corporation 3D technologies help product designers, engineers and architects create the right designs the first time. Professionals use ZPrinter 3D printers, ZBuilder Ultra rapid prototyping machines and ZScanner® 3D laser scanners to compress the design cycle, generate new concepts, communicate clearly, foster collaboration and reduce errors. These solutions span the entire 3D CAD/BIM design process from concept through design verification.



**Z CORPORATION**™

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